A Primer on Climate Policy Math

CO2 COALITION

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EXECUTIVE SUMMARY

Over the last 25 years, climate has been an important focus of American energy policy. The discussion, however, has been dominated by a single viewpoint proclaimed by the media, academia, many politicians and various corporations. The narrative, presented as fixed and unassailable, argues that:

- Scientists have determined that carbon dioxide emissions from fossil-fuel use are already causing storms, droughts, wildfires, sea-level rise and ocean acidification, and that future CO_2 emissions will cause our climate to deteriorate with catastrophic consequences.

- In response, the world is in the process of engineering an "energy transition" away from fossil fuels and toward renewable technologies, particularly wind and solar. In this view, since renewable energy costs less than fossil fuels, this transition is easy and will bring major benefits in job creation and economic growth.

Underlying this narrative is the idea that "expert opinion" is a reliable source of scientific and economic truth. Many people accept the prevailing narrative unquestioningly because it has become part of the progressive canon, or they are afraid of the social or even career consequences of challenging climate orthodoxy or simply because they are comfortable defaulting to the views of self-appointed experts. Those people who are actually involved in the policy process, however, or who wish to be informed voters should reject "expert" opinion and work through climate logic themselves.

The climate policy debate has two components: scientific and economic. In terms of the science, people should ask the following questions:

- On what basis do climate activists refer to carbon dioxide (CO_2), a life-giving molecule essential for all life on Earth, as "pollution"?

- Are the computer models which generate catastrophic climate scenarios reliable?

- Is it true that adverse events such as hurricanes, tornadoes, wildfire, floods, ice melt, etc. are actually increasing or is our recent experience within the range of natural variation?

In terms of economics, people should ask:

- What is the role of energy in the economy?

- Who emits carbon dioxide in the world?

- What are the costs involved in actions to reduce CO_2 emissions?

- What are the actual trends in energy use?

Others have addressed the scientific controversies in detail. This monograph will offer a primer on the economic landscape of CO_2 and provide a basis for interested readers to “run the numbers” and make up their own minds about the costs and benefits of proposed climate policies.

The two main sources of CO_2 emissions from fossil fuels are electric power generation and transportation.

We will look at the costs – and benefits – of the two sources. The key points are:

Regarding electric power generation:

- Since storing large amounts of electricity with batteries is prohibitively expensive, modern electricity grids require a high proportion of dispatchable generating capacity. Too much intermittent power, like wind and solar, undermines the reliability and stability of the grid.
- When the costs of backup capacity are included, wind and solar power are much more expensive than electricity generated by fossil fuels.
- The industrial countries are struggling to find a political balance between the need for a high-quality electricity grid and the demands of climate activists.
- In seeking this balance, politicians in the industrial countries will push renewable energy into the marketplace until they hit limits based on the voting public’s willingness to tolerate high costs, unreliable electricity supply and national security risks.
- The developing countries are growing their electricity grids rapidly with whatever local and affordable sources are available, mainly fossil fuels and hydro.
- The growth in renewable energy in the developing world is largely an artifact of international lending institutions responding not to the needs of the poor but to the political demands of wealthy countries.

Regarding transportation:

- Automobile ownership in the industrialized countries is reaching a plateau. In the developing countries, however, the driving-age population is growing rapidly, and they will demand mobility.
- Gasoline-powered vehicles provide that mobility at the lowest cost and best performance.
- Powered by heavy subsidies, electric vehicles (EVs) have made slight inroads in the U.S. and some other countries, but these vehicles remain much more expensive than gasoline-powered cars, and the numbers are still small.

- The high cost and limited performance of batteries are the main obstacles to further market penetration by EVs. Battery technology is likely to improve, but there is no guarantee that the improvement will be sufficient to allow widespread adoption of EVs.

- In the U.S., EVs are a niche market serving mainly upper middle-class males in California.

- Aviation is a high-growth segment throughout the world, and there are no viable substitutes for jet fuel in the foreseeable future.

- Public transport remains a small part of total travel throughout the world. Even major increases in travel on public transit would have a negligible impact on CO_2 emissions.

- The recently passed Infrastructure and Jobs Act and Inflation Reduction Act offer expensive, but largely symbolic, carbon reductions in an effort to help President Biden fulfill his largely rhetorical 2030 promise.

- The current objective of the climate movement is “net zero” emissions by 2050.

- The technology for carbon capture, utilization and storage (CCUS) does not yet exist, implying that “net zero” must be accomplished entirely by reductions in CO_2 emissions.

- Climate politics are significant primarily in the industrial countries. The developing world “talks the talk” primarily to encourage financial flows from the rich countries.

- None of the pledges made by the developing countries in the various climate agreements has yet been translated into real actions, and nothing in the numbers suggests any trend toward “net zero” emissions.

- An “energy transition” away from fossil fuels may happen, but there is no evidence that it is happening now.

- According to the latest projections by the U.S. Energy Information Administration, the trends evident in the last 25 years are likely to continue. Specifically, the strong growth of CO_2 emissions in the developing world will probably overshadow any actions taken by the industrial countries. Even if the industrial countries reduced their CO_2 emissions to zero, total global emissions would still increase through 2050.

- The climate debate is not over pathways to “net zero” emissions but, rather, about whether to spend large amounts of money in order to achieve modest reductions in the rate of growth in CO_2 emissions in industrialized countries.

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INTRODUCTION

In 1988, the wonderful British comedy show “Yes, Prime Minister” coined the term “The Politician’s Syllogism”, which runs as follows:

1. We must do something.
2. This is something.
3. Therefore, we must do this.

This approach works well for politicians, who are interested primarily in appearances, but the consequences of public policy decisions are often quite serious, affecting the living standards of average Americans.

Climate policy is a perfect example of the Politician’s Syllogism at work. The climate agenda is based on a carefully constructed narrative that has two components:

- Scientists have determined that carbon dioxide emissions from fossil fuel use are already causing storms, droughts, wildfires, sea level rise and ocean acidification and that future CO_2 emissions will cause our climate to deteriorate with catastrophic consequences.

- In response, the world is in the process of engineering an “energy transition” away from fossil fuels and toward renewable technologies, particularly wind and solar. In this view, renewable energy costs less than fossil fuels and, therefore, this transition will be easy and bring major benefits in job creation and economic growth.

This catastrophic climate narrative has gained wide circulation in the U.S., but it is not clear how much of this complex subject the public understands. Some people absorb the climate narrative by osmosis from the media’s constant repetition. Others accept the narrative because they wish to be seen by family friends and colleagues as good progressives. The climate narrative is an inseparable part of the progressive canon and questioning its premises can cause people serious career problems or at least raised eyebrows in their social circle. Many people simply avoid talking about climate altogether.

Public opinion surveys, many conducted by climate-activist organizations, are often presented as evidence of widespread public support for the climate agenda, but the answers are often limited to non-controversial questions like “Do you believe the Earth’s temperature has probably been increasing over the past 100 years?” or “Do you believe that human actions have been at least partially causing global warming?”[1] These assertions may appear meaningful, but few people on either side of the debate would disagree with them.

The late 2021 survey by the Energy Policy Institute of the University of Chicago[2] asked more substantive questions, such as how much people would be willing to pay for carbon dioxide reduction. Thirty-three percent of respondents supported paying $1 per month, but only 9% were willing to pay $100 per month. The Chicago survey, however, did not offer respondents any information on what carbon dioxide reduction actually costs.

Those people involved in the formulation of policy, or who just want to be informed citizens, have been served poorly by climate activists demonizing those who disagree and keeping alternative views out of the public discussion. Finding useful information to form independent, analytically based views on the climate issue is difficult. As a result, many people simply default to the climate narrative as reflecting “expert opinion”. Succumbing to this temptation is dangerous for anyone seeking to understand or formulate public policy since it puts them at the mercy of people with credentials and a political agenda.

The “we must do something” issues in the climate debate are scientific. Although climate activists often argue that the science is “settled” and that only qualified climate scientists can hold valid opinions, the basic issues are both debatable and easily understood. First of all, those interested in climate policy must avoid the fallacy of scientific “consensus.” Science is only one thing: the testing of ideas against evidence. As the great physicist Richard Feynman said, “It does not make any difference how beautiful your guess is, it does not make any difference how smart you are, who made the guess, or what his name is — if it disagrees with experiment, it is wrong.”[3] The motto of the Royal Society, Britain’s preeminent scientific community founded in 1660, is “nullius in verba” or “take nobody’s word for it.” According to the Royal Society, its motto is “…an expression of the determination of Fellows to withstand the domination of authority and to verify all statements by an appeal to facts determined by experiment.”[4]

Using this principle, those interested in the climate debate should investigate the following questions:

- On what basis do climate activists refer to CO_2, a life-giving molecule essential for all life on Earth, as “pollution”?
- Are the computer models which generate catastrophic climate scenarios reliable?
- Is it true that adverse events such as hurricanes, tornadoes, wildfire, floods, ice melt, etc. are actually increasing or is our recent experience within the range of natural variation?

Different people can reach different answers to these questions, but a working knowledge of climate policy requires that these questions at least be asked. (For a full treatment of the scientific issues, see Steven Koonin’s book *Unsettled: What Climate Science Tells Us, What it Doesn’t and Why it Matters*, BenBella Books, 2021).

After reaching careful analytical conclusions on whether “something must be done,” people interested in climate policy must also look carefully at the “somethings” that are actually being proposed. Before the United States continues to spend large amounts of taxpayers’ money in response to the climate narrative, it would behoove us to “run the numbers” to understand the economic impacts, side effects and true costs of proposed climate policies. The purpose of this monograph is to provide a reference on the landscape of our energy economy, the economics of fossil fuels versus renewables and the geography of where and how carbon dioxide is generated.

BACKGROUND

The global political effort to define and address climate change started with the creation of the U.N. Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC produced a 1,200-page First Assessment Report (FAR) in 1990 attempting to describe comprehensively the science of climate and the influence of CO_2. The FAR led to the negotiation of the U.N. Framework Convention on Climate Change (UNFCCC) in 1992, signed by 197 countries, which has as its stated objective, "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

The IPCC then held three annual Conferences of Parties (COPs 1-3) and produced a second Assessment Report (SAR), providing the basis for the Kyoto Protocol, signed by 192 countries in 1997. The Kyoto Protocol was the first effort to define concrete steps to reduce CO_2 emissions.

Implementation of Kyoto between 1997 and 2012 was accompanied by COPs 4-18 and the third (TAR) and fourth (AR4) Assessment Reports. Subsequently, AR5 plus several supplementary IPCC reports and COPs 19-21 produced the Paris Climate Agreement in 2015, signed by 197 countries. Since the signature of the Paris Agreement, the IPCC has held COPs 22-26, issued parts of AR6, and published several additional supplemental studies.

One of the signature outcomes of the UN's climate process was the establishment of the Green Climate Fund (GCF) at COP-17 in Durban in 2011. The GCF was intended to collect and distribute funds to support renewable energy development in poorer countries. In the Paris Agreement of 2015, participants promised $100 billion to the GCF. As of September 30, 2021, after six years, pledges totaled only $8.31 billion.[5] The funding of the GCF and the distribution of the money have been major points of contention in global climate negotiations.

It is difficult to estimate the resources devoted to these activities over the years, but the creation of this massive bureaucracy has been expensive, measured in tens of billions of dollars and tens of thousands of staff. The Secretariat of the UNFCCC alone has 450 permanent staff.[6] The U.S. Government has multiple offices with climate responsibilities, including the President's Climate Change Commission, the White House Council on Environmental Quality, the State Department's Office of Global Change, the Departments of Energy, Defense, Commerce, Transportation, Health and Human Services and the Interior, the Environmental Protection Agency, the National Aeronautics and Space Administration (NASA), the National Oceanographic and Atmospheric Administration (NOAA) and others, all of which have staffs devoted to climate issues.

Many other western governments have similar bureaucracies. There are hundreds of non-profit organizations insisting that we "do something" about climate. Students around the world are earning degrees in climate change and entering careers in the global climate bureaucracy.[7]

According to the BBC, about 40,000 delegates attended COP26 in Glasgow in October-November 2021, with Brazil in first place with 479 delegates. Even poor countries sent massive delegations, including Kenya (310), Bangladesh (296) and Sudan (236). The purpose of these delegations was mainly to lobby for more money from the wealthy countries. Even the fossil fuel industry sent a total of 503 delegates.[8]

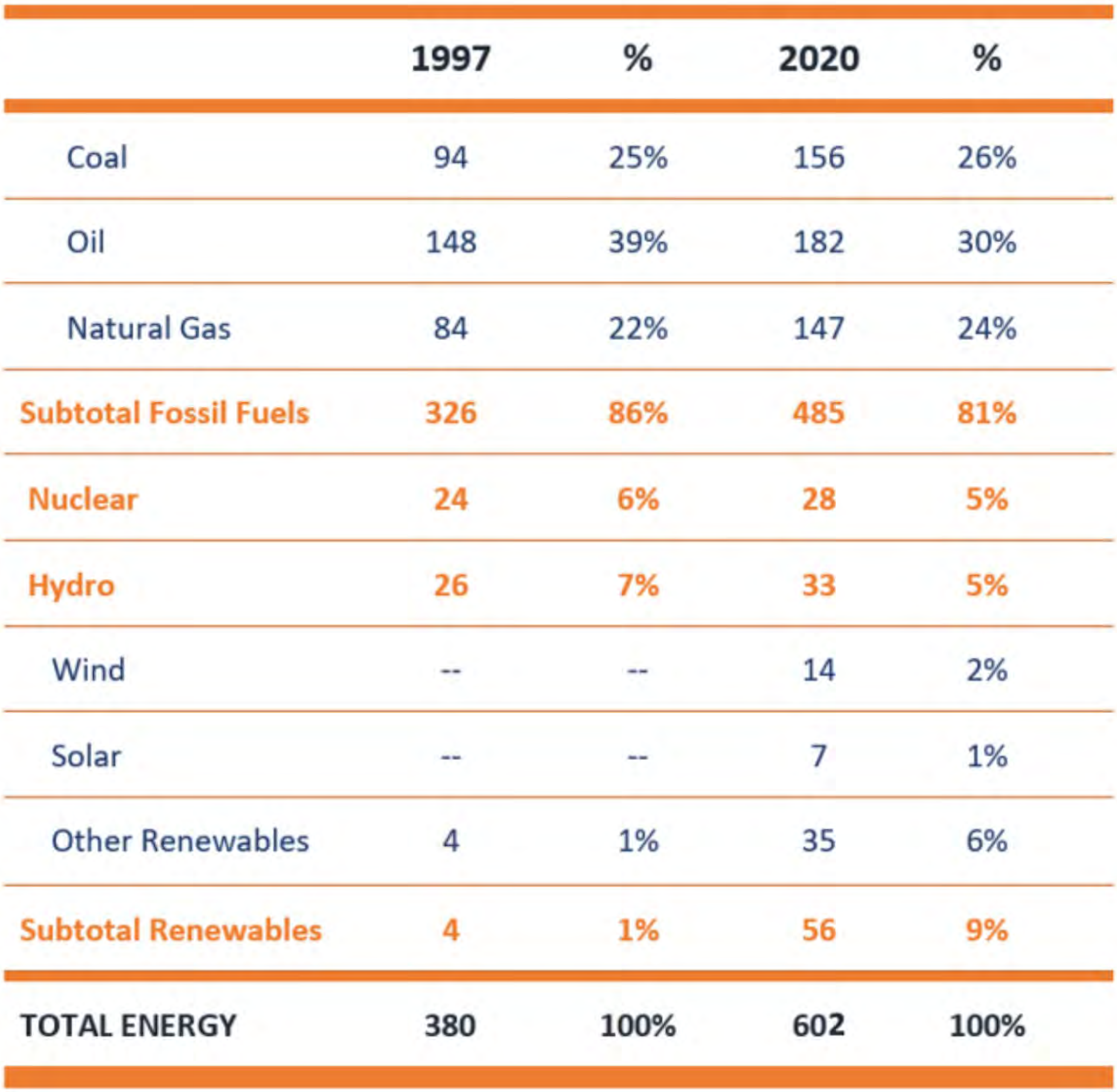
The Scottish Police estimated the cost of COP26 at “several hundred million pounds.”[9] All this expensive activity supposedly demonstrates that the international community has finally come together in a serious effort to save the world from climate catastrophe.

The core of this global fight against climate change is the supposed “energy transition” from fossil fuels to renewable energy. A Google search of the term “energy transition” generates over 29 million hits. PWC, one of the Big 4 accounting firms, claims: “The energy transition is fully underway around the world, with a major shift from fossil fuels to renewable sources."[10] Consulting firm Wood McKenzie states, “The energy transition currently underway is about a transformational switch away from fossil fuels and into renewable and clean sources of energy (solar, wind and water) … Powering the energy transition is a technology-based switch from fossil fuels to renewables, supported by an almost ubiquitous societal push towards a sustainable future."[11]

The prestigious law firm of Norton, Rose, Fulbright claims, “The energy transition is firmly underway. While global demand for energy continues to rise, increasing pressure from governments, investors, and consumers to support the decarbonization of the industry has spearheaded radical change. In recent years we have seen the overhaul of entire business models from a focus on fossil fuels to clean energy ..."[12]

The “energy transition” narrative sounds impressive, but what has actually happened since 1997, when the international community first decided to set quantitative targets via the Kyoto Protocol? Table 1 shows the growth in world energy demand over this 23-year period.

Table 1: Global Energy Consumption by Fuel, 1997 and 2020[13] (Quadrillion Btu[14])



	1997	%	2020	%
Coal	94	25%	156	26%
Oil	148	39%	182	30%
Natural Gas	84	22%	147	24%
Subtotal Fossil Fuels	**326**	**86%**	**485**	**81%**
Nuclear	**24**	**6%**	**28**	**5%**
Hydro	**26**	**7%**	**33**	**5%**
Wind	--	--	14	2%
Solar	--	--	7	1%
Other Renewables	4	1%	35	6%
Subtotal Renewables	**4**	**1%**	**56**	**9%**
TOTAL ENERGY	**380**	**100%**	**602**	**100%**

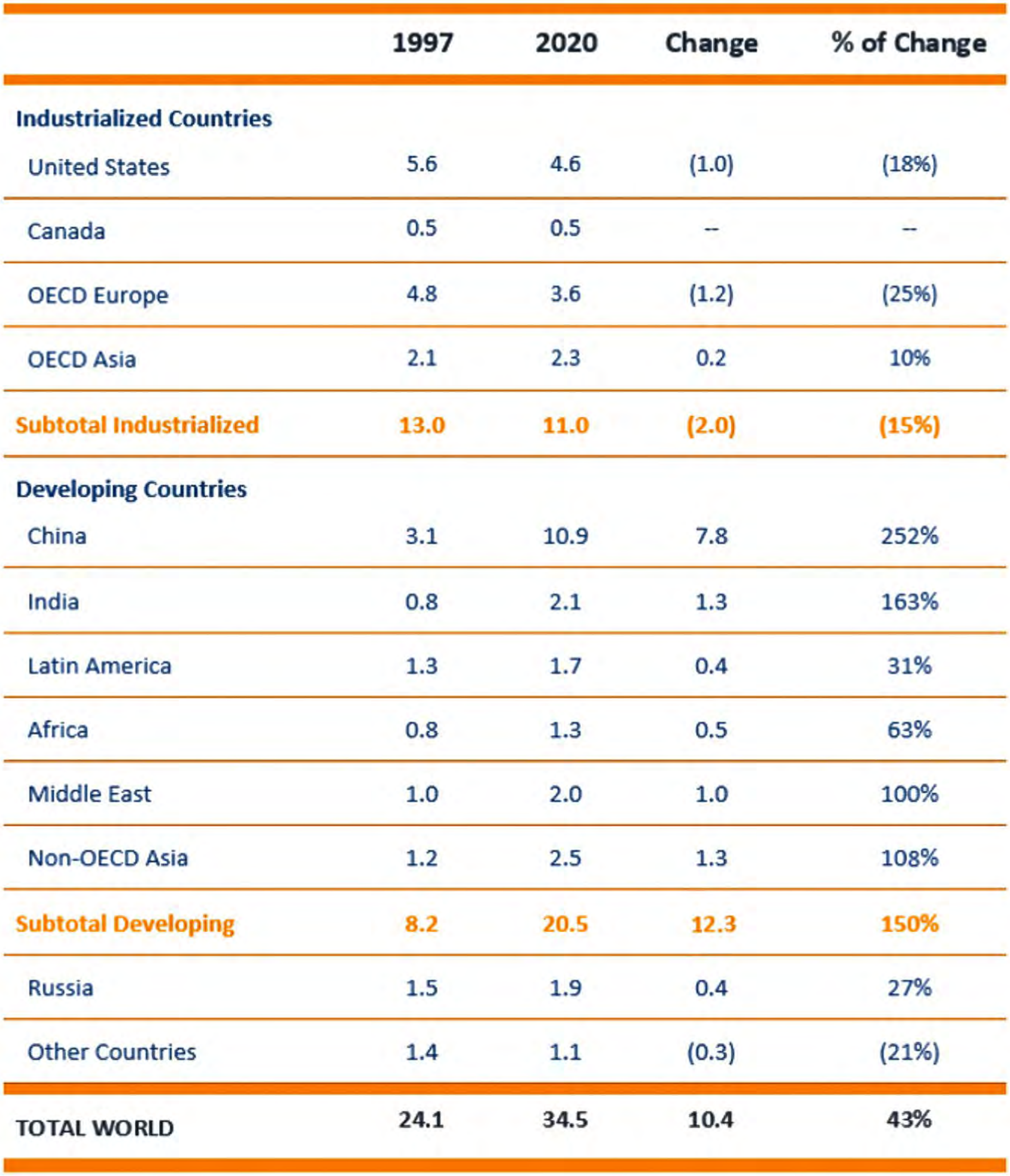
Source: U.S. Energy Information Administration, International Data Tables and International Energy Outlook 2021; BP, "Statistical Review of World Energy", July 2021

In 1997, the world consumed 380 quadrillion Btus (quads) of energy, including 326 quads (86%) of fossil fuels, 50 quads of nuclear and hydro (13%) and a negligible amount of wind, solar and other renewables. By 2020, global energy consumption had increased 58% to 602 quads. Fossil fuels accounted for 485 quads (81%), nuclear and hydro for 61 quads (10%) and wind, solar and other renewables for the remaining 56 quads (9%).

In other words, 23 years after the signature of the Kyoto Protocol, the global energy market is much bigger, but fossil fuels continue to dominate. Fossil fuels now have a 5-percentage point smaller share but have increased in absolute terms. Each of the three major fossil fuels had grown substantially over this period (coal by 66%, oil by 23% and natural gas by 75%).

As shown in Table 2, CO_2 emissions increased by 43% between 1997 and 2020.

Table 2: Comparison of CO_2 Emissions in Industrialized and Developing Countries, 1997 and 2020 (Gt[15])



	1997	2020	Change	% of Change
Industrialized Countries				
United States	5.6	4.6	(1.0)	(18%)
Canada	0.5	0.5	--	--
OECD Europe	4.8	3.6	(1.2)	(25%)
OECD Asia	2.1	2.3	0.2	10%
Subtotal Industrialized	**13.0**	**11.0**	**(2.0)**	**(15%)**
Developing Countries				
China	3.1	10.9	7.8	252%
India	0.8	2.1	1.3	163%
Latin America	1.3	1.7	0.4	31%
Africa	0.8	1.3	0.5	63%
Middle East	1.0	2.0	1.0	100%
Non-OECD Asia	1.2	2.5	1.3	108%
Subtotal Developing	**8.2**	**20.5**	**12.3**	**150%**
Russia	1.5	1.9	0.4	27%
Other Countries	1.4	1.1	(0.3)	(21%)
TOTAL WORLD	**24.1**	**34.5**	**10.4**	**43%**

Source: U.S. Energy Information Administration, International Data Tables and International Energy Outlook 2021

Emissions depend on the absolute amount of fossil fuel burned, not its share in the overall energy economy.

In 1997, the world emitted 24.1 Gt of CO_2. About 55% of the total was attributable to the industrialized countries of the Organization for Economic Cooperation and Development (OECD) and 45% to the rest of the world. In the early days of the climate debate, developing countries often told the industrialized world, “You caused it, you fix it.” In this context, the industrialized countries agreed to take on the initial commitments under Kyoto, and by 2020 had managed to reduce their emissions by only about 15%. Half the reduction was in the United States, which signed but did not ratify the Kyoto Protocol. The developing countries, however, more than doubled their emissions over this period, with China more than tripling theirs.

Today’s Global Energy Market

The world energy market now has two components. Driven by domestic political pressures, the industrialized world struggles to achieve modest reductions in CO_2 emissions, while the developing countries grow their fossil fuel use, and hence CO_2 emissions, at a rapid pace.

It is worth noting that even the modest reduction in the industrialized countries was partly illusory. True pollutants, like smog, particulates, carbon monoxide and lead, are largely local phenomena and can be successfully mitigated by reducing local sources of emission. Carbon dioxide, however, is well-mixed in the atmosphere. As a result, the location of CO_2 emissions makes no difference to the overall atmospheric concentration. Some of the apparent reduction in CO_2 emissions in the industrialized countries involved a relocation of energy intensive industries to developing countries. If, for example, a factory closed in Europe and a comparable one opened in India, the European statistics would show a decline in CO_2 emissions, but the global impact would be zero. By the same token, the European mandates for the use of biodiesel are partly met by palm-oil plantations in Southeast Asia developed using slash-and-burn agriculture that releases large amounts of CO_2. Studies have shown that this process actually increases global CO_2 emissions,[16] but the European carbon balance still shows a credit.

If, as climate advocates claim, renewables are not only cleaner but cheaper than fossil fuels, why are we not seeing the widespread adoption of these technologies? Why the continued growth in fossil fuels and related CO_2 emissions? A dive into the energy economy in the U.S. and other countries can cast some light on why carbon-based fuels continue to dominate.

As economies become more complex, energy needs become specialized. For the first hundred years of American history, wood and animals were the primary sources of energy. By the early 20th century, coal accounted for 75% of U.S. energy needs, including direct industrial use, home heating, railroad transportation and electric power generation.[17] Today’s U.S. energy economy is far more complex with a mix of oil, natural gas and multi-sourced electricity, each with its own special characteristics.

ELECTRIC POWER GENERATION

Let us consider, for example, electric power, which is critical to economic activity and accounts for nearly 40% of global CO_2 emissions.[18] Power supply is not just a matter of wattage, but also voltage and frequency, variations in which can wreak havoc on modern machinery, like computers. Politicians are wary of disrupting power supply since outages not only impose personal hardships on the citizenry, particularly in cold regions, but bring economic activity to a temporary standstill.

The electric power grid is unlike other energy systems. Gasoline, for example, is easy to store. American drivers currently consume about 8 million barrels (MB) per day of gasoline. The gasoline supply system has considerable inventory at refineries and distribution terminals, estimated at about 200 MB or 25 days' supply at any given time. The 150,000 U.S. gas stations also hold inventory, and consumers generally carry a few days' supply in their gas tanks. This system is highly flexible, and oil refineries do not have to be concerned with the hourly or daily driving habits of consumers.
In contrast, the electric power system has virtually no storage capacity. Electricity must be generated instantaneously to meet whatever demand exists at that moment. Although batteries can store small amounts of power for brief periods, they are extremely expensive. Some utilities also utilize pumped storage systems where water is pumped uphill at night when surplus power is available and then allowed to run downhill through turbines to generate power in the daytime. Such systems, however, are expensive and confined to areas with suitable topography. In 2020, the U.S. had a total of 1,200 gigawatts[19] (GW) of electric generating capacity, but only 22 GW of pumped storage and about 1 GW of battery storage.[20]

Electrical generating capacity is of two types: dispatchable, which can generate power on demand, and intermittent, which is available only when nature supplies it. Natural gas, coal, oil, hydroelectric and nuclear plants are dispatchable, but wind and solar are intermittent and can supplement but not replace other sources of power.[21] If a grid relies totally on wind, for example, power generation could fall to zero when the wind stops blowing.

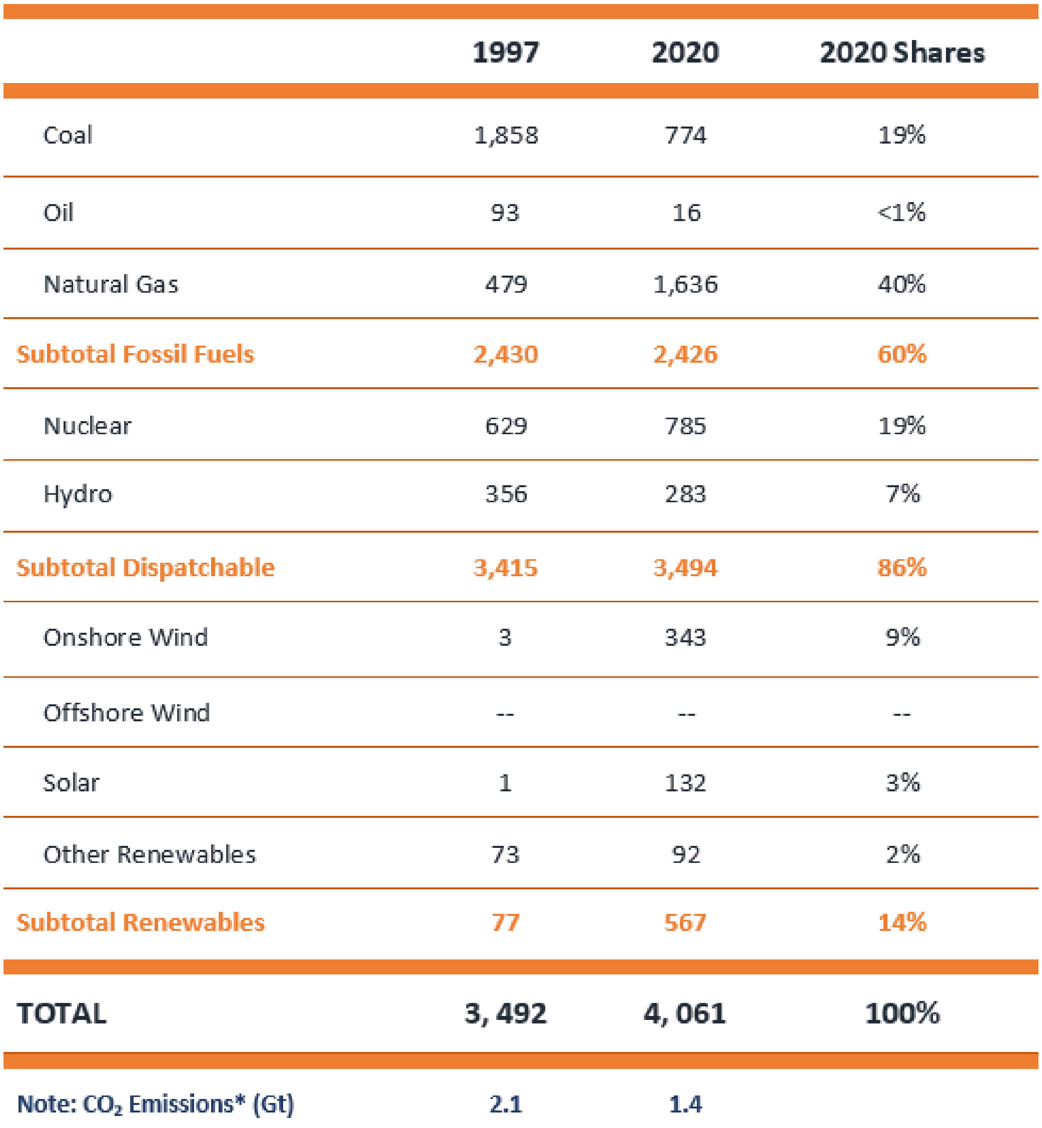
Consider as an analogy a restaurant with an "intermittent" kitchen that produces cooked meals at random intervals regardless of how many customers are in the dining room. Such a restaurant would face two problems. First, the restaurant would have to throw away the meals the "intermittent" kitchen cooks in excess of the number of customers in the restaurant at any given time. Second, the restaurant would have to turn away customers when the "intermittent" kitchen was not producing. The restaurant would need a second "dispatchable" kitchen that could produce meals on demand for the diners not served by the "intermittent" kitchen.

So it is with electric power. Intermittent wind and solar can function only if there is sufficient dispatchable generating capacity in the form of coal, oil, natural gas, hydro or nuclear to compensate when the wind does not blow or the sun does not shine. Power grids are complex systems which develop organically over long periods of time. The amount of intermittent power that can be accommodated depends on the specific grid and is difficult to calculate in advance. Finding the limit, however, is a dangerous experiment. The great Texas freeze of February 2021 was at least partly the result of the failure of Texas' large wind and solar capacity during a prolonged period of adverse weather with insufficient fossil fuel capacity for backup.[22]

Traditionally, politicians and regulators in all countries try to ensure that electricity supplies are adequate, reliable, stable – and affordable. Many poor countries have so far been unable to achieve this goal. According to the World Bank, about 750 million people have no access to electricity at all.[23] Many others in poor countries have only sporadic access to power. Solving these problems is a key element of economic development strategies in emerging countries.

In recent years, politicians in the wealthy countries began to face another political requirement: the demands of climate activists. Governments have responded to these demands in different ways depending on their economic situation, resource availability and domestic political calculations. Let us consider the U.S. first.

Table 3: U.S. Electricity Generation by Fuel, 1997 and 2020 (Terawatt hours)



	1997	2020	2020 Shares
Coal	1,858	774	19%
Oil	93	16	<1%
Natural Gas	479	1,636	40%
Subtotal Fossil Fuels	**2,430**	**2,426**	**60%**
Nuclear	629	785	19%
Hydro	356	283	7%
Subtotal Dispatchable	**3,415**	**3,494**	**86%**
Onshore Wind	3	343	9%
Offshore Wind	--	--	--
Solar	1	132	3%
Other Renewables	73	92	2%
Subtotal Renewables	**77**	**567**	**14%**
TOTAL	**3, 492**	**4, 061**	**100%**
Note: CO_2 Emissions* (Gt)	**2.1**	**1.4**	

*Electricity sector only

Sources: Electricity statistics: BP Statistical Review of World Energy, July 2021;
CO_2 *statistics: U.S. Energy Information Administration Annual Outlook, 2020*

As shown in Table 3, U.S. electricity demand increased by 569 TWh or about 16% between 1997 and 2020, and the generation mix changed. As late as 2015, many energy analysts assumed that coal would remain the leading U.S. power generation fuel for the foreseeable future. That situation changed with the advent of inexpensive natural gas, produced in quantity by the process of hydraulic fracturing, known informally as "fracking." After peaking in 2008 at $9.26 per million Btu (MBtu), the price of natural gas sold to power plants fell below $3.00 per MBtu in 2016. Prices have recovered somewhat to over $7.00 in mid-2022 but remain below their highs of 14 years ago. The result was a huge shift of power generation from coal to natural gas.

Nuclear power, another important source of dispatchable power, is politically unpopular in the U.S. A number of nuclear plants have encountered either severe local opposition to their commissioning (e.g., Shoreham on Long Island) or demands for early decommissioning (e.g., Pilgrim in Massachusetts and Indian Point in New York). Nonetheless, the U.S. still has 93 operating nuclear reactors at 56 power stations with a total capacity of about 97 GW and able to supply about 20% of U.S. power demand. As of this writing, only two nuclear reactors (Voglte 3 and 4 in Georgia) are currently under construction with a capacity of just over 2 GW. In the future, the U.S. is expected to lose nuclear capacity as decommissionings outpace new builds. Nonetheless, the U.S. will have a significant nuclear industry for the foreseeable future.

Hydroelectric power accounted for about 7% of U.S. power generation in 2020. Approximately 2,300 U.S. dams generate power, but most of the output comes from a handful of large dams along the Columbia River and a few other locations. Hydroelectricity is fully dispatchable over hours, days and weeks, but year-to-year variations in output can be significant, depending on precipitation in the mountains that feed the big rivers. Opportunities for the addition of large new dams in the United States are limited.

In 1997, fossil fuel accounted for 70% of U.S. power generation. Dispatchable power, i.e., fossil fuels plus nuclear and hydro, accounted for 98% of supply. Even though the U.S. had not ratified the Kyoto Protocol, climate advocates, with the support of wind and power producers, began to lobby hard for subsidies and mandates for renewable power. By 2020, renewables had appeared in the U.S. energy balance with wind accounting for 8% and solar for 3% of total electricity supply. Fossil fuels, however, still accounted for 60% of power generation and dispatchable power for 86%.

The push for renewable energy is not new. According to the Congressional Research Service, the U.S. Government spent over $33 billion (in $2021) on renewable energy over the 70-year period between 1948 and 2018[24]. Following the "oil crisis" of 1973-74, the federal government began serious efforts to develop non-fossil fuel sources. The Energy Reorganization Act of 1974 created, among other agencies, the Energy Research and Development Administration (ERDA) with 7,222 employees and a budget of about $20 billion ($2021). Most of the budget was devoted to nuclear energy, but one of ERDA's stated goals was "to concentrate on underused technologies capable of being rapidly developed for the mid-term and beyond, such as solar heating and cooling and the use of geothermal power". Alongside ERDA, Congress established The Solar Energy Research Institute to "to support ERDA's solar program and to aid in establishing an industrial base for solar energy". Initially, wind energy was part of the solar research program[25].

ERDA was rolled into the new U.S. Department of Energy in 1977, but its research efforts continued. Nearly a half century after the initiation of these expensive programs, solar energy accounts for only 3% of U.S. electric power generation and all renewables only 14%.

Although U.S. climate policy over the last 30 years has not produced much in the way of results, the push for an "energy transition" continues. Before we continue to commit scarce resources to this effort, an assessment of the true cost of renewable energy is essential. A proper economic evaluation of costs must steer clear of the following popular misconceptions.

The first misconception is that the wind and the sun are free while fossil fuels require expensive exploration, production, refining and distribution. Many schools teach this idea to children, along with the view that renewable energy is good and fossil fuels bad. In fact, although wind and solar energy have zero fuel cost, the equipment required to capture that energy, convert it to useable power and distribute it to consumers is expensive. Furthermore, even when the machinery is in place, the availability of renewable energy is quite low. According to the U.S. Energy Information Administration, load factors[26] are 41% for onshore wind, 44% for offshore wind, 25% for solar photovoltaics with tracking and 15.7% for home solar, compared to 80-90% for fossil fuel plants.[27]

A second misconception is the "moon shot" argument, often expressed as "If we can put a man on the moon, we can …". The Apollo program was an extraordinary achievement in human history. Its basis, however, was NASA's ability to do something technologically difficult a few times at great cost. The six successful moon missions landed 12 men on the moon at a total cost of about $300 billion ($2021) or $25 billion per man.[28] R&D on energy technologies, however, is designed to produce results that can be scaled up at low cost – just the opposite of the Apollo approach. Climate studies often assume that (a) the cost and performance of existing energy technologies will remain fixed over time, (2) the cost and performance of new technologies can be driven down by government R&D and forced commercialization and (3) eventually all new technologies become cheaper than existing ones.[29] There is no historical support for these assumptions. (For a more detailed discussion of this problem, see this author's "Back to Basics on Energy Policy", Issues in Science and Technology, Fall 2012 at https://issues.org/bruce/)

A third mistake is to include government mandates and subsidies in the cost calculation. Subsidies do not reduce costs, but merely transfer them from consumers to taxpayers or other consumers. Any product is economically viable if the subsidies are high enough. Subsidies can be either direct cash payments or regulatory requirements such as renewable portfolio standards, net-metering or "feed-in tariffs." A variant of this argument is that fossil fuels receive higher subsidies than renewables. In view of the high taxes imposed on fossil fuel use, this argument is untrue by any reasonable definition (For more information, see this author's "Study Finds Fossil Fuels Aren't Subsidized; They're Overtaxed" at https://co2coalition.org/news/study-finds-fossil-fuels-arent-subsidized-theyre-overtaxed/.)

A fourth analytical error is to understate returns on capital. Capital-intensive investments require sufficient revenue to cover operating costs, repay bank loans and provide investors with an acceptable rate of return. In many analyses, the assumed cost of capital reflects either low government borrowing rates or investors' efforts to capture government subsidies rather than an open market risk.

A fifth misconception is the measurement of generating capacity rather than actual generation. Wind and solar power are available only when nature allows, while fossil fuel and nuclear plants can run whenever needed. In 2020, wind and solar accounted for 14% of U.S. generating capacity, but less than 11% of electricity generated.

A final mistake is to look just at the cost per kilowatt-hour (kWh) in isolation, i.e., generated without reference to the impact on the rest of the generation system. An intermittent kWh is worth less than a dispatchable kWh for the reasons outlined above, but regulated markets prevent price discovery.

If these misconceptions are the wrong way to look at electrical generation costs, what is the correct way? First and foremost, economics are in the eye of investors, who make their best assumptions regarding costs and operational parameters and use cash flow modeling to calculate the price required to satisfy investor expectations. For purposes of this monograph, the calculations will exclude any taxes or subsidies in order to arrive at the true cost.

The general assumptions common to all the calculations are shown in Table 4.

Table 4: General Economic Assumptions for Utility Cost Calculations[30]

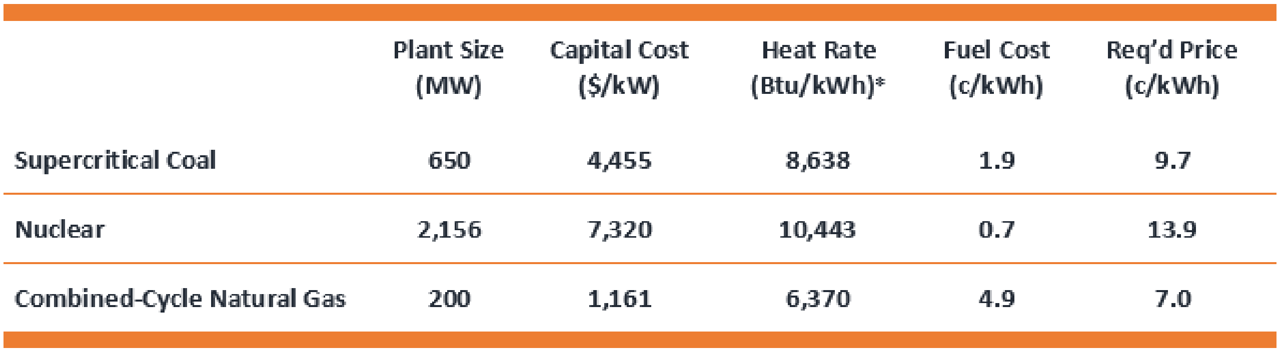
Project Duration (Years)	**30**
Annual US Inflation 2023-2025	**5%**
Annual US Inflation 2026+	**2.5%**
Debt/Equity Ratio	**50/50**
Interest Rate	**6%**
Required Return on Equity	**15%**
Weighted Average Cost of Capital	**10.5%**

The specific technical, operational and cost data have been taken, to the extent possible, from the Energy Information Administration (EIA).[31]

These assumptions are, in general, optimistic. Solar and wind farms are unlikely to last a full 30 years, since the materials degrade and the electronics wear out. Return on equity at 15% may be too low to encourage entrepreneurs to take full market risk and may be applicable only to renewable systems supported by government regulation. Given recent experience, inflation assumptions may also be too low. On balance, these calculations will be favorable to renewable energy with much more downside than upside risk.

Using these assumptions, the required prices for the three basic dispatchable technologies are shown in Table 5. All are assumed to be operating at load factors of 87%, the conventional benchmark for baseload power.

Table 5: Comparative Economics of Basic Dispatchable Power Technologies ($2022)**



	Plant Size (MW)	Capital Cost ($/kW)	Heat Rate (Btu/kWh)*	Fuel Cost (c/kWh)	Req'd Price (c/kWh)
Supercritical Coal	650	4,455	8,638	1.9	9.7
Nuclear	2,156	7,320	10,443	0.7	13.9
Combined-Cycle Natural Gas	200	1,161	6,370	4.9	7.0

* A heat rate of 3,412 Btu/kWh would represent 100% efficiency. A heat rate of 6,370 represents an efficiency of about 54%, etc.

** The comparable number for biomass power generation would be about 25¢/kWh.

These cost estimates are national averages and will vary significantly by region. For context, the average retail price of electricity in the U.S. in 2020 was 10.6¢/kWh with Hawaii the highest at 27.6¢ and Louisiana the lowest at 7.5¢. Transmission and distribution costs account for the difference between the generating plant and the end-user.

It should be noted that these are prices calculated to meet the pre-set economic criteria. Actual utility pricing structures are often set to ensure that all renewable energy can be sold by giving a number of regulatory advantages to wind and solar. Actual experience suggests that the transmission costs associated with renewables, particularly wind farms and desert solar systems, may be significantly above those assumed here.

On average, combined cycle natural gas (NGCC) plants are the lowest cost generation technology in most of the U.S. at 7.0¢/kWh and are the "case to beat" for analysis of future generating plants. New coal plants are, on average, more expensive than NGCC, since coal plants involve high capital costs and low efficiency. However, coal is expensive to transport, and coal economics will be better for plants near coal-producing areas.

Nuclear plants offer an option with high fixed cost but low variable costs. The primary constraint on new nuclear plants is their long lead times – 6 years versus 4 years for coal and 3 years for NGCC. Part of this problem is the complexity of the plant, but an important contributor is an extensive regulatory burden, which can change over time, and the opportunity for lawsuits by local opposition, often resulting in injunctions. When construction times are extended and new technical requirements added, the cost of construction and carried interest can become excessive. New nuclear technologies, including small-scale reactors, may alleviate some of these problems, but few utilities today are willing to take the risks. As noted above, only two new nuclear power plants are currently under construction in the U.S., and the EIA does not project any additional nuclear builds before 2050.

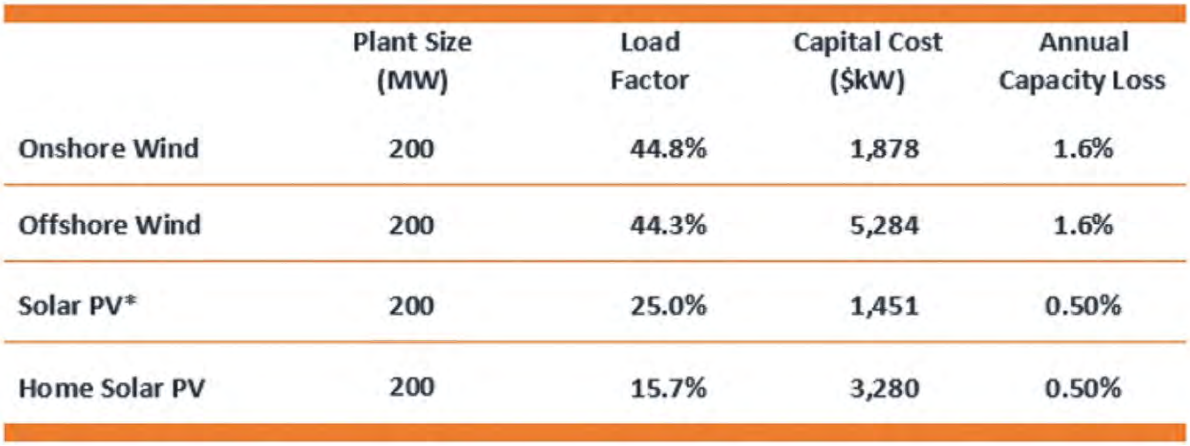
Hydroelectric plants are dispatchable, but there are few opportunities for large-scale new facilities in the U.S. It should be noted that simple cycle turbines are also dispatchable. Although they are inexpensive to build and start up very quickly, these machines are inefficient and expensive to operate. As a result, they tend to be used only at peak times with load factors of 5-10%.

Without the distortions imposed on the industry by the climate agenda, the U.S. could easily grow its electricity generating industry by adding new NGCC and coal for baseload and simple cycle turbines as required for peak shaving. Forcing renewables into the mix brings not only higher costs but additional complexity. To ensure that power is fully dispatchable, every kW of renewable power must be backed up by a kW of dispatchable power. Otherwise, the grid will be neither stable nor reliable.

A proxy for a maximum renewable system would be to pair a 200 MW renewable generating plant with a 200 MW backup NGCC plant. In this hypothetical power plant, the renewable component would generate every kWh it could, while the back-up NGCC would provide whatever additional power was required to reach a load factor of 87%. This system would maximize the use of the renewable component while remaining fully dispatchable.

Table 6 shows the cost and operational parameters for the major forms of renewable energy. These are national average numbers, which can vary based on location. The fuel cost, of course, is zero.

Table 6: Cost Parameters for Renewable Energy ($2021)



	Plant Size (MW)	Load Factor	Capital Cost ($kW)	Annual Capacity Loss
Onshore Wind	200	44.8%	1,878	1.6%
Offshore Wind	200	44.3%	5,284	1.6%
Solar PV*	200	25.0%	1,451	0.50%
Home Solar PV	200	15.7%	3,280	0.50%

*Utility scale, with tracking

Table 7 shows the economics of a matched renewable/NGCC generating plant. The essential problem with renewables is that their capital costs add to rather than replace those of the NGCC plant. The NGCC plant would be idle much of the time, but its capital and fixed operating costs would still need to be covered by the electricity price.

Table 7: Comparative Economics of Matched Renewable/NGCC Generation ($2021)

	Plant Size (MW)	Renewable Share of Output	Capital Cost	Req'd Average Price (c/kWh)	NGC Contribution	Req'd Renewable Price (c/kWh)
NGCC Only	200	--	222	7.0	7.0	NA
NGCC/Onshore Wind	200	52%	643	8.2	7.0	9.9
NGCC/Offshore Wind	200	51%	1,314	16.4	7.0	30.1
NGCC/Solar PV*	200	27%	555	10.2	7.0	19.0
NGCC/Home Solar PV**	200	17%	888	12.7	7.0	41.0

*Utility scale, with tracking

**Assumes 33,333 6 kW rooftop solar systems plus a 200 MW NGCC plant

As noted above, on average, NGCC plants can generate electricity for about 7.0¢/kWh. If we build a 200 MW onshore wind farm, together with a 200 MW NGCC plant for backup, the capital cost of the system would be $643 million, versus $222 million for the NGCC alone. Assuming that the entire system runs at a load factor of 87%, the wind farm would generate power at its maximum load factor of 45%, and the NGCC would provide the remaining 42%. To cover all the financing, maintenance and fuel costs, the entire system would have to sell power at a price of 8.2¢/kWh. Since the NGCC could sell power at 7.0¢, the wind power would have to contribute 9.9¢/kWh to achieve the required weighted average price. An important factor in this calculation is the gradual degradation of wind turbines through scratching and other loss of aerodynamics. At the beginning of this project, the wind component contributes a little more than half the total system output, but by the end of the project, the wind turbines are contributing less than one-third. In actual practice, load factors for renewable energy may prove much lower than those shown.

The economics are even worse for offshore wind, which has capital costs more than double that of onshore wind. An offshore wind farm with a NGCC backup would require an average selling price of 16.4¢/kWh with the wind component needing to contribute 30.1¢. It is not surprising that offshore wind farms have faced difficult challenges gaining public support.

Utility-scale solar plants have lower capital costs than onshore wind ($1,451/kW versus $1,878) but their load factors are very low (25% for solar versus 45% for wind). As a result, the solar unit would generate only about 27% of the combined system's power with the NGCC unit contributing the remaining 73%. The required average price for this system would be 10.2¢/kWh with the solar component required to contribute 19¢.

As a final example, Table 7 also shows the economics of 200 MW of rooftop solar units with a 200 MW NGCC plant as backup. The U.S. has some 90 million single-family homes,[32] but only about 4% have rooftop solar panels. At $3,280 per kW, rooftop installations are expensive compared to utility-scale photovoltaics at about $1,451/kW. A utility-scale system can be built on open land with a tracking system that keeps the panels pointed at the sun. Most houses are not aligned at the best angle or in the optimum southerly direction, and roofs are often obstructed by trees, hills or nearby structures. As a result, the load factors of rooftop solar systems tend to be lower than utility scale plants (15.7% versus 25%).

Furthermore, there are often problems attaching solar panels to roofs that have limited lifespans, a tendency to leak or difficulty draining rain or snow. Finally, a rooftop solar unit will produce some of its power when the homeowner does not need it, and the homeowner will need power when the sun is not shining. Most U.S. state regulatory systems allow homeowners with solar panels to access power from the grid when needed and to sell surplus power to the utility at average rates, essentially providing a subsidy.

On a true cost basis, the rooftop solar/NGCC system would need to sell at an average price of 12.7¢/kWh with the solar units needing to contribute 41¢.

A penny or two may not seem like very much, but the U.S. currently consumes about 3,500 TWh or 3.5 trillion kWh. Each additional cent therefore adds $35 billion in costs annually or about $250 for each of the 140 million households in the U.S.

In addition to these direct costs, there are other constraints on the application of renewable technology. A major problem is land use. A 200 MW NGCC can fit into a city block. Natural gas is a much cleaner fuel than coal or fuel oil, emitting negligible amounts of sulfur and particulates. Although facilities of this type are generally not welcome in residential areas, they can easily be sited in industrial or commercial zones. Wind power, on the other hand, requires a great deal of land. In windy areas, individual 2 MW turbines need minimum spacing to avoid turbulent interference with each other. The EIA estimates the limit at about 17 MW per square mile.[33] Our 200 MW of wind turbines would therefore require about 12 square miles of land. The wind turbines, of course, do not take up all the land and can easily be installed on farmland or grassland, which makes them more suitable for the Midwest and great plains. Land requirements are much more problematic in the Northeast and Southeast which are more highly developed and have much less open land.

Massachusetts, for example, lacks the wide-open spaces conducive to efficient wind farms. As of this writing, the state's wind industry consists of 23 small wind farms generating a total of 106 MW.[34] In 2010, the town of Falmouth on Cape Cod installed two Vestas V82 turbines of 1.65 MW each at its waste disposal facility. Soon after, nearby residents started complaining about noise and shadows, and the town finally decided to dismantle the turbines leaving the town with significant debts and shut-down costs.[35]

The proposed solution in many coastal communities is to shift to offshore wind farms where land availability and neighborhood disruption are less of a problem. Unfortunately, as shown in Table 6, offshore wind power is far more expensive than onshore wind. Although a number of these offshore projects have been under discussion for years, none has yet been built in the U.S.

Solar photovoltaic (PV) presents an even more difficult land use problem. According to the National Renewable Energy Lab (NREL), utility- scale solar PV systems require 6-9 acres per MW. Using the lower end of that range, our 200 MW solar unit would require 1,200 acres or just under two square miles. The land needed is less than that for wind power, but solar panels cover the entire space. If the solar panels are raised, some marginal activities, such as parking spaces, can be installed beneath the solar system, but the utility of the land is low. Huge solar arrays in the desert look impressive, but they tend to be far from population centers. It is difficult to achieve economies of scale with solar power plants in heavily populated areas.

A few comments on batteries, which are often cited as a solution to the intermittency of wind and solar. With today's technology, batteries are too expensive to have a major impact. For example, a 200 MW solar array would generate 1,200,000 kWh on an average day (200 X 24 X 25% X1,000). Industrial scale batteries today cost about $400[36] per kWh. Storage for one day's electricity would cost about $480 million in addition to the $265 million for the solar array itself. The battery would allow smoother dispatch of power over a 24-48 hour period, but power could not be offered to the grid operator more than 48 hours in advance. For a 200 MW onshore wind farm, the battery would cost $750 million on top of the turbine cost of $345 million. Without major technological improvements, utility-scale batteries are not an economic option.

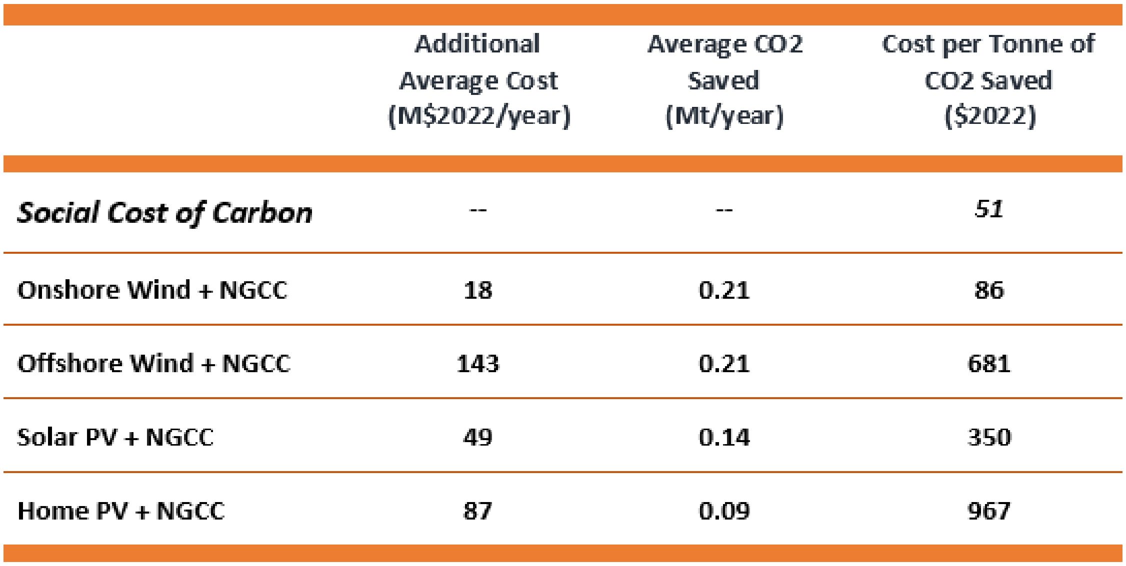
Many rooftop solar units are paired with batteries to reduce grid dependence, but these systems too are very expensive. A 6kW rooftop solar system operating at the national average of 15.7% load factor[37] generates roughly 23 kWh per day. A Tesla Powerwall battery with a capacity of 13.5 kWh (<60% of an average day's output) currently costs $10,500 and may require another $2,500 in home upgrades.[38] These systems are not economical for the average homeowner.

How do climate advocates assess the benefits of these expensive technologies?

In 2009, the Obama administration established a parameter called the Social Cost of Carbon (SCC). The SCC is supposed to be an estimate of "the monetized damages associated with an incremental increase in carbon emissions in a given year." More precisely, the SCC is intended to tell us the cost to the global economy of increasing carbon dioxide emissions by one metric tonne (1,000 kilograms, or 2,205 pounds).

The SCC is a highly politicized number, estimated by the Obama Administration at $40-45/tonne, by the Trump Administration at $1-6/ tonne and by the Biden Administration at $51/tonne. A case can also be made that SCC's should be negative,[39] but let us just use the current Biden Administration number and compare the cost of carbon dioxide reductions in the combined NGCC/renewable cases just discussed.

Table 8: Comparative Cost of Carbon Reductions for Renewable Electricity



	Additional Average Cost (M$2022/year)	Average CO2 Saved (Mt/year)	Cost per Tonne of CO2 Saved ($2022)
Social Cost of Carbon	--	--	*51*
Onshore Wind + NGCC	18	0.21	86
Offshore Wind + NGCC	143	0.21	681
Solar PV + NGCC	49	0.14	350
Home PV + NGCC	87	0.09	967

Table 8 shows the estimated cost of reducing CO_2 emissions for one of the matched renewable/NGCC systems shown in Table 7, compared to using NGCC alone. In the onshore wind/NGCC case, CO_2 reduction costs are over 50% more than the current estimated Social Cost of Carbon. In other words, by the Biden Administration's own logic, the supposed harm done by emitting a tonne of CO_2 is less than the cost of eliminating that CO_2 by installing an onshore wind turbine. Offshore wind costs 13 times as much, utility-scale solar PV costs seven times as much, and home solar systems nearly 20 times as much as the SCC.

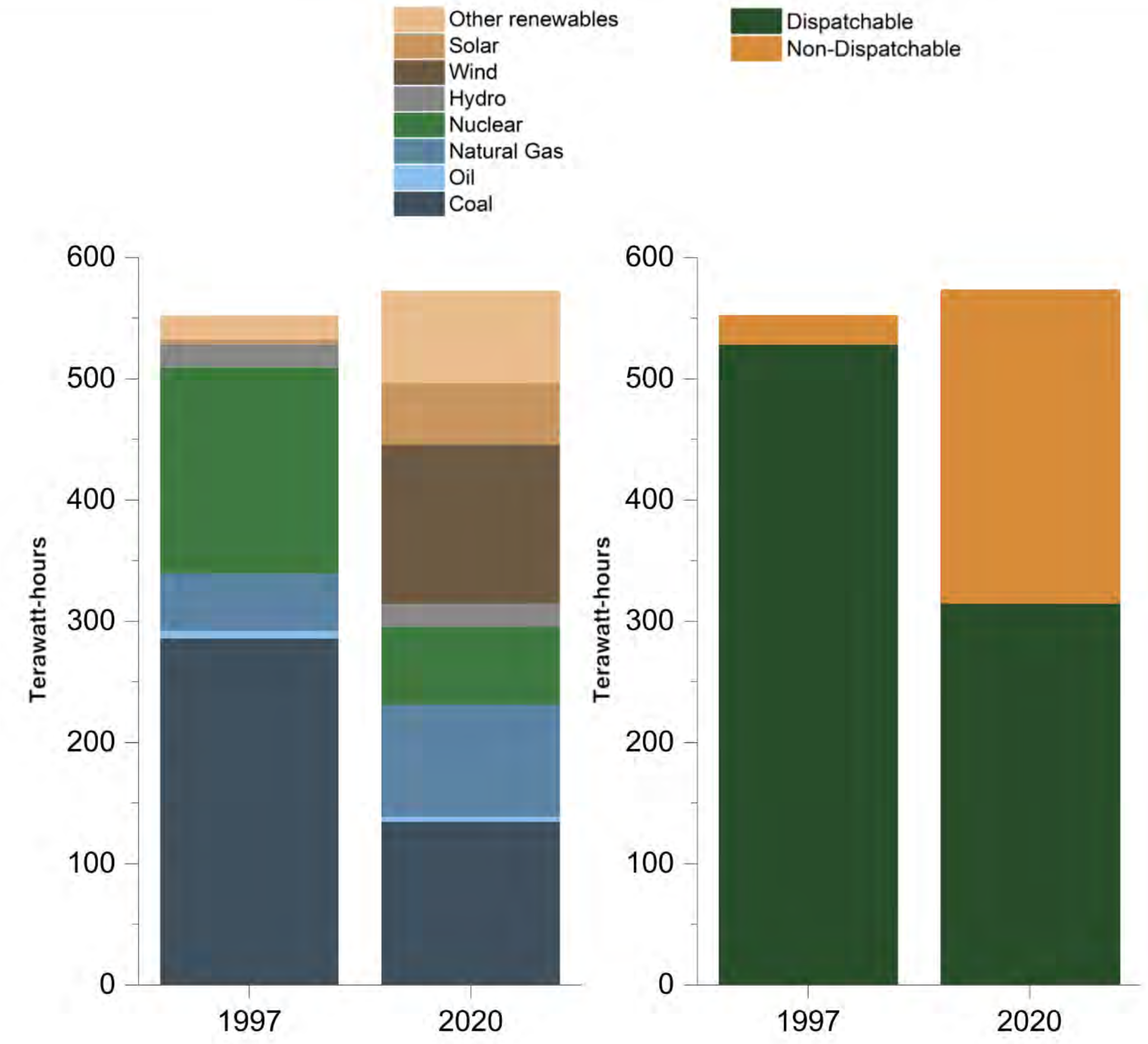
Conclusions:

- Coal, oil natural gas, nuclear and hydro are all dispatchable sources of electric power generation.
- Wind and solar are intermittent and therefore not dispatchable.
- Renewable electricity cannot operate without dispatchable power as backup.
- The addition of renewable power requires consumers to bear the capital costs of both the renewable generator and its dispatchable backup, making renewable energy expensive.
- Renewables can replace some but not all dispatchable power without the grid becoming unstable and unreliable.
- Reducing CO_2 emissions through the use of renewable electricity generation costs 1.5 to 20 times as much as the Biden Administration's stated Social Cost of Carbon.

The United States is fortunate to have a huge resource base of hydrocarbon fuels, as well as hydroelectric resources and nuclear capabilities and therefore has great flexibility in choosing power generation fuels. Other countries are not so lucky and have fewer degrees of freedom in balancing policy goals. A few examples will illustrate.

With its promise of a fundamental energy transition known as the Energiewende, climate activists often cite **Germany** as the shining example of how renewable energy can replace fossil fuels without economic hardship. Tom Friedman wrote a New York Times column in 2015 with the self-explanatory title “Germany, the Green Superpower.”[40] As shown in Figure 1, the development of their electricity sector certainly looks impressive from a renewables standpoint. From virtually zero in 1997, German wind and solar had grown to 32% of electricity supply by 2020 through a series of subsidies and regulatory requirements, including “feed-in tariffs” which ensured the profitability of renewable electricity. At the same time, Germany gradually reduced its expensive and high-polluting coal industry, centered largely in Eastern Germany, shut down a number of politically unpopular nuclear reactors and increased the use of natural gas. As a result, Germany was able to reduce its CO_2 emissions from its electricity sector by about one quarter between 1997 and 2020 from 0.4 Gt to 0.3 Gt, much to the applause of climate advocates.

Figure 1: Germany Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

There are, however, two flies in the German energy ointment. The first is the high prices German consumers must pay for energy. Forcing wind and solar into the energy mix is not cheap. A recent price survey found that residential electricity prices in Germany averaged $0.339 per kWh, compared to $0.153 in the U.S.[41] Other German energy prices are also high, with gasoline recently reaching $6.60 per gallon and household natural gas prices 60% above the average U.S. level.[42]

The second problem is the consequences of the decision to phase out nuclear power. Since the early 1970s, Germany has built 36 nuclear reactors with a total capacity of 26 GW. By 1997, Germany had decommissioned 17 of the older reactors, totaling 5 GW, leaving 19 operating nuclear reactors with a combined capacity of 21 GW. These reactors provided just over 30% of Germany's electricity in 1997.

The Chernobyl disaster in 1986 reignited a latent anti-nuclear movement in Germany. When the Greens and Social Democrats took power in 1998, a "nuclear consensus" was reached limiting the lifespan of nuclear power plants to 32 years. Although some politicians objected to the phase-out, the Fukushima accidents in Japan sealed the fate of the German nuclear industry. As of this writing, Germany has only three nuclear power plants in operation, all originally scheduled to be decommissioned in 2022.

The elimination of nuclear power would present Germany with a major problem. As shown in Figure 1, in 1997, Germany's generation mix included 96% dispatchable power. By 2020, that share had dropped to 55%. The preferred source of dispatchable power is now natural gas. Unlike the U.S., however, Germany has little domestic natural gas. In 1970, Germany consumed 16 billion cubic meters (BCM) of natural gas, 75% of which was produced domestically. By 2020, consumption had increased by a factor of 5½ to 86.5 BCM, but only 5% came from domestic sources. More than half of current imports come by pipeline from Russia.

The only short-term incremental source of natural gas is LNG (liquefied natural gas) which has a small spot market. According to the Financial Times, however, recent European LNG prices have spiked to over $48 per MBtu,[43] compared to utility gas prices of just $6 in the U.S. Since the natural gas logistical system is complex and rigid, it takes years and a great deal of investment to increase supply. Germany's reluctance to abandon the Nord Stream pipeline from Russia with its initial capacity of 55 BCM is clear in this context.

The distribution of electric power in Germany is also a problem, with wind turbines sometimes generating less and sometimes more power than the German grid can accommodate. Germany does trade electricity with its neighbors, exporting about 15% of its generated power and importing about 5%. Trade, however, is not a long-term solution for German power supply.

Finally, there is some local opposition to the continued growth in onshore wind power in Germany based on other environmental concerns, such as damage to the landscape, interference with local economies and excessive bird strikes.

Without nuclear power and with a rigid natural gas supply system, the only flexible dispatchable source of power in Germany is coal. During the first half of 2021, Germany was forced to confront this dilemma. A recent article in Foreign Policy quotes German energy expert Georg Stamatelopoulos:

“Renewables now cover around half of the [German] demand, and there is still sufficient available power in the system and there is still the possibility of obtaining electricity from our neighbors. What is certain, however, is that further expansion of renewables will increase the volatility in the system. That is why we will always need available service, i.e., service that is available to us when we have the corresponding need.”[44]

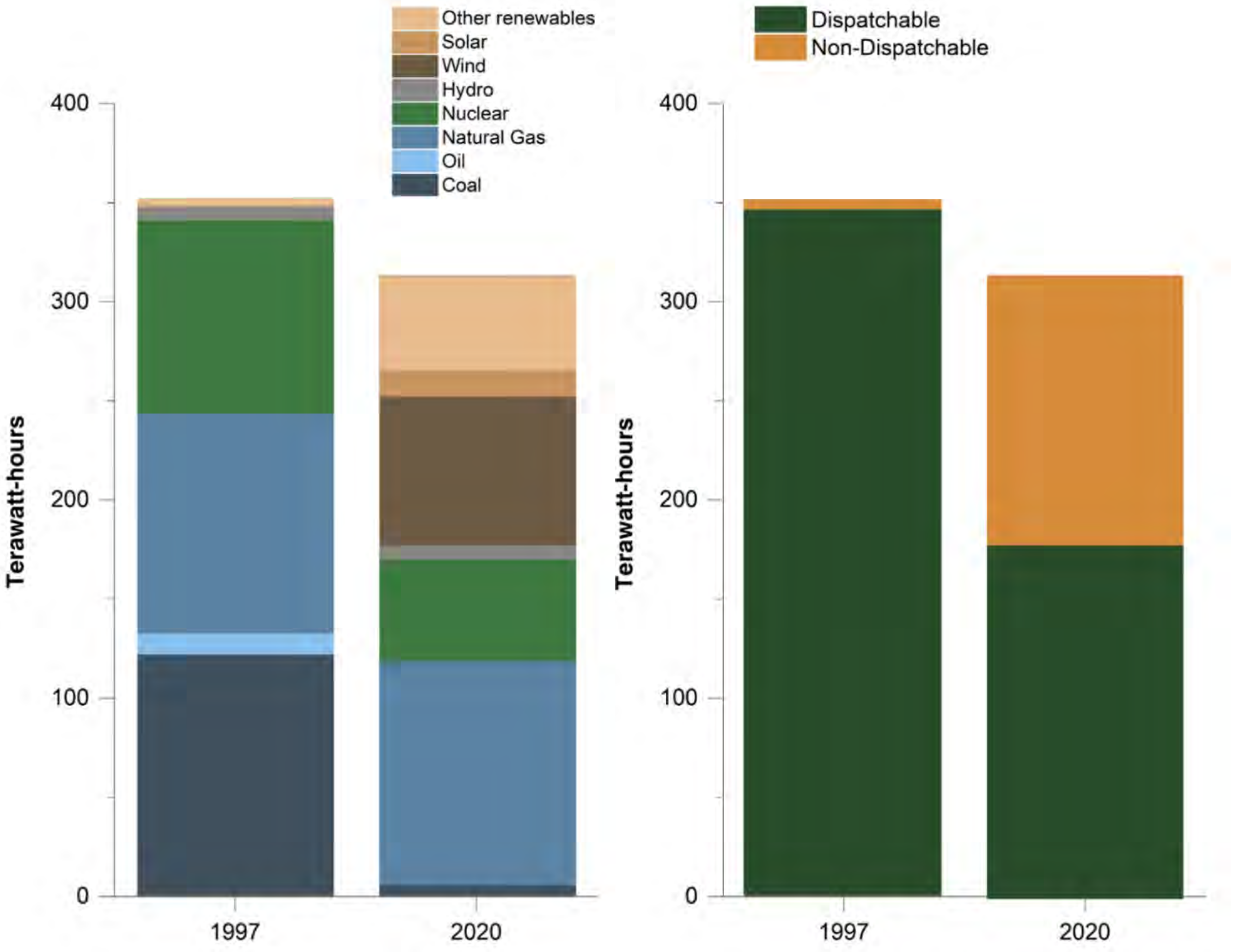
The result of these contortions has been a reduction in CO_2 emissions of 0.1 Gt per year - significant for Germany but only about 0.3% of the global total. German politicians have tried hard to satisfy their domestic political constituencies clamoring to “do something” about climate change, but the price is high: constraining domestic dispatchable electricity, high prices and a dangerous dependence on Russian gas.

The Russian invasion of Ukraine has upset Germany’s green plans. The national security consequences of heavy dependence on Russian energy are now clear to politicians across the German spectrum. The decision to put the Nord Stream 2 pipeline on hold is the first step in a fundamental rethink of German energy policy, including continuing operation of the remaining nuclear plants. Climate activists are unlikely to be happy with the outcome.

The **United Kingdom** faces similar problems, as shown in Figure 2. Dispatchable energy accounted for almost 99% of power generation in 1997 but had fallen to 57% by 2020. Between 1997 and 2020, the U.K. phased out its remaining coal production and, like other countries, reduced the use of expensive fuel oil for power generation.

Natural gas use has increased, but U.K. North Sea gas production now covers only about 50% of requirements, with the rest imported by pipeline from Norway or as LNG from the world market. As a result, the U.K. reduced CO_2 emissions from its electricity sector by about half between 1997 and 2020 from 0.2 Gt to 0.1 Gt.

Figure 2: U.K. Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

The British nuclear program has been characterized by fits and starts. One of the participants in the World War II Manhattan project, the U.K. pioneered the development of the Magnox reactor, a natural uranium system designed to produce both civilian electrical power and nuclear weapons grade material. So far, the U.K. has built 44 nuclear reactors, including 26 Magnox type, with a total capacity of just over 13 GW. By 1997, nine of the older reactors had been shut down, leaving 35 in operation with a combined capacity of around 12 GW. Another 23 reactors, including all the old Magnox types, had been shut down by the end of 2021, leaving 12 operating reactors with a total capacity of 7 GW. All remaining operational reactors are scheduled to be decommissioned by 2035. Nine modern reactors are under construction or planned, suggesting that future nuclear capacity should remain at about 7-8 GW, well below its peak.

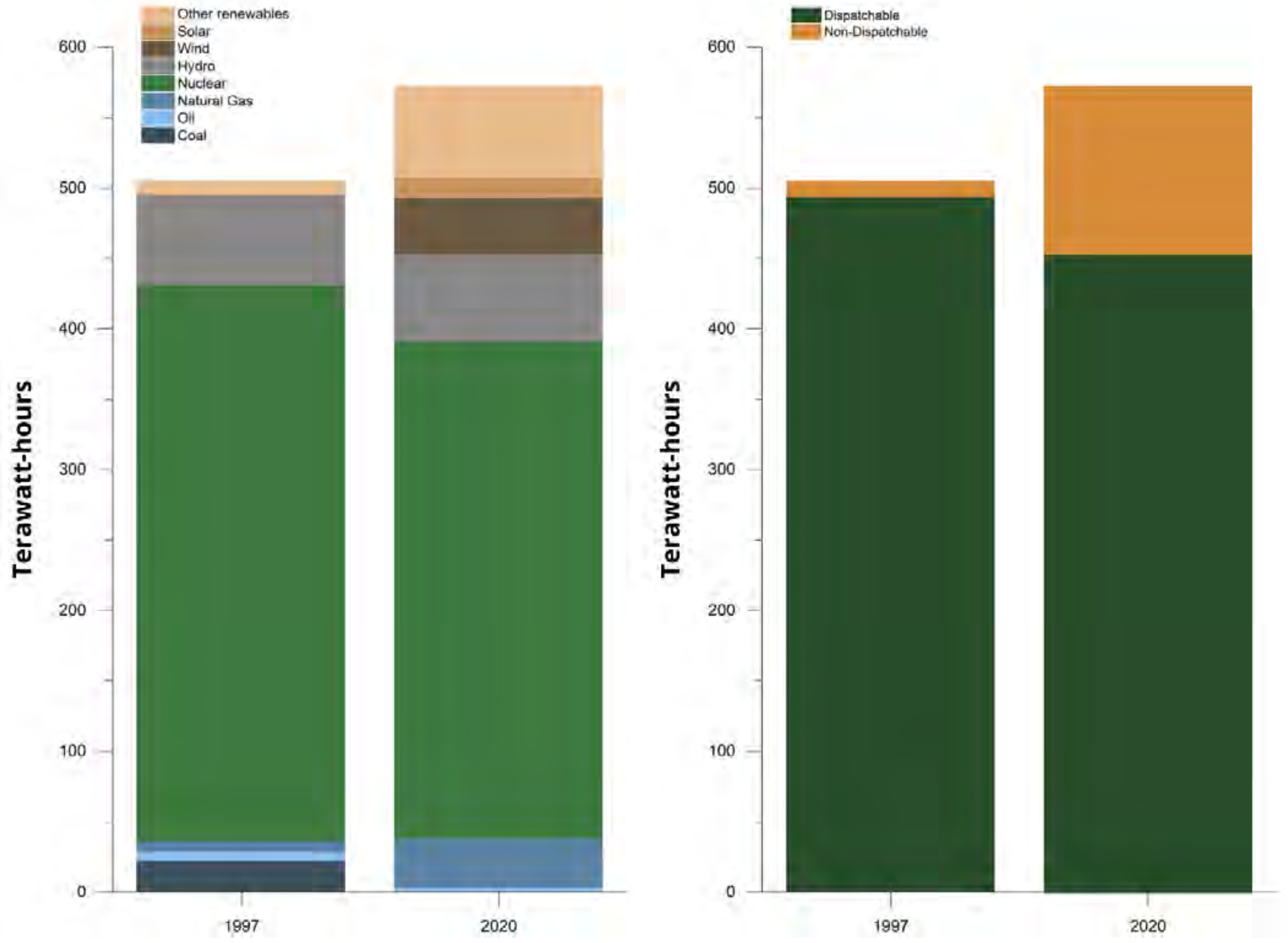
Following the dictates of its climate policy, the U.K. has installed a considerable amount of wind and solar power, which accounted for over a quarter of its electricity output in 2020. As in the case of Germany, however, a low-wind period in the first half of 2021 caused problems. The U.K. was, like Germany, forced to scramble for scarce natural gas supplies on the world market at very high prices. As

Sophie Mellor from Fortune magazine put it, “Just as Europe needs energy the most, the wind in the North Sea has stopped blowing, forcing regional energy markets to scramble for gas reserves to heat homes and power businesses. This has had expensive consequences."[45] U.K. households are now paying $0.335/kWh for electricity,[46] just below German prices but twice the average U.S. level.

These expensive efforts by the U.K. have reduced annual CO_2 emissions from power generation by only 0.1 Gt over 23 years. The U.K. accounts for 3.3% of global GDP[47] but its renewables program has reduced global CO_2 emissions by only 0.4%.

In contrast, **France** is in a much better position than either Germany or the U.K. As shown in Figure 3, France is the only major country to concentrate on nuclear power. As of this writing, France had 56 operating nuclear reactors with a combined capacity of 61 GW. In 1997, nuclear energy accounted for nearly 80% of French power generation. That share fell to 62% by 2020 as nuclear output declined somewhat and wind and solar capacity was added. Because of the high nuclear share, France’s electricity sector does not emit much CO_2.

Figure 3: France Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



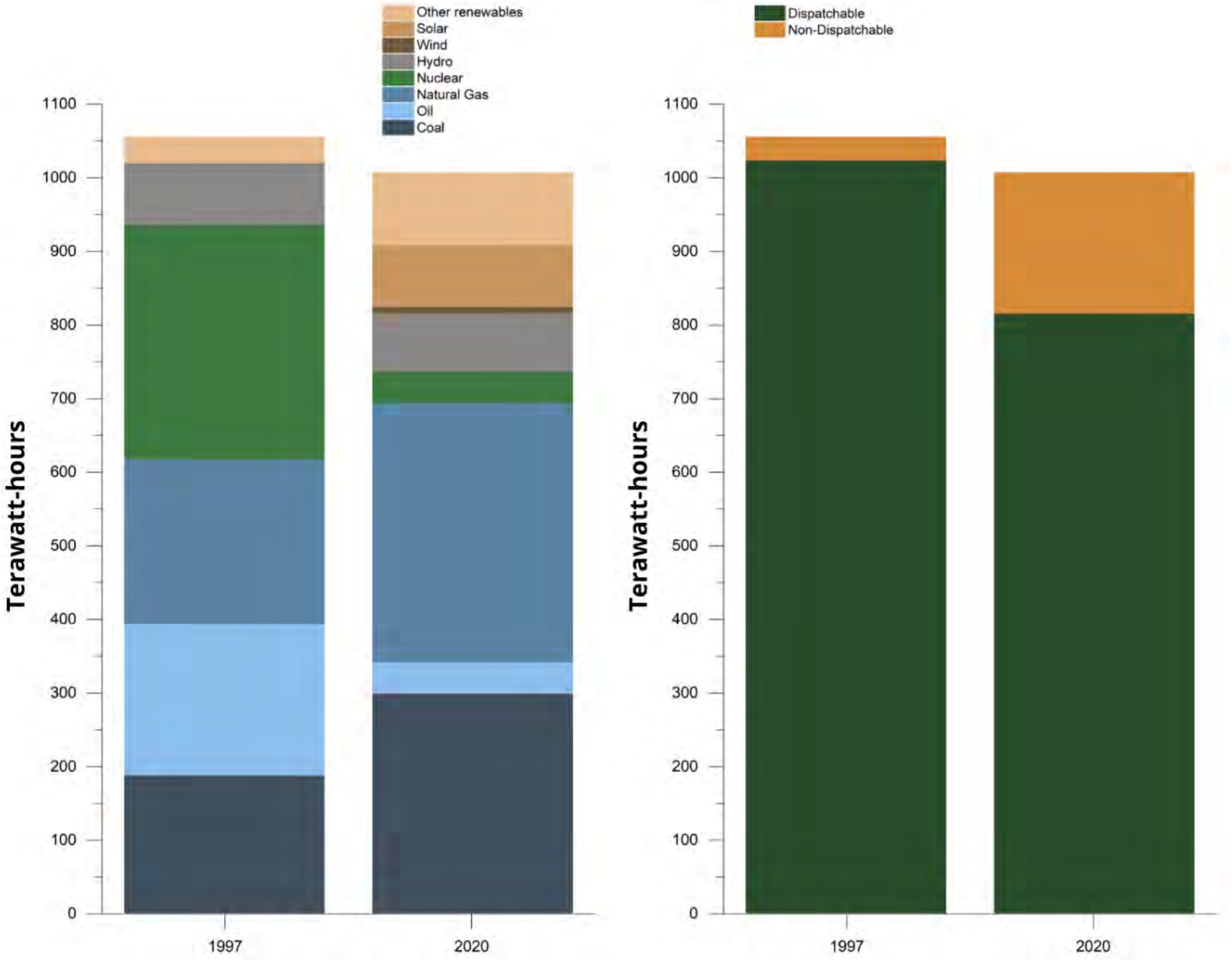
Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

France has an economical and stable electricity system with 2020 dispatchable power accounting for nearly 80% of generation, compared with 55% in Germany and 57% in the U.K. French nuclear power not only underpins the French electricity market but also provides a measure of stability to neighboring countries through exports. Furthermore, French baseload power is not subject to serious national security concerns, since its uranium is largely obtained under contract from friendly countries, primarily Canada and Niger. French household electricity consumers currently pay $0.187/kWh, above the U.S. level but much less than Germany or the U.K.

French carbon dioxide emissions from power generation, which were only 66 Mt in 1997, fell even further to 41 Mt by 2020, largely because of the phase-out in coal use. Given the high proportion of nuclear power, France has never emitted much CO_2 from this sector and thus has little room for further reductions.

With no domestic energy resources to speak of, **Japan** has a particularly challenging problem with electricity supply, as shown in Figure 4. The 1997 generation mix reflected the Japanese Government's desire to diversify its electric power system to four dispatchable fuel sources: coal, natural gas, oil and nuclear. By 2019, petroleum had become just too expensive for baseload power. The reduction in oil use was offset by increasing imports of liquefied natural gas, and all seemed well until the Fukushima nuclear accident of 2011. The political reaction to the disaster was so strong that Japan immediately shut down 33 operable reactors.

Figure 4: Japan Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

Japan's nuclear program will face serious economic and political pressures in the coming years. On the one hand, Japan intends to restart as many of the existing reactors as it can following extensive safety checks. On the other hand, domestic opposition to nuclear power remains strong and may frustrate recommissioning plans. Without nuclear power, Japan will be forced to rely on either more LNG or coal to ensure sufficient dispatchable power.

The need to maintain the electricity grid in the face of these problems has made it difficult for Japan to achieve any reductions of CO_2 emissions in this sector.

The governments of the five largest industrialized countries profiled above are all engaged in the same political and economic balancing act: maintaining the quality and affordability of the electricity grid while trying to satisfy climate activists. The complicated political trade-offs between the needs of consumers and the demands of climate advocates have imposed substantial costs on consumers in these countries while making only modest reductions in CO_2 emissions. Developing countries, on the other hand, have an entirely different set of political drivers.

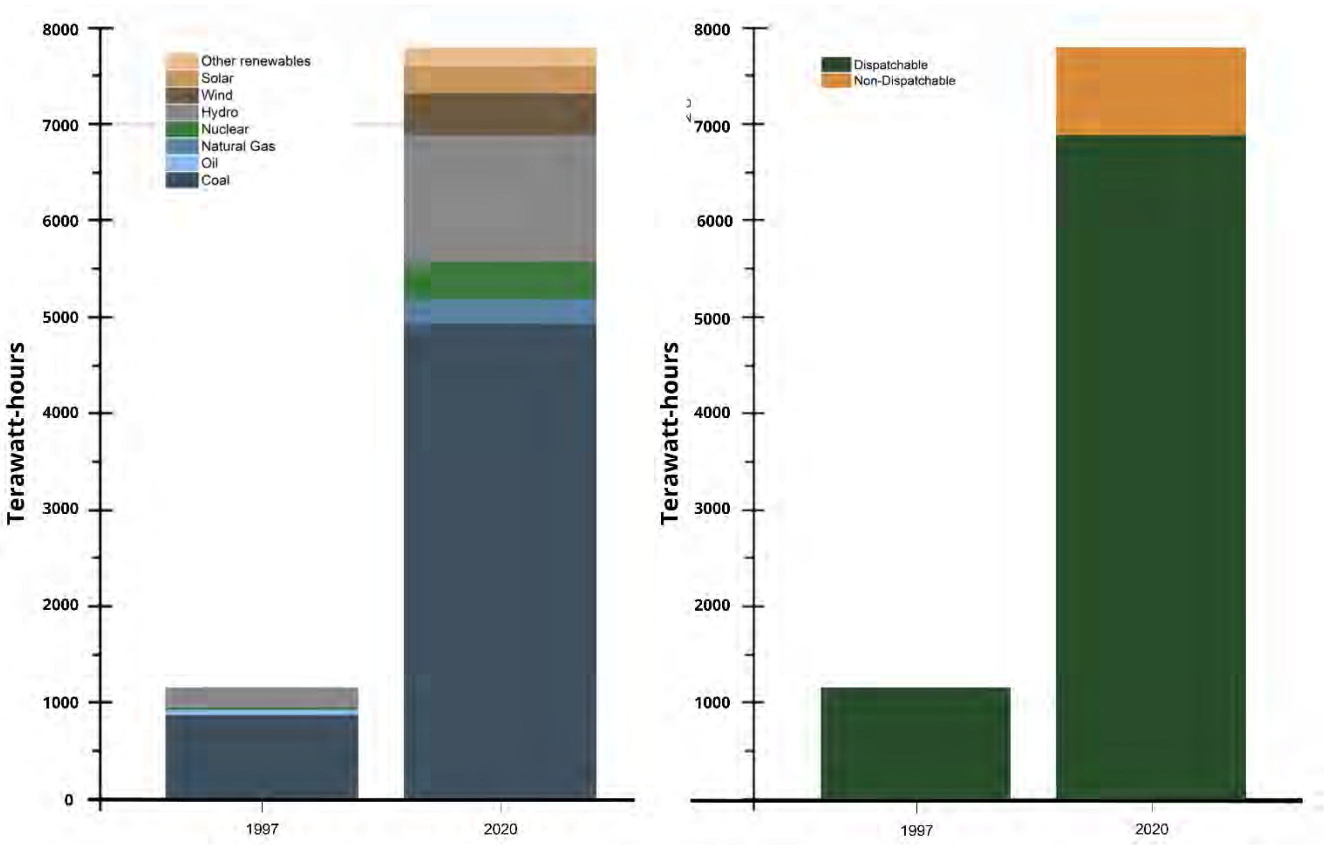
China. President Xi Jinping's goals have become increasingly clear in recent years: preserving the Communist Party's political monopoly and establishing China as a predominant regional and ultimately global military power. Strategic success for Xi requires above all else continued strong economic growth both to provide an improving living standard to 1.4 billion people and to build a large, technologically advanced military.

According to the World Bank, between 1997 and 2020, China increased its GDP from just under $1 trillion to over $14 trillion (current dollars).[48] This growth required massive amounts of electricity, and Figure 5 shows how they got it. Over 60% of the increase was coal. China has 1,082 coal-fired power plants – more than any other country. Number two, India, has 281 plants and number three, U.S., has 252. In 1997, China consumed a third more coal than the United States. Today, it consumes nine times as much. With its large reserves, accounting for just under one-fifth of the world total, Chinese coal is abundant, domestic, cheap and under the direct control of the state, making it the perfect choice for a centrally planned economy.

Another quarter of the growth was hydro and nuclear, which are domestic resources, but expensive, and natural gas, of which China has only limited reserves.

Climate advocates tend to focus on the rapid growth of renewable energy in China as proof of China's commitment to the climate agenda. In 2019, Prof. Kelly Sims Gallagher at the Fletcher School at Tufts wrote, "China is positioned to lead on climate change as the U.S. rolls back its policies."[49] The International Energy Agency (IEA) has published articles like "China has a clear pathway to build a more sustainable, secure and inclusive energy future"[50] and "A new era of shared clean energy leadership begins in China."[51] The numbers tell a different story.

Figure 5: China Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

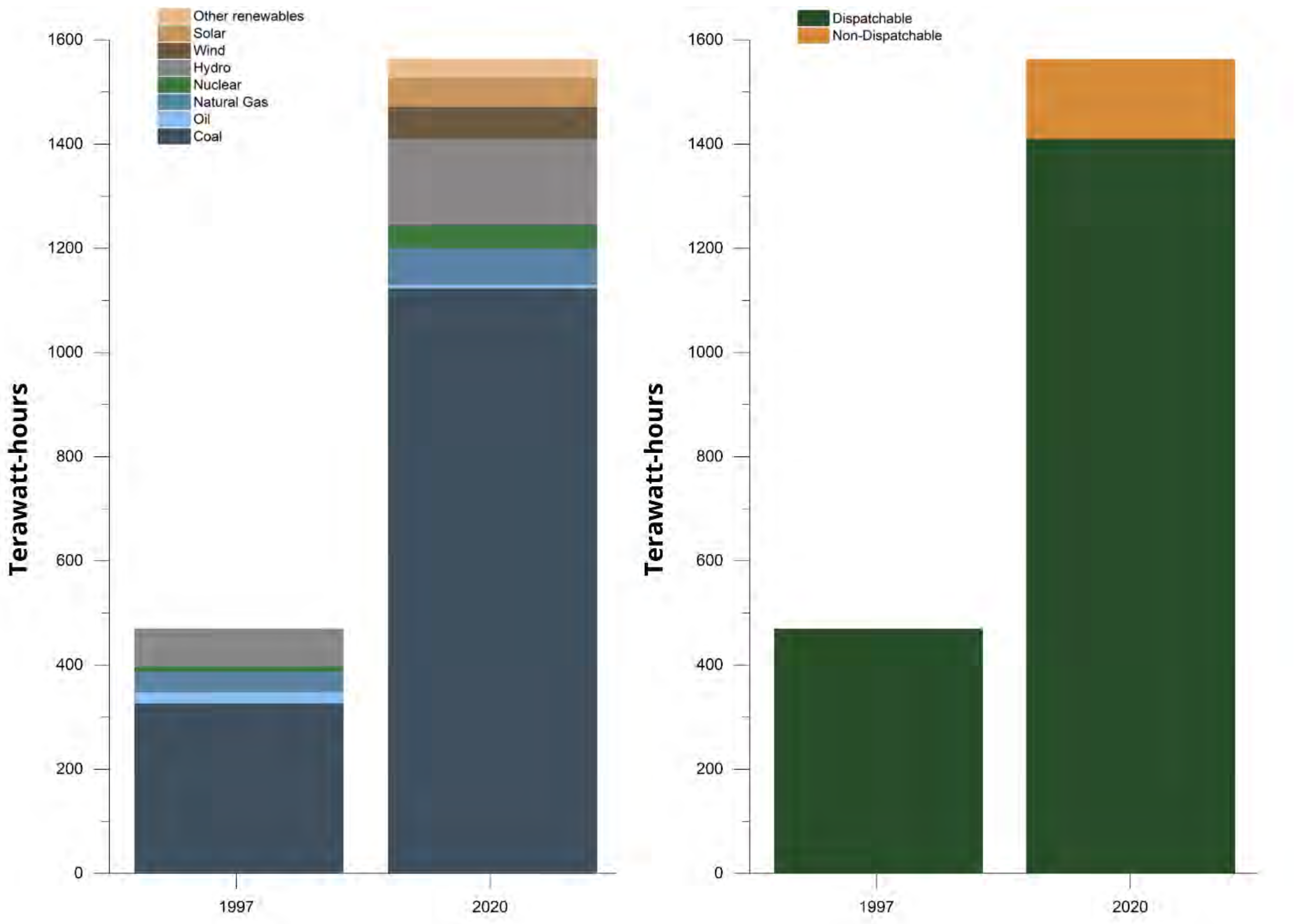
Wind and solar have grown rapidly in China, but from a base of almost zero. Wind accounts for only 5% of Chinese electricity generation and solar 3%. The economics of renewable energy, however, are different for China than for other countries. Unlike hydrocarbons, which are resource-based, wind turbines and solar panels are manufactured items with a high labor content – precisely the industries where China has a strong competitive advantage. It is not surprising that China is now the world’s leading exporter of renewable energy equipment for the artificial market created by western subsidies and mandates. Despite the strong growth in renewable energy in absolute terms, China still maintains almost 90% dispatchable power.

Cheap domestic coal remains the lynchpin of the Chinese energy economy. Global CO_2 emissions increased from 24.1 Gt in 1997 to 34.5 Gt in 2020. China’s power sector accounted for over 35% of the total global increase in CO_2 emissions over this period.

The Chinese have been willing to “talk the talk” on climate but have never shown any inclination to “walk the walk.” Xi may believe, rightly or wrongly, that the U.S. will offer substantive concessions in return for Chinese participation in global climate negotiations. In any case, Chinese promises and public statements on climate help to burnish their image in the West since the contradictions between their public statements and actual policies have drawn little attention from the western press.

India. Indian GDP has also grown rapidly from just over $400 billion in 1997 to about $2.7 trillion in 2020 (in current dollars).[52] According to the latest available World Bank data, India reduced its poverty rate from 45% in 1993 to just over 13% in 2015[53] and continues to make progress. Nonetheless, there are still over 100 million Indians living on less than $1.90 per day, the World Bank standard for extreme poverty. India faces other major strategic challenges as well, including threats from nuclear-armed China and Pakistan, serious ethnic tensions, terrorism and suffocating economic bureaucracy. Continued strong economic growth is critical to solving India's problems, requiring substantial increases in electricity as shown in Figure 6.

Figure 6: India Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

Electricity demand in India increased from 469 TWh in 1997 to 1,562 TWh in 2020, and the pattern is similar to China's. Over 75% of the growth in power generation came from coal, an abundant and cheap domestic resource. India has about one-seventh of the world's coal reserves and lots of labor to produce it.

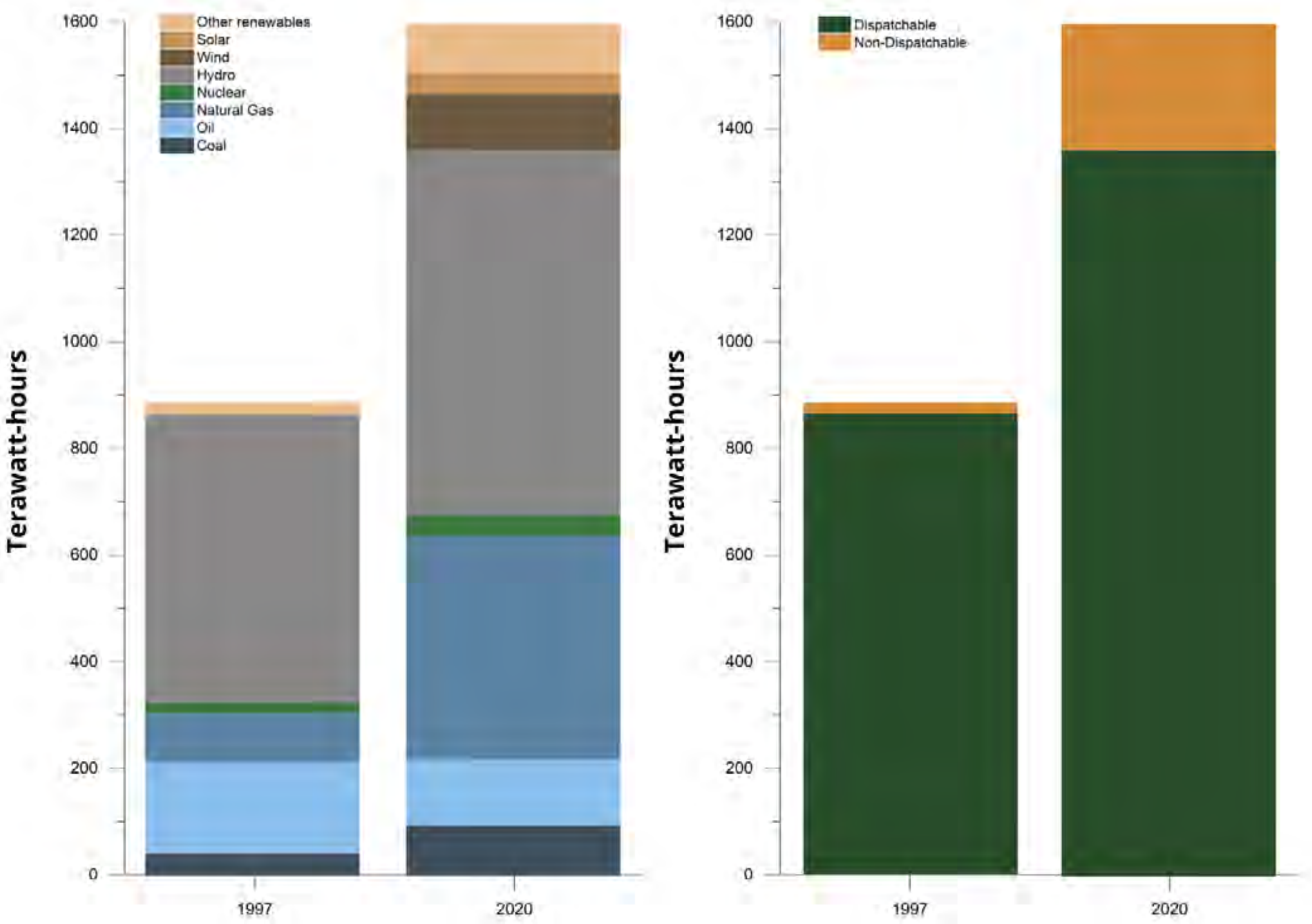
Overall, fossil fuels accounted for 77% of power generation fuel in 2020. Nuclear and hydro play a lesser role accounting in total for about 13% of 2020 electricity supply. Wind and solar together account for only about 6%, giving India more than 90% dispatchable power.

Much of the growth in wind and solar in India has been based on international financial support. According to the World Bank and its partner agencies, India received $10.7 billion between 2010 and 2018, including $4 billion for wind and solar.[54] These concessionary funds are often used to leverage private capital by offering low interest rates and long payment periods. Between 2016 and 2021, the World Bank Group financed $109 billion in “climate finance” around the world and proudly announced that it will no longer finance fossil fuel projects, even though fossil energy remains the cornerstone of economic development.[55] The World Bank and its partner organizations are responding to the demands of climate advocates in the wealthy countries, not economic needs in the poor ones.

At COP26 in Glasgow, Indian Prime Minister Modi pledged to reach “net zero” by 2070, to reduce CO_2 emissions by one billion tonnes by 2030 and to install 500 GW of non-fossil generating capacity by 2030. With annual CO_2 emissions having grown from 0.4 Gt in 1997 to 1.1 Gt in 2020 and less than 80 GW of renewable capacity today, these promises do not appear to be consistent with India’s actual energy policies.

Latin America (including Mexico) has about 650 million people – roughly 8% of the world's population. Figure 7 shows the dispatchable and generation mix for the region.

Figure 7: Latin America Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

Latin America is a resource-rich region with not only plentiful hydrocarbons but also substantial hydroelectric potential, particularly the Amazon Basin. Between 1997 and 2020, electricity generation increased almost 90% from 885 TWh to 1,595 TWh, an increase of 710 TWh. Almost 50% of the increase was from fossil fuels with another 20% from hydro. Total dispatchable electricity was 85% in 2020.

Wind and solar accounted for a small share of the growth and contributed 6% and 2% of power generation, respectively, in 2020. Much of the renewable investment was financed by the World Bank and other international lending agencies, with Argentina receiving $6.5B between 2010 and 2018, Ecuador $4.4B, Chile $3.8B. Mexico $2.4B, Brazil $2.3B, Bolivia $2B, Colombia $1.9B, Costa Rica $1.9B, Peru $1.8B, Venezuela $1.7B and Honduras $1.6B.[56]

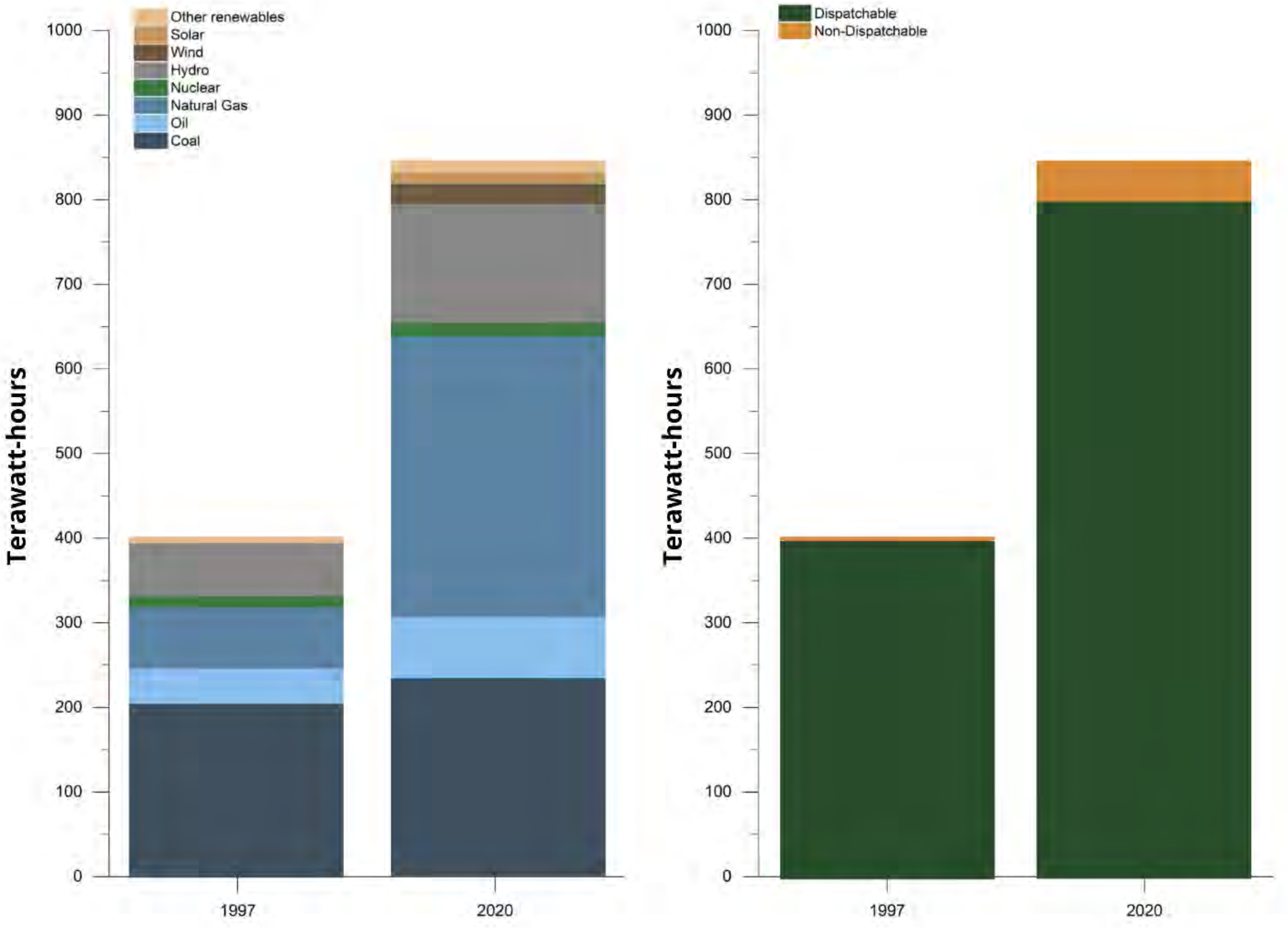
With the large increase in fossil fuel use, CO_2 emissions from the power sector increased from 0.3 Gt in 1997 to 0.5 Gt in 2020.

Africa has a total population of 1.3 billion, over a sixth of the world total. Like other poor regions of the world, Africa has relied heavily on electrification for its development. Electricity generation more than doubled between 1997 and 2020 to 845 TWh. Like Latin America, Africa is rich in both hydrocarbon and hydroelectric resources, which have formed the basis for its power industry. As shown in Figure 8, nearly two-thirds of the increase in power generation between 1997 and 2020 came from oil and gas with another 7% from coal and 18% from hydro, almost all of it dispatchable.

Wind and solar currently account for only 3% and 1% of power generation, respectively. Several African countries have also been recipients of international financial assistance. Between 2010 and 2018, Nigeria received $6.6B, Morocco $4.3B, Kenya $4B, Egypt $3.9B, South Africa $2.9B, Zambia $2.9B, Uganda $2.7B, Ethiopia $2.1B, Cameroon $1.9B, Guinea $1.7B and the Democratic Republic of the Congo $1.5B.[37]

Between 1997 and 2020, power sector CO_2 emissions increased by two-thirds to 0.5 Gt annually.

Figure 8: Africa Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh

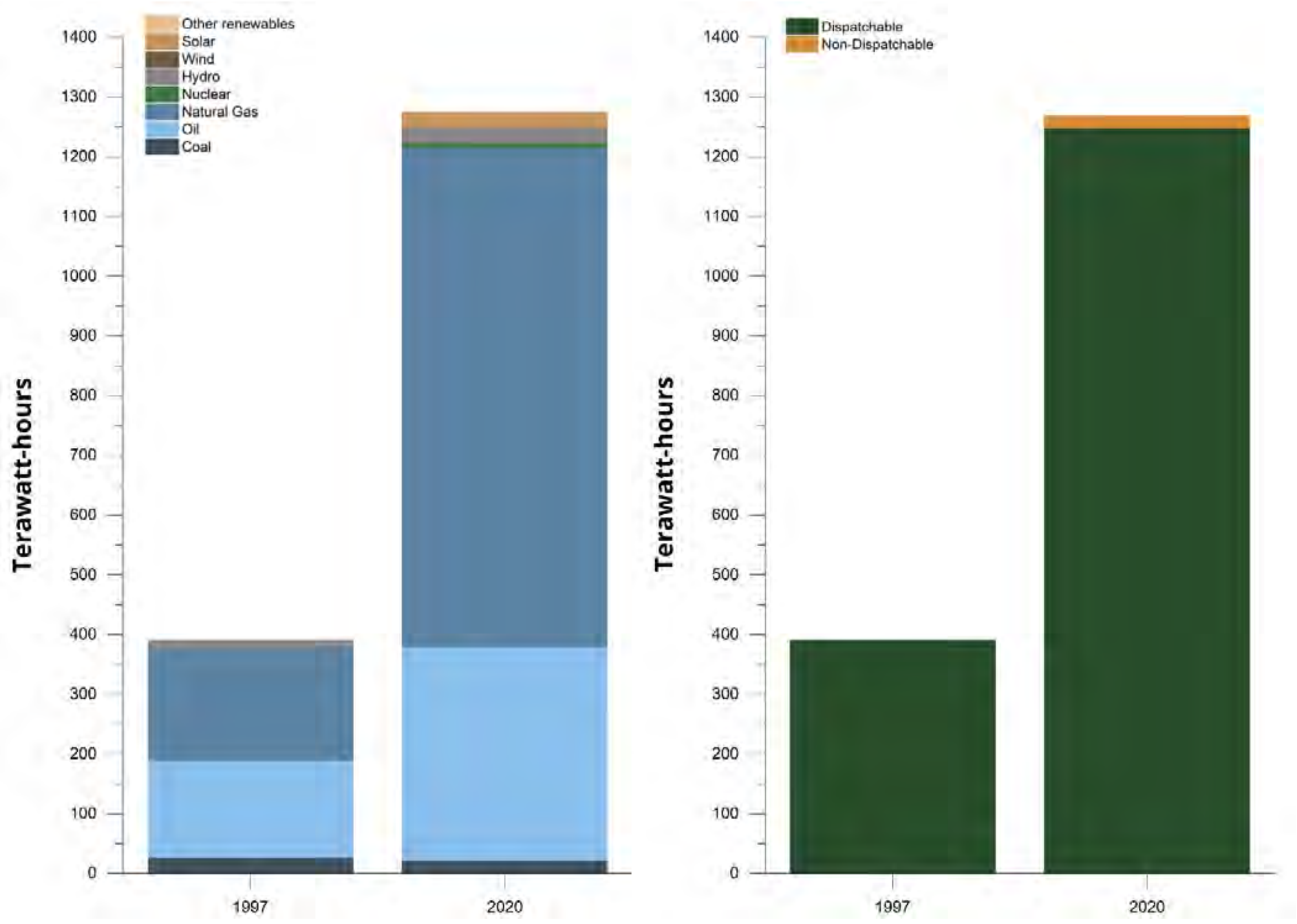


Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

It is no surprise that the **Middle East**, home to the world's major hydrocarbon resource base, has built its electrical system on fossil fuels, which accounted for 96% of power generation in 1997 and the same share in 2020, virtually all of it dispatchable, as shown in Figure 9. Wind and solar power are negligible in these countries. Jordan, one of the poorer countries in the region, received $1.6 billion for renewable energy projects from international lending institutions between 2010 and 2018.[57]

CO_2 emissions from the power sector more than doubled from 0.4 Gt in 1997 to 1 Gt in 2020.

Figure 9: Middle East Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



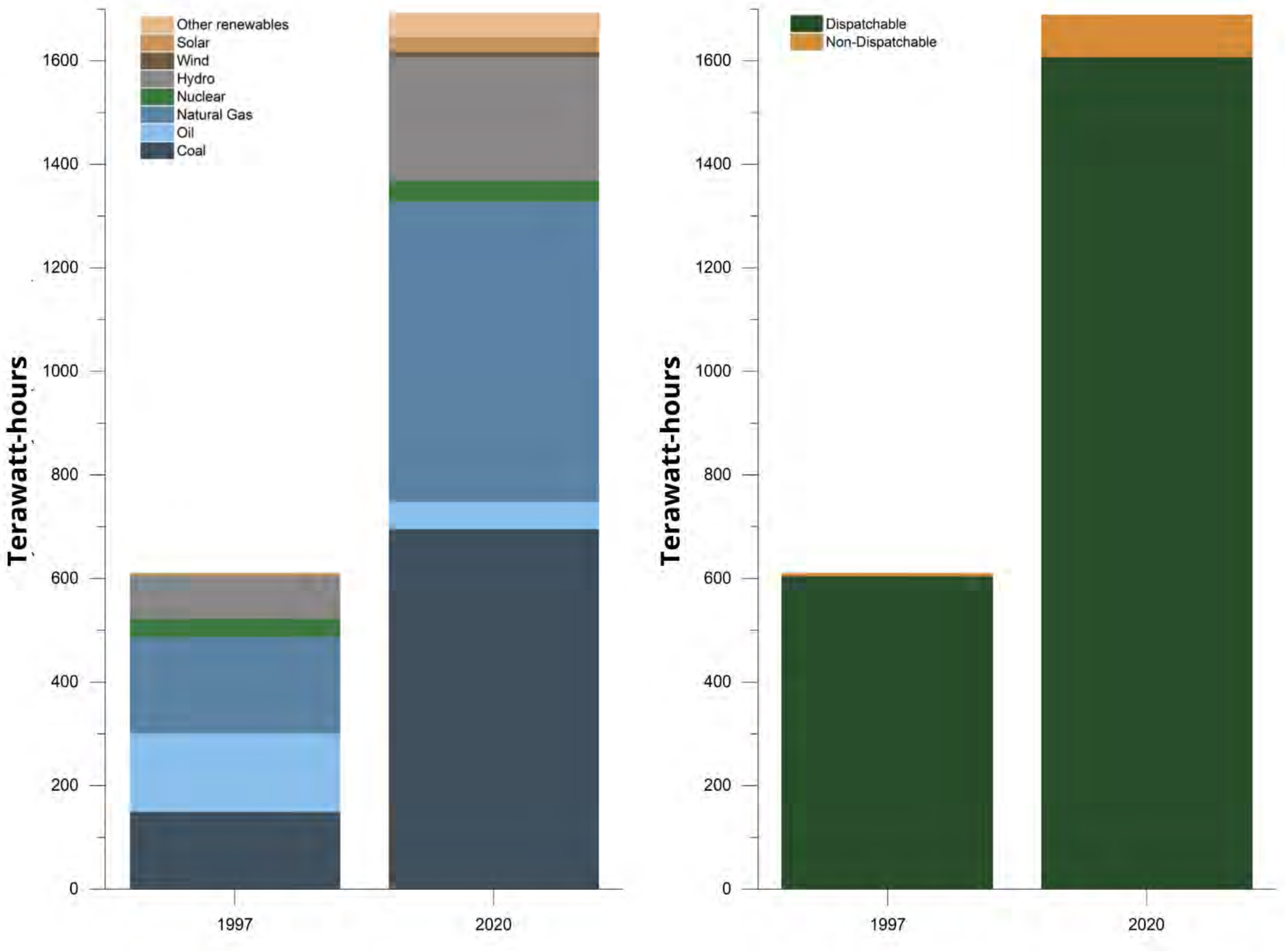
Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

The **Non-OECD Asia** group includes 21 nations of the region with a total population of 1.2 billion and a GDP of over $4.5 trillion.[58] As shown in Figure 10, electricity generation in this group nearly tripled between 1997 and 2020 to 1,691 TWh, almost all of it dispatchable. Half the increase came from coal, over a third from natural gas and another 15% from hydro.

As in the other developing countries, wind and solar still play a minor role, accounting for only 2.5% between them. Several countries in this group received significant financing from international lending institutions. Between 2010 and 2018, for example, Pakistan received almost $10 billion and Laos $4.5B.

CO_2 emissions in this group of rapidly industrializing countries more than doubled over this 23-year period from 0.4 Gt to 0.9 Gt.

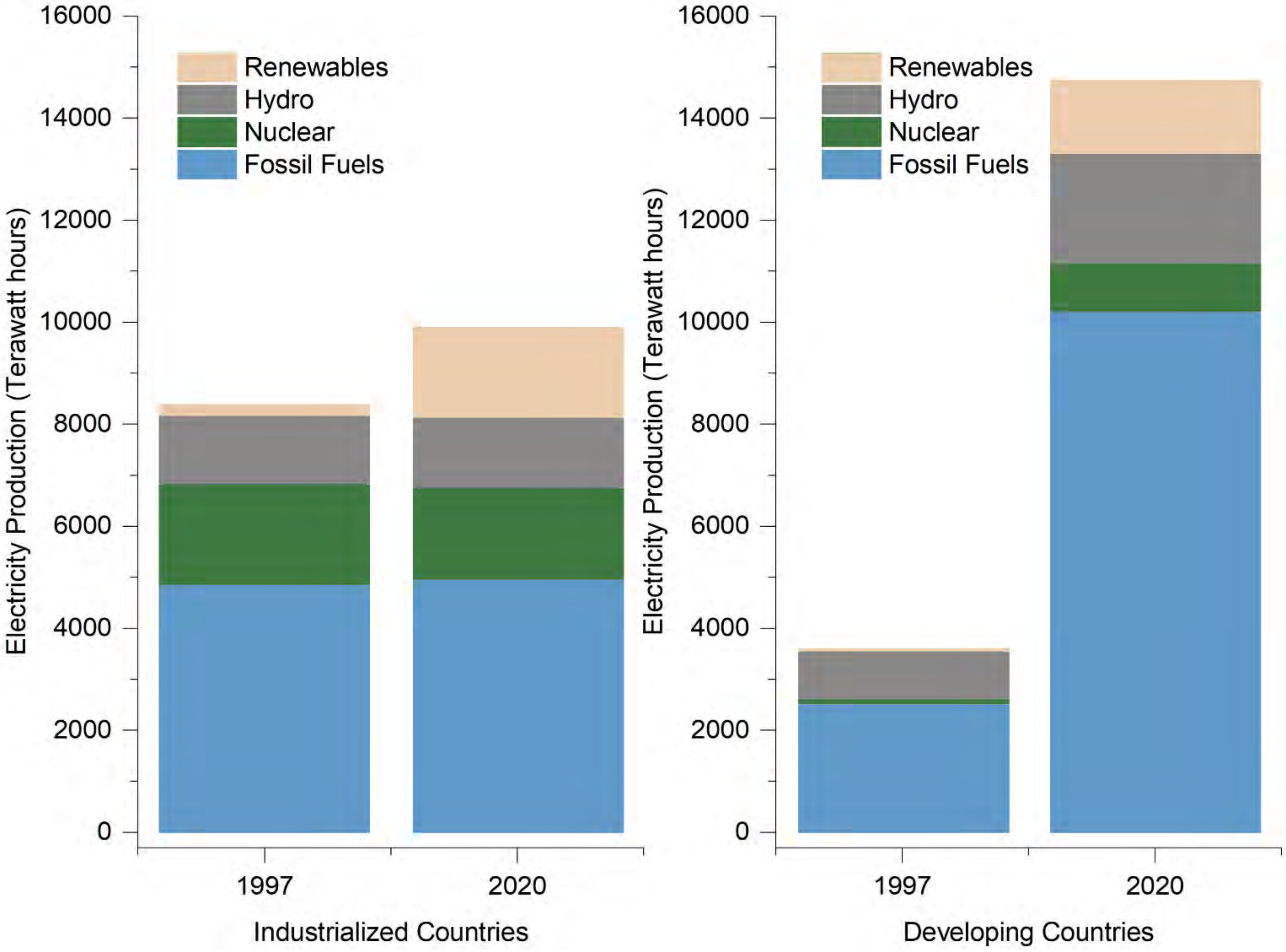
Figure 10: Non-OECD Asia Electricity Generation by Fuel and Dispatchability, 1997-2020, TWh



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

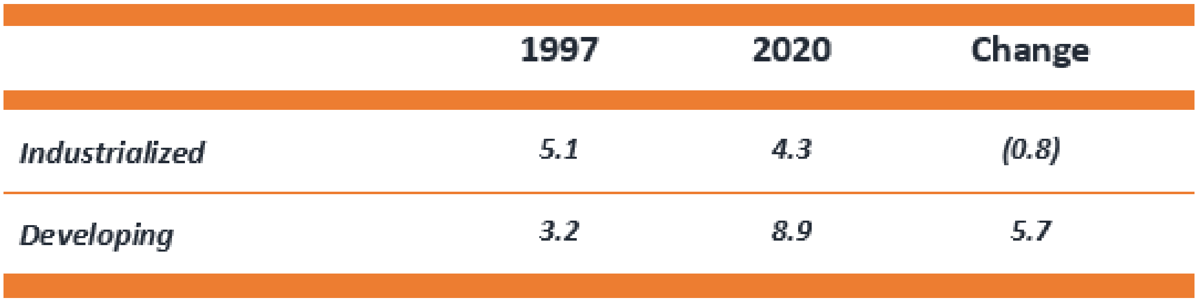
Figure 11 and Table 9 summarize the evolution of electric power generation and CO_2 emissions between 1997 and 2020 for the industrialized countries as well as the 121 developing countries discussed above.

Figure 11: Comparison of Electricity Production in Industrialized and Developing Countries by Fuel, 1997 and 2020



Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

Table 9: Comparison of CO_2 Emissions from Electricity Generation in Industrialized and Developing Countries, 1997 and 2020 (Gt)



	1997	2020	Change
Industrialized	*5.1*	*4.3*	*(0.8)*
Developing	*3.2*	*8.9*	*5.7*

Source: Electricity statistics: BP Statistical Review of World Energy, July 2021

A few conclusions:

- The industrialized countries have struggled to meet demands from climate activists while still providing stable and reliable power to their economies.

- The outcome of this tension has been a growth in total fossil fuel use, a switch from coal to natural gas, a forced penetration of renewables, higher consumer costs, modest CO_2 reductions and, in some cases, grid stability problems.

- Electricity growth in the developing countries greatly outstripped that of the industrial countries. The poorer countries accounted for 32% of total power generation in 1997, but almost 60% in 2020. Major decisions on future electric power development will be centered more in Beijing and New Delhi than in Washington and Berlin.

- While the industrial countries have struggled to find a politically acceptable fuel mix, the developing countries have simply relied on the lowest cost energy available to them.

- As a result, fossil fuels have dominated power-gen growth in the developing world, accounting for nearly 70% of the increase.

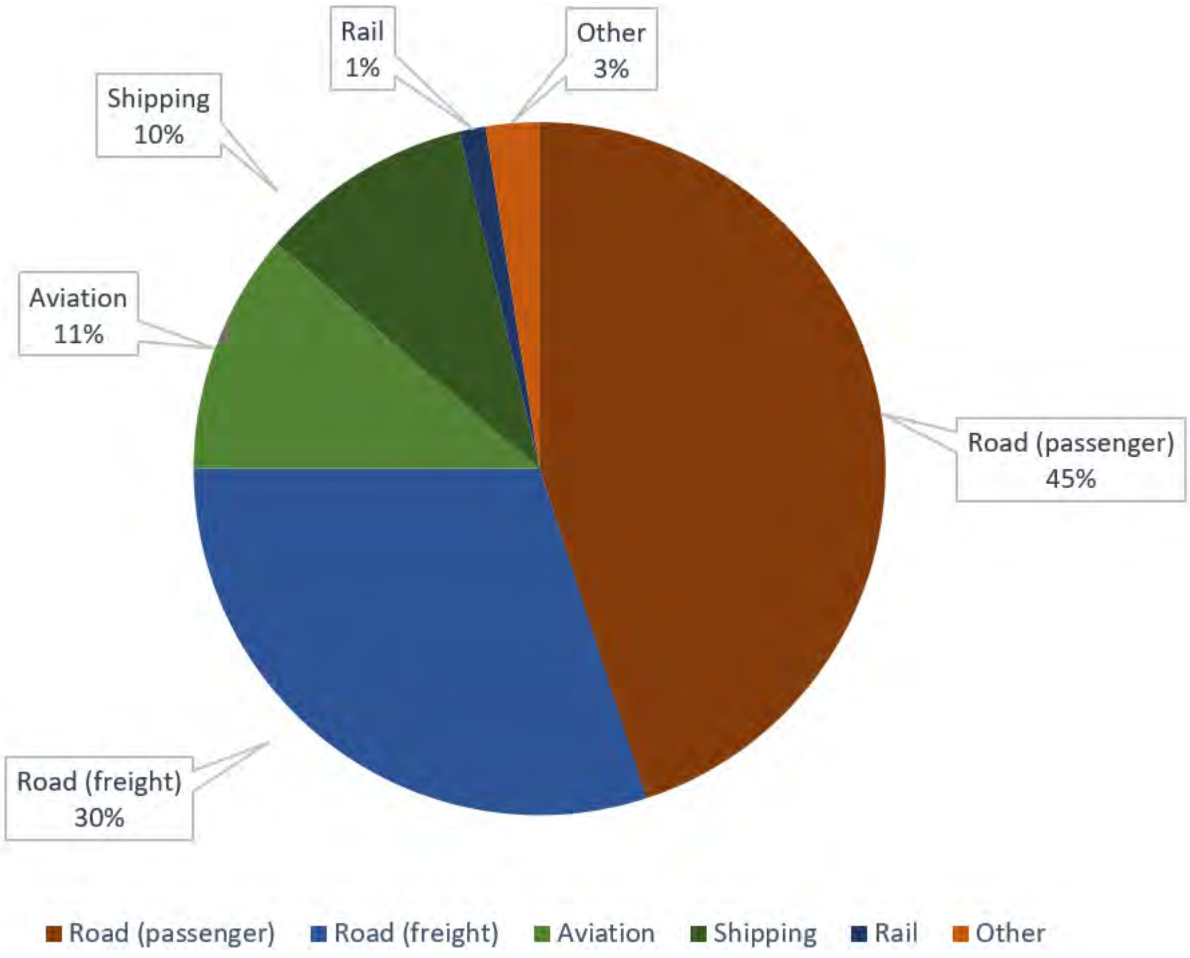
- Developing countries have added a small amount of renewable power, accounting for about 10% of total generation in 2020. Much of this investment, however, was financed or facilitated by international lending agencies which respond primarily to the political demands of the wealthy countries.

- As a result of these trends, the small reduction in CO_2 emissions achieved by the industrial countries (-0.8 Gt) has been overwhelmed by the increase in the developing world (+5.7 Gt).

TRANSPORTATION

In 2018, the last year for which data are available, transportation accounted for about 8 Gt, or 24% of global CO_2 emissions. Figure 12 shows estimated global CO_2 emissions from transportation by mode in 2018.

Figure 12: Global CO_2 Emissions from Transportation by Mode



Source: Our World in Data

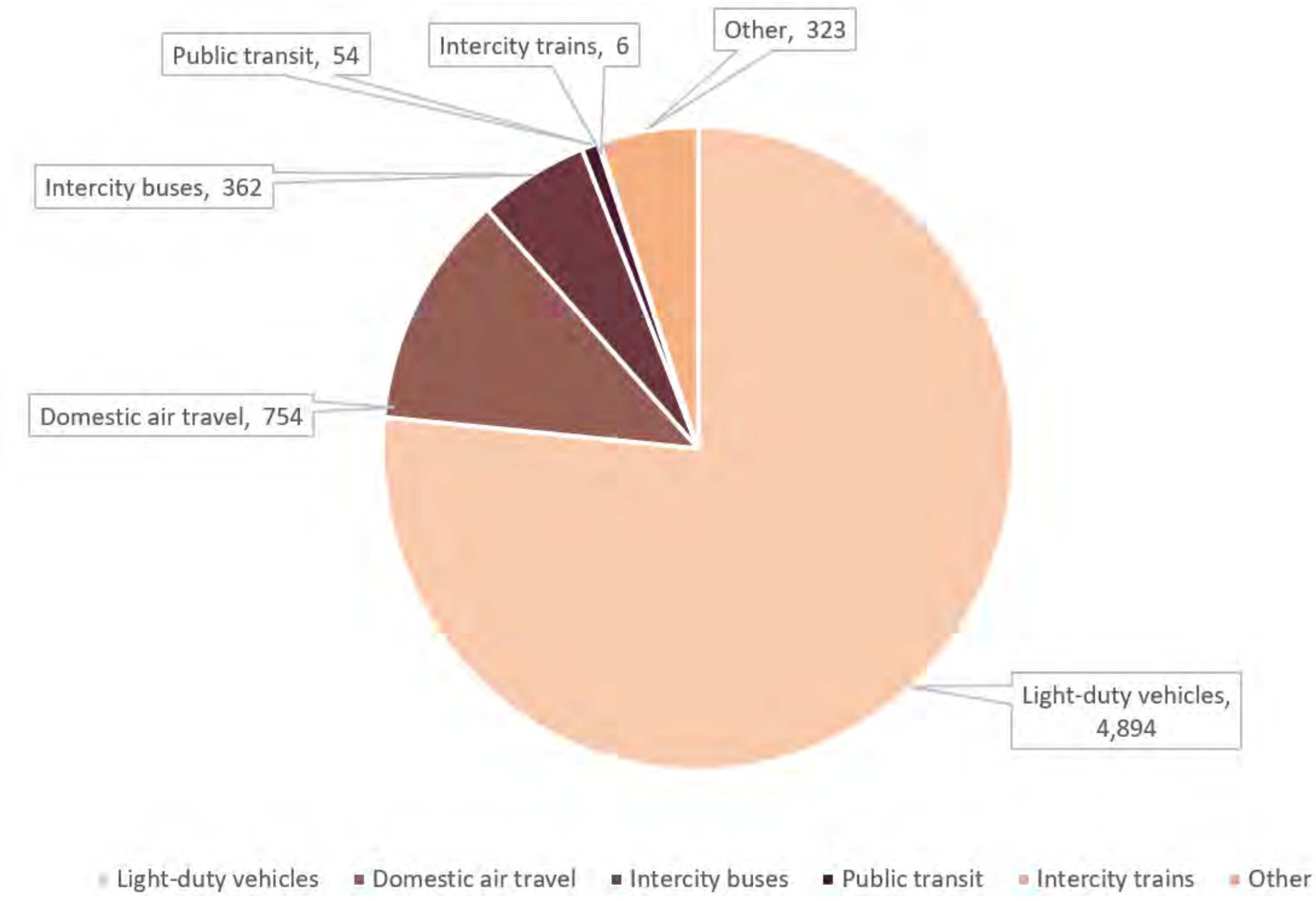
Over 85% of the emissions came from road transport and aviation. Politicians have tended to focus CO_2 reduction efforts on passenger transport as being "discretionary", as opposed to freight traffic, which is essential to the economy. Personal transportation, however, is an important human drive. As human beings gain wealth, they seek stable food supply, security and comfortable shelter. Close behind these needs is mobility. As incomes have risen, people have moved from traveling on foot and horseback to bicycles to motor bikes, of which there are now an estimated 380 million in the world,[59] and finally to automobiles.

For the past 100 years, all transport modes have depended on oil with its low cost, high performance and energy density. Oil has been pushed out of many other markets in the world, particularly power generation, by lower-cost, better-performing alternatives like coal, natural gas and nuclear. For the time being, however, there are no cost-effective alternatives to oil in transportation.

Every country has a different transportation network, and there are no detailed global data sets. The industrialized countries, however, show similar patterns.

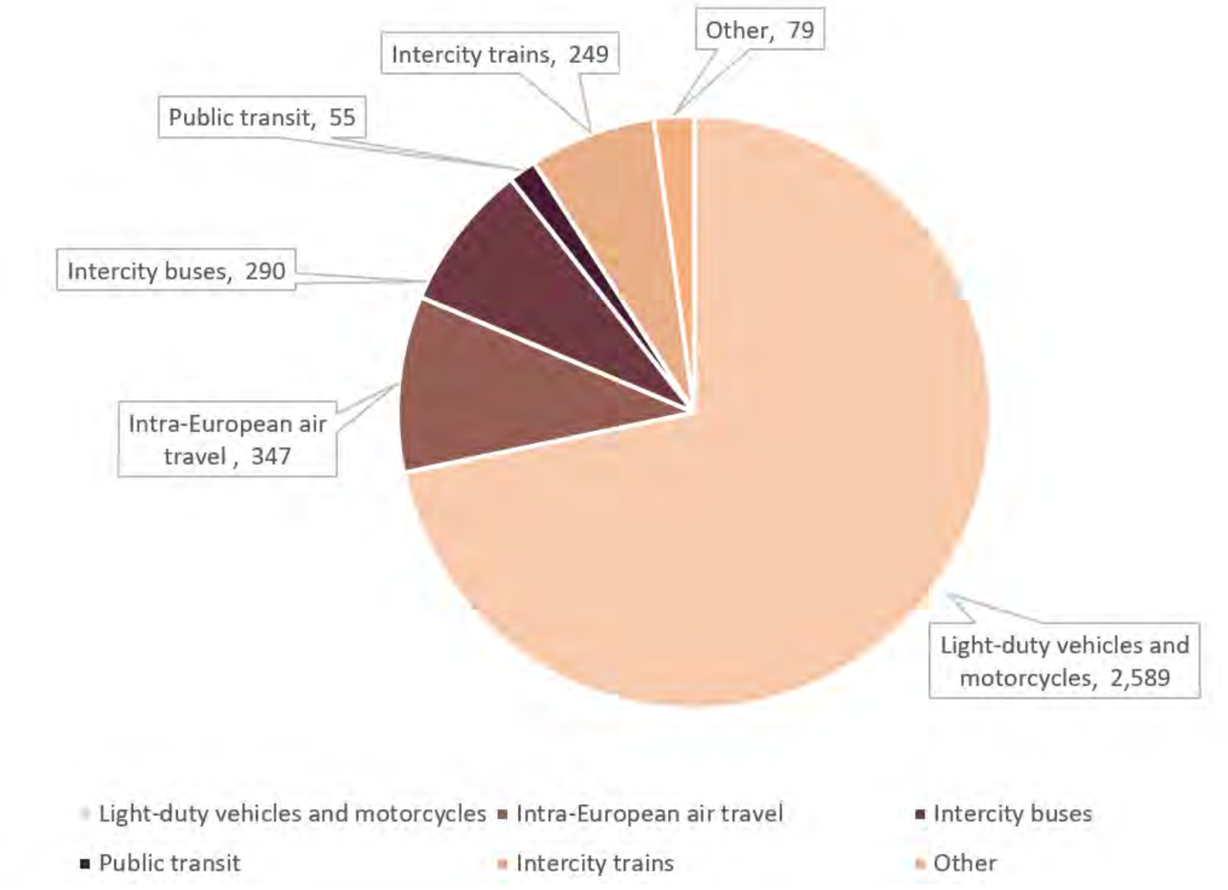
The break-down of passenger-miles by mode is shown for the U.S. in Figure 13 and for the European Union in Figure 14.

Figure 13: The U.S. Passenger Transportation System by Mode, 2021



Source: U.S. Bureau of Transportation, "National Transportation Statistics, 2021"

Figure 14: The E.U. Passenger Transportation System by Mode, 2019

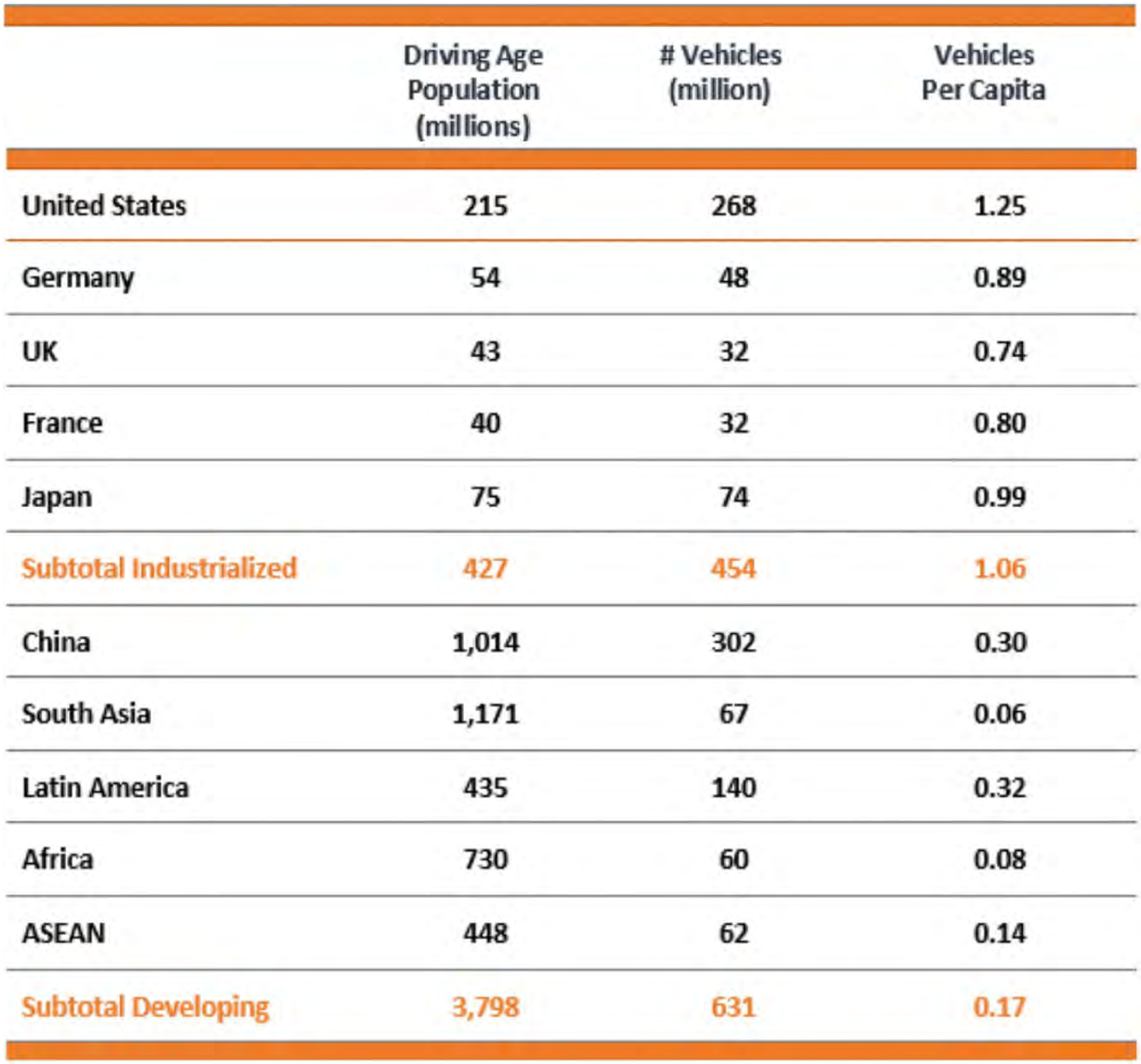


Source: Statista at https://www.statista.com/statistics/280520/share-of-passenger-mileage-in-eu-27-by-mode/

Americans tend to travel more than Europeans. On the margin, Europeans use a little more public transportation and take the train a bit more than Americans do. Europeans also drive smaller vehicles in response to higher gasoline taxes, but the automobile is the dominant form of transport in both the U.S. and Europe.

As shown in Table 10, automobiles have given the industrialized countries unprecedented levels of mobility, and vehicle ownership is reaching a plateau. The five largest industrial countries have about the same number of cars as people of driving age. Consumers in the industrial countries buy vehicles for performance, safety, style, comfort and advanced technologies like GPS, collision avoidance and Wi-Fi.

Table 10: Comparison of Worldwide Automobile Ownership in Industrialized and Developing Countries (millions)



	Driving Age Population (millions)	# Vehicles (million)	Vehicles Per Capita
United States	215	268	1.25
Germany	54	48	0.89
UK	43	32	0.74
France	40	32	0.80
Japan	75	74	0.99
Subtotal Industrialized	427	454	1.06
China	1,014	302	0.30
South Asia	1,171	67	0.06
Latin America	435	140	0.32
Africa	730	60	0.08
ASEAN	448	62	0.14
Subtotal Developing	3,798	631	0.17

Source: For population: Our World in Data, 2019; for vehicle numbers, Wikipedia at https://en.wikipedia.org/wiki/List_of_countries_by_vehicles_per_capita

In developing countries, however, people simply want mobility. The developing world now has two billion more people of driving age than it did in 1997, and, as shown in Table 10, automobile ownership on a per capita basis is well below the standards achieved in the West. The question is not whether these new drivers will get cars but what kind of cars they will drive.

The global automobile market currently offers several types of engine-fuel combinations:

Conventional gasoline vehicles, including cars, SUVs, vans and light trucks, currently total 229 million in the U.S., or 89% of light duty vehicles on the road. Globally, gasoline vehicles account for about 85% of the fleet or 850 million vehicles.

Conventional diesel vehicles comprise less than 1% of the U.S. fleet. U.S. excise taxes are similar for diesel and gasoline, while European countries impose much heavier taxes on gasoline than on diesel. As a result, the European fleet of diesel passenger cars is much bigger at 42.3%. Although diesel engines are marginally more efficient than gasoline engines, the impact on CO_2 emissions is negligible and these engines can emit real pollution, such as particulates. A number of European cities, including Madrid, Paris, and Hamburg, have placed severe limitations on the use of diesels in downtown areas, and the European fleet of private diesel cars is now in decline.

Flex-fuel vehicles, currently about 8% of the U.S. fleet, are conventional gasoline vehicles that have been modified to use high-ethanol blends. U.S. federal regulations require a certain amount of ethanol (a corn-based alcohol with the chemical formula C_2H_5OH) in the gasoline pool. Most U.S. automobiles can tolerate blends of up to 10% ethanol (known as E10), but car manufacturers warn that blends with more than 10% ethanol can damage engines without special modifications. These modifications generally cost only a few hundred dollars and permit the vehicle to burn blends up to 85% ethanol (E85). Several car companies have produced these vehicles, but they are not gaining popularity with drivers in either the U.S. or Europe. E85 stations are limited in number, and E85 has only about 70% of the energy content of E10 leading to a significant range debit. According to U.S. Department of Energy surveys, many flex-fuel drivers are not even aware of their ability to burn E85.[60]

The value of corn-based ethanol in improving engine performance is the subject of considerable debate. It is also unclear whether ethanol use lowers CO_2 emissions or not. Before the ethanol gets into the gasoline pool, the cropland must be cultivated and fertilized, corn must be harvested and transported to the distillery, and the alcohol then distilled – itself an energy-intensive process. Currently, the U.S. uses 40% of its corn crop to replace 2.5% of its petroleum supply.[61] Ethanol is better seen as a subsidy for corn farmers than as an energy or environmental policy.

Gasoline-electric hybrids, such as the iconic Toyota Prius, account for about 2% of the U.S. light duty fleet and slightly less than 2% of the global fleet.[62] Their power plant includes a gasoline engine, an electric motor and a computer control system. The gasoline engine can either drive the vehicle or recharge the battery which drives the electric motor. Although some companies advertise their hybrid sales as part of an overall electrification program, hybrids are simply more efficient gasoline vehicles, since all the energy generated on the vehicle comes from gasoline. Although hybrids are more expensive than their conventional counterparts, some consumers value their enhanced range and other performance characteristics.

Plug-in hybrids, such as the Chevrolet Volt, comprise about 0.2% of the U.S. and global fleets.[63] These vehicles have a gasoline engine, a large electric motor capable on its own of powering the vehicle and an oversize battery that can be charged directly from the grid. The vehicle can run for some period in all-electric mode, usually 25-50 miles, and can then switch over to gasoline. In addition to the high initial cost of these vehicles, there are several constraints on the ability of average consumers to fully utilize these capabilities. A Ford Fusion Energi, for example, can charge its battery from ordinary 110/120V household current, but it takes seven hours for a full charge. A 240V Level 2 charger can fill the battery in 2.5 hours, but, according to Kelly Blue Book,[64] these devices cost about $2,000 installed in the home. Furthermore, many older American homes lack sufficient household electrical capacity to support a Level 2 charger without expensive upgrades. Studies suggest that American plug-in hybrid owners drive 55% of their miles in all-electric mode and the other 45% on gasoline.[65]

All-electric vehicles (EVs) have no gasoline engine and draw their energy entirely from a large battery. Although the imminent demise of the gasoline-powered vehicle has become a common theme, electric cars and light trucks currently total about 800,000 or about 0.3% of the U.S. fleet of 257 million light-duty vehicles.[66] California, which has its own state incentive system, accounts for about 42% of U.S. EVs followed by Florida with 6% and Texas with 5%.[67] The rest are scattered around the country. EVs are quiet and emit no tailpipe pollution, such as sulfur oxides, nitrogen oxides and carbon monoxide. Electric systems are also more efficient and require less maintenance. Unfortunately, they have some serious drawbacks.

The battery is the most serious problem. Recent surveys show battery prices as low as $132 per kWh,[68] although these prices are heavily influenced by several unquantifiable hidden subsidies. Assuming the Tesla Model 3 RWD claim of 0.25 kWh/mile, the vehicle's advertised 272-mile range would require useful capacity of 68 kWh.[69] Batteries, however, cannot be fully discharged without damage, a parameter known as "depth of discharge." Furthermore, drivers will have to keep some capacity in reserve to avoid the electrical equivalent of "running out of gas." Assuming that the useful capacity is 80% of its total capacity, the Tesla Model 3 battery would need to have roughly 85 kWh at a cost of about $11,220. Tesla sells these cars with battery options of 50 or 75 kWh, suggesting that the actual range is likely to be somewhat below the advertised level. In addition, the battery has to operate the lights, air conditioning, sound system and other peripherals and, depending on how the driver manages the battery, capacity may decline over time. As a final point, cold temperatures reduce battery performance, so EVs will do better in warmer climates.

The other main issue with EVs is charging. According to Tesla, a Model 3 can charge only 3 miles of range per hour from a standard 110/120V household outlet (Level 1 charger). A 220V Level 2 home charger can provide 30 miles of range per hour,[70] requiring 9 hours for a full charge. Level 3 chargers are much faster and advertise the ability to charge a Tesla Model 3 battery in less than an hour. Level 3 chargers, however, are commercial machines costing upwards of $50,000.[71]

Despite the hype by climate advocates, the media and various politicians, EVs remain very much a niche player in the U.S. automobile market. The U.S. auto industry sold 15 million cars in 2021, but only about 3% were all-electric. According to a Fuels Institute study conducted by Ricardo Strategic Consulting,[72] 2019 EV owners were predominantly middle-aged white males with a college degree or higher and earning more than $100,000. This demographic has been the primary beneficiary of federal and state EV subsidies. According to the 2020 Census Bureau data, this group has about 15 million households,[73] or about 10% of total households in the U.S. The industry has not yet demonstrated its ability to sell EVs to the broader population, which tends to be more price and performance sensitive.

(In addition to the conventional, hybrid, plug-in and all-electric vehicles, there are a few other types, such as compressed natural gas vehicles, but their numbers are insignificant and can be ignored for purposes of this analysis.)

These vehicle types have different performance characteristics and have elicited different consumer responses. Conventional vehicles emit the most CO_2, followed by hybrid, plug-ins and EVs. As CO_2 emissions get lower, however, the costs get higher. The question, of course, is how much does the CO_2 reduction cost?

Before we begin the quantitative analysis, a few comments about comparisons. First, the comparison must be between vehicles of comparable size and comfort level. Comparing a Lexus SUV with a Ford Fiesta will not provide much insight into consumer preferences and societal trade-offs.

Second, subsidies distort the comparison. As noted earlier, subsidies do not reduce costs but simply transfer them from consumers to taxpayers or other consumers. Plug-in hybrids and EVs have enjoyed major subsidies for years. In 2009, the Obama Administration enacted a $7,500 subsidy for the first 200,000 plug-in or all-electric vehicles by each manufacturer. Some states offer additional subsidies, and California has a credit system requiring companies that do not sell enough electric cars to buy credits from those that do. Since Tesla sells only EVs, Elon Musk has been a major beneficiary of this system. Tesla also received a $465 million Department of Energy loan, since repaid, for the construction of its Model S.[74]

Third, there is disagreement on how to compare the mileage of gasoline-powered cars with EVs. There are three basic ways to measure vehicle efficiency. The first is "tank-to-wheels", which evaluates only what is on the vehicle. By this definition, EVs are "zero emission vehicles," and the car manufacturers like to present them in this way. If the issue were urban pollution, this approach might make sense. Since CO_2 is well-mixed in the atmosphere, however, this measure is meaningless for purposes of carbon accounting.

The second approach is "well-to-wheels", which takes the calculation back to the source of the vehicle's energy, on the assumption that all oil or gas produced from the ground is converted into water and CO_2 at some point. For gasoline vehicles, this segment would be the oil well through the refining and distribution process to the car's tank, a loss of about 18%. For natural gas, which does not need refining, the loss is about 15%. For electric cars and plug-ins, the calculation must include the losses in power generation, which can be 50-70% depending on the generation technology. We will use the "well-to-wheels" approach for analysis.

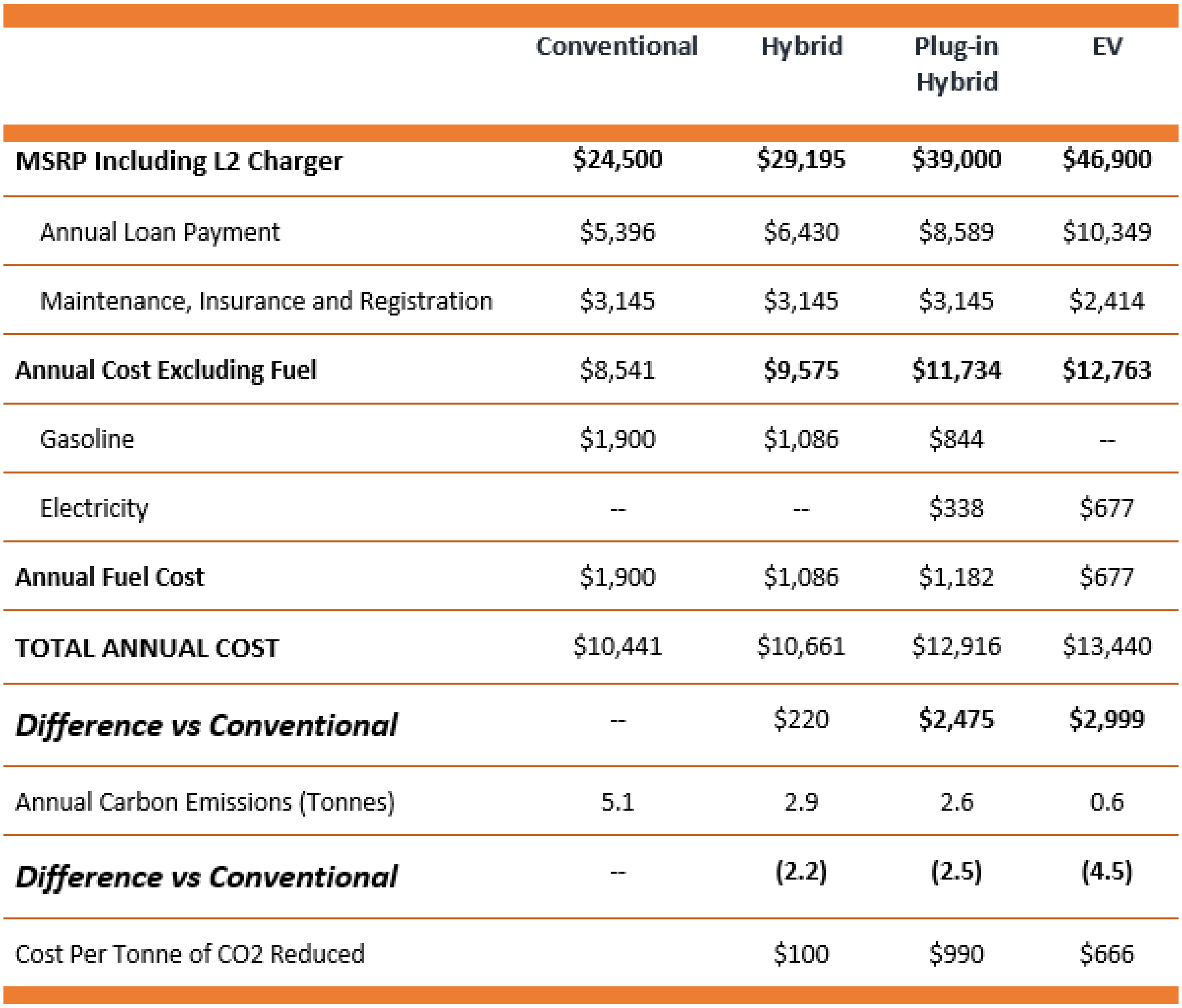
The final approach is "life cycle analysis" which takes the "well-to-wheels" approach and adds in the energy used and emissions generated to produce the vehicle, including parts, battery, shipment, assembly and ultimate vehicle disposal. This approach is the most comprehensive but must be done for each individual vehicle model and is thus cumbersome for an overall assessment. (For readers interested in this analysis, see Schernikau, Smith and Falcon, "Full Cost of Electricity 'FCOE' and Energy Returns 'eROI'", Journal of Management and Sustainability, Vol. 12, No. 1, 2022.)

As an example of the impact of methodology, the EPA window sticker on the Tesla Model 3 RWD shows fuel economy of 132 miles per gallon of gasoline equivalent. This number is a “tank-to-wheels” estimate which considers only the electricity used by the vehicle and ignores the energy required to generate that electricity. On a “well-to-wheels” basis, if the Tesla were charged with electricity generated by natural gas, the mileage should properly be 60 miles per gallon. If coal, the mileage would be 38. The correct number depends on what question is being asked. If the issue is the mileage of a single Tesla Model 3 being purchased today, the average fuel mix of the generation system in the car’s home area would be correct. If we are talking about adding large numbers of EVs to the national fleet over time, the proper comparison basis is the incremental source of electric power generation. For purposes of this analysis, we assume the marginal power source for future EVs to be the matched onshore wind/NGCC system described above.

Finally, EV advocates often assume that technological progress will eliminate the cost disadvantages of EVs in the future. Although such a development is possible, history is full of examples of “sure-fire” energy technology developments that failed to materialize. See, for example, “nuclear power too cheap to meter”, synthetic fuels, fusion, cellulosic ethanol, and hydrogen fuel cell vehicles. Policy analysis should focus on technologies in hand today.

Table 11 shows a detailed comparison of four U.S. vehicles which are similar except for the power plant: a 2020 Ford Fusion SE FWD (conventional gasoline), a 2020 Ford Fusion hybrid SE FWD (gasoline hybrid), a 2020 Ford Fusion Energi (plug-in hybrid) and a 2020 Tesla Model 3 RWD. All are similar mid-sized sedans. A summary of the comparison is shown in Table 11:

Table 11: Comparison of U.S. Sedans by Powerplant Type



	Conventional	Hybrid	Plug-in Hybrid	EV
MSRP Including L2 Charger	**$24,500**	**$29,195**	**$39,000**	**$46,900**
Annual Loan Payment	$5,396	$6,430	$8,589	$10,349
Maintenance, Insurance and Registration	$3,145	$3,145	$3,145	$2,414
Annual Cost Excluding Fuel	$8,541	**$9,575**	**$11,734**	**$12,763**
Gasoline	$1,900	$1,086	$844	--
Electricity	--	--	$338	$677
Annual Fuel Cost	$1,900	$1,086	$1,182	$677
TOTAL ANNUAL COST	$10,441	$10,661	$12,916	$13,440
Difference vs Conventional	--	$220	**$2,475**	**$2,999**
Annual Carbon Emissions (Tonnes)	5.1	2.9	2.6	0.6
Difference vs Conventional	--	**(2.2)**	**(2.5)**	**(4.5)**
Cost Per Tonne of CO2 Reduced		$100	$990	$666

As noted above, hybrids are just a bit more expensive than conventional models, but are in no sense electric vehicles, but just more efficient gasoline cars. Some drivers may choose this option because they value the extended range or other performance characteristics, but the cost of CO_2 reduction at $100/tonne is still above the Biden Administration's Social Cost of Carbon.

Plug-in hybrids are considerably more expensive than hybrids, mainly because of the need for a larger battery. Consumers who choose these vehicles over conventional cars will enjoy extended range and $900 in annual fuel savings, but only at cost of more than $3,000 a year in extra car payments. Of all the vehicle options, plug-in hybrids are the most expensive means of CO_2 reduction at $990/tonne.

As noted above, all-electric vehicles account for less than 1% of the U.S. vehicle fleet, and their popularity is limited to a small demographic. The annual car payment today for an electric sedan like the Tesla Model 3 would be almost $5,000 more than a comparable gasoline-powered sedan. Maintenance on electric cars is likely to be simpler, and fuel would be relatively inexpensive. These two advantages, however, would offset only about 20% of the additional cost of the vehicle. Although battery costs have fallen, they have not approached the level required for economic comparability with gasoline.

As shown in Table 11, EVs are an expensive means of carbon reduction. Recalling that the Administration's own Social Cost of Carbon is $51, the CO_2 reduction cost is nearly twice that amount for hybrids, 19 times for plug-ins and over 12 times for all-electric vehicles compared to gasoline-powered cars. This analysis applies only to new car purchases. Used car costs will be lower. The average age of the vehicle fleet in the U.S. is about 12 years, but the EV market is too new to allow an evaluation of how and when a secondary market might develop. Given the cost and performance issues, particularly range and battery life, the ability of EV's to penetrate broader U.S. vehicle markets remains to be seen.

Other countries are also focusing on EVs to varying degrees. Total world automobile production in 2021 fell slightly in light of supply chain issues, to roughly 80 million units.[75] Global EV production is estimated at 4 million or 5%, and plug-in production at 2.4 million or 3%.

The economics of electric vehicles will differ from country to country. For example, countries with high gasoline prices and low electricity prices will show better EV economics. Furthermore, some countries impose heavy excise taxes on automobiles which can be lower to provide incentives for electric vehicles.

The European Union is encouraging EVs with a new set of automobile emission limits established in 2020. The E.U. private car fleet averaged about 42 miles per gallon (mpg) in 2015. For the 2020-2024 period, cars must emit no more than 95 grams of CO_2 per kilometer traveled, equivalent to 57 mpg. The allowable CO_2 emissions will be reduced by 15% in 2025 (to 66 mpg) and 37.5% (to 90 mpg) in 2030.[76] Using well-to-wheel calculations, these standards will require a substantial increase in EV penetration. Each E.U. member country is to determine its own policy mix to meet this objective.

Germany, for example, offers a subsidy of €9,000 ($9,900[77]) for fully electric vehicles and up to €6,750 ($7,425) for plug-in hybrids. At the end of 2020, Germany had 330,000 EVs and 300,000 plug-in hybrids on the road. The German government has indicated a goal of 15 million EVs by 2030, which would constitute nearly a third of the German private car fleet.[78] So far, the subsidies have been working with more than a half million EVs on German roads. Extending the current subsidy to all EVs, however, would cost the government the hefty sum of over $150 billion. It is not clear how German EV sales would respond if the subsidies were reduced or eliminated.

In addition to the cost, switching German cars from gasoline/diesel to EVs only relocates the problem from the gasoline market to Germany's overstretched electricity system with its dependence on Russian gas.

The U.K. government is offering a smaller subsidy of £1,500 (about $1,950).[79] In a fleet of 32 million cars, EVs account for 370,000 (1%) and plug-ins for 710,000 (2%). Like Germany, EVs in the U.K. essentially involve switching from imported oil to the overstretched electricity grid.

France is in a more comfortable position since it can rely on its large nuclear industry to power its EV fleet. Nonetheless, EVs are still expensive in France. For 2022, the government is offering a subsidy of €2,000-6,000 ($2,200-6,600) per EV and €1,000 ($1,100) per plug-in.[80] During the pandemic, the government offered a direct loan of €5 billion ($5.5 billion) to partially state-owned Renault to help cover its losses. As of October 2021, the French government was planning to offer French car manufacturers €4 billion ($4.4 billion) to spend on electric cars and public transport.[81] As of December 2021, France's fleet of 32 million cars included 500,000 EVs (1.5%) and 785,000 plug-ins (2.5%).

Norway is a special example with gasoline prices around $8.60 per gallon,[82] residential electricity prices of 14.2¢/kWh and excise taxes on new automobile purchases that can reach $30,000-$50,000 for high-horsepower gasoline or diesel vehicles.[83] A substantial reduction in the excise tax for EVs has facilitated rapid penetration with EVs accounting for over two-thirds of new car sales in Norway.[84] It is worth noting, however, that EVs in Norway are still quite expensive, just relatively less expensive than their conventional competitors. Norway also has an unusual situation with over 90% of its electricity derived from hydroelectric power. Thus, an EV offers a significant reduction in CO_2 emissions without increasing import dependence. Norway's situation, however, is unique and its entire light-duty vehicle fleet totals less than 3 million vehicles.

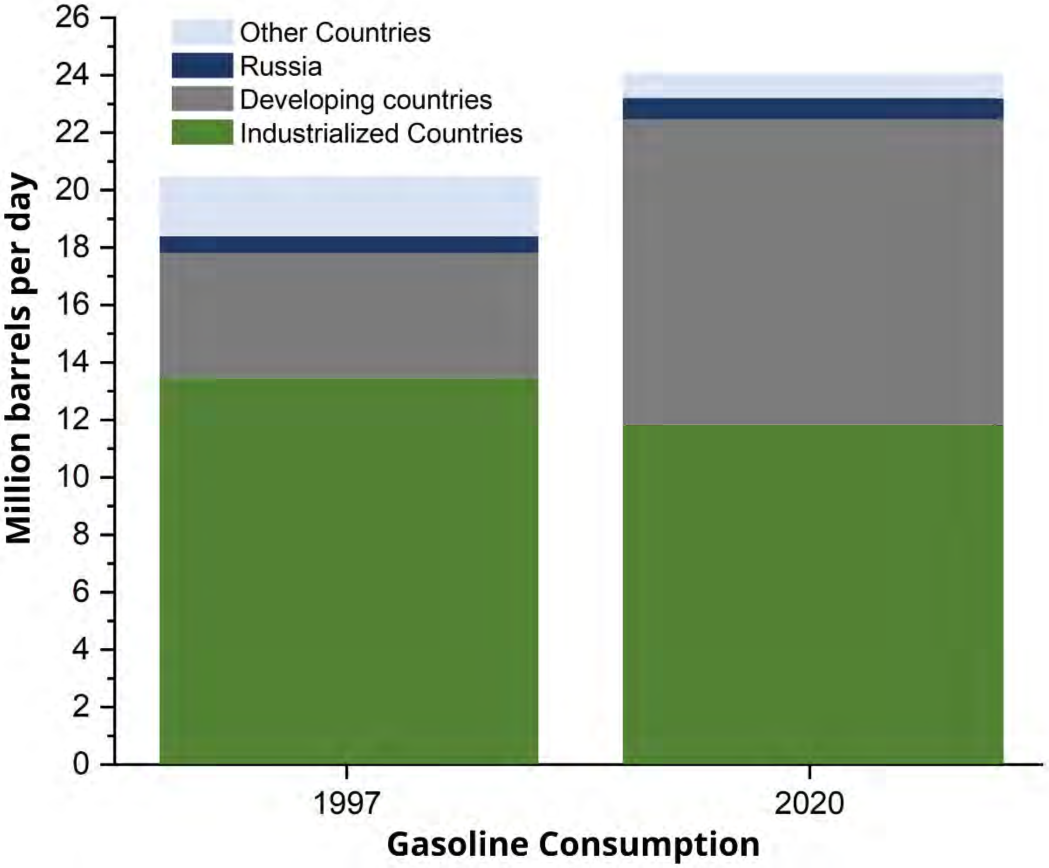
Japan has lagged Europe in electric car penetration with only about 135,000 EVs and 155,000 plug-ins by year-end 2020[85] out of a total vehicle fleet of 82 million. The government is currently offering subsidies of 800,000 yen ($6,560[86]) for EVs, but the total subsidy is capped at only 37.5 billion yen ($308 million) for FY2021, an amount which would subsidize fewer than 50,000 EVs. As in the case of Germany, EVs just push the problem from the oil market to Japan's stressed electricity system.

China has emerged as one of the world's largest EV producers, with an estimated 3 million EVs and 3.5 million plug-ins sold out of total 2020 production of about 26 million units.[87] Chinese consumers, however, are looking for different types of vehicles than their American counterparts. The average U.S. new car has a curb weight (i.e., without passengers or cargo) of 4,156 lbs[88] and an average price of $47,077.[89] The average of the ten most popular cars in China shows a curb weight of 2,890 lbs and an average price of $16,500. Manufacturing costs are lower in China, so pricing will generally be more favorable to consumers, but most of these vehicles have smaller engines (less than 2 liters) and fewer advanced features. It is unlikely that the Chinese new car fleet would sell well in the U.S., so a comparison of the two markets is not particularly useful.

Most Chinese cars are gasoline and diesel powered. Since coal is China's primary power generation fuel, EVs in China are in a sense coal-burners, which emit 25% more carbon dioxide than gasoline-powered vehicles. It seems likely that the Chinese government is more interested in reducing their growing reliance on imported oil than in reducing CO_2 emissions.

Figure 15 shows the evolution of global demand for gasoline.[90] The pattern is much the same as for electricity. The industrialized countries have experienced a leveling or modest decline in demand as the automobile market matures and government policy limits average miles per gallon and forces small numbers of alternative vehicles into the fleet. The developing world, however, continues to drive more gasoline-powered automobiles as the driving-age population grows. The increase of 6.1 MBD in the developing countries was four times the reduction in the industrialized countries.

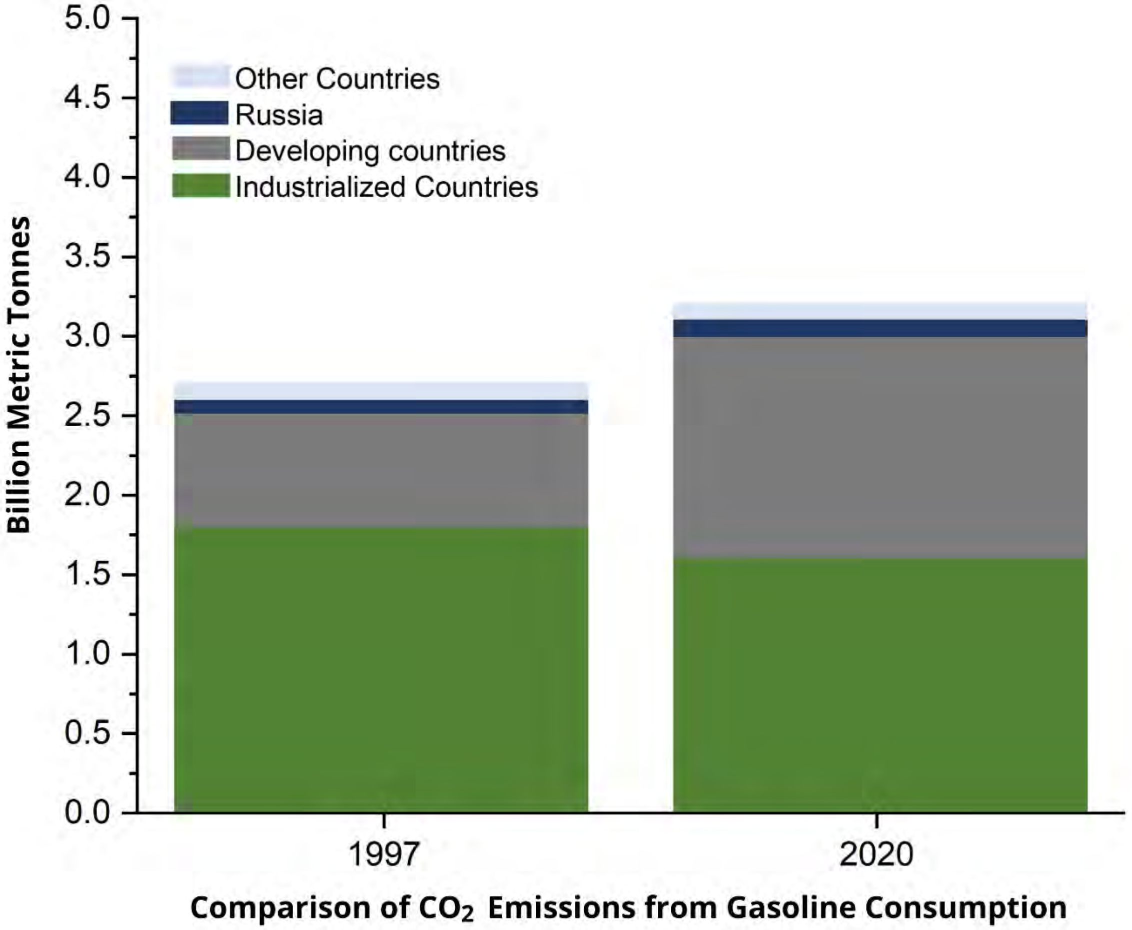
Figure 15: Comparison of Gasoline Consumption in Industrialized and Developing Countries (Million Barrels per Day)



Source: U.S. Energy Information Administration, International Data Tables and BP Statistical Review of World Energy, July 2021

Figure 16 shows global CO_2 emissions from gasoline use. As would be expected from the gasoline demand pattern, the small emissions reduction in the industrialized countries was more than offset by the increase in the developing world. Overall, global CO_2 emissions from gasoline rose 27% from 2.6 Gt in 1997 to 3.3 Gt in 2020. (Note also that 2020 was the primary pandemic year in which mobility was drastically reduced all around the world.)

Figure 16: Comparison of CO_2 Emissions from Gasoline Consumption in Industrialized and Developing Countries, 1997 and 2020 (Gt)



Calculated from Figure 15 at a conversion factor of 0.4578 tonnes of CO_2 per barrel of gasoline.

Conclusions about private vehicles:

- Despite the prevailing narrative that electric cars are replacing internal combustion engines, the global vehicle fleet remains overwhelmingly powered by gasoline and, to a lesser extent, diesel.
- EVs are beginning to penetrate some markets but only because of heavy government subsidies and mandates. EVs remain very expensive primarily because of high battery costs. Range and charging requirements are also impediments to consumer acceptance.
- Battery costs have fallen in recent years but are still far from the level at which EVs become competitive on a market basis.

- Although governments in the industrialized countries have set ambitious EV targets, it remains unclear whether they will be politically and economically able to extend the current high subsidy rates to support a meaningful EV fleet.

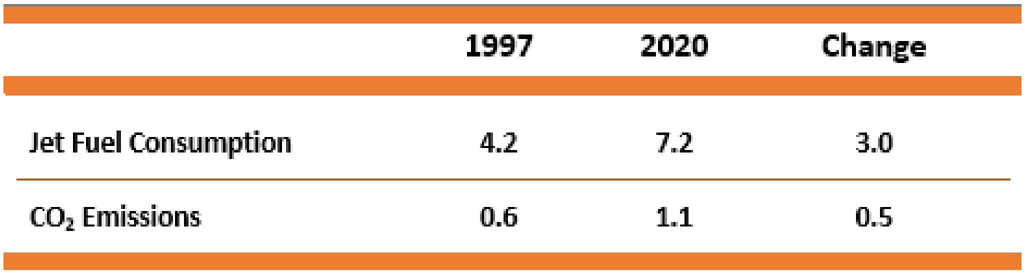
- If subsidies disappear or are scaled back, EV penetration may decline significantly.

- In many countries, such as Germany, the U.K. and Japan, EVs simply shift the required energy supply from the oil market to an already overstretched electricity system.
- Depending on the mix of power-gen fuels, the switch to EVs may or may not reduce CO_2 emissions by any significant amount.

- The developing world has added two billion new drivers over the last 20 years or so and the number continues to grow. These new drivers are looking for the affordable transportation currently available from gasoline-powered cars but not yet from EVs.

Air transportation is a crucial element of the global economy and has grown rapidly over the years. Air travel transcends borders, so a global rather than national assessment makes the most sense. Table 12 shows the growth of worldwide jet fuel use between 1997 and 2019. The year 2019 was chosen because 2020 saw drastic reduction in air travel during the pandemic. Travel recovered strongly in 2021 and continues to grow in 2022.

Table 12: Global Jet Fuel Consumption[91] (MBD) and CO_2 Emissions (Gt) 1997 and 2020



	1997	2020	Change
Jet Fuel Consumption	4.2	7.2	3.0
CO_2 Emissions	0.6	1.1	0.5

Jet fuel use increased over 70% in the 22-year period. Air travel is one of the great technological feats of the last 100 years and has increased human mobility with an extraordinary performance and safety record, well beyond the imagination of its early pioneers. In 1960, air travel in the U.S. accounted for 31 billion passenger-miles or about 3% of the passenger miles traveled by automobile. By 2019, air passenger-miles totaled 754 billion, equivalent to 15% of automobile passenger-miles. Even with substantial improvements in aircraft fuel efficiency, jet-fuel use continues to grow rapidly throughout the world.

For the time being, there are no meaningful alternatives to jet fuel for air travel. Climate advocates focus on three future possibilities.

The first is known as "sustainable aviation fuel" or SAF – essentially a form of biodiesel. Although such fuels work in jet engines in a technical sense, SAF faces the same problems as other biofuels. The feedstocks currently used to produce test batches of SAF are waste cooking oils, waste forest products and various other organic materials. None is available in a quantity sufficient to produce SAF at scale. A recent Forbes article[92] estimated the cost of SAF at eight times the current price of petroleum-based jet fuel.

A second approach is the replacement of aircraft with high-speed trains. There are a number of such trains in the world, including in Europe, Japan and China and, in many cases, these trains provide fast and convenient service in high-density areas. Overall, however, intercity trains are a small component of the transportation system, accounting for about 0.1% of all passenger-miles in the U.S. and 7% in Europe.

Passenger-train usage in Europe is higher than in the U.S. because population density is greater, the railroads are heavily subsidized by their government owners, tourist traffic is high, and the cost of gasoline provides an incentive to choose other transportation means. Nonetheless, railroads have not fared well in the competition with airlines. According to the World Bank, air travel in the E.U. increased at an annual rate of nearly 6% between 1997 and 2019 while rail travel declined.[93] The ultimate impact of railroad policy on CO_2 emissions is likely to be small.

The only commercially successful intercity passenger rail route in the U.S. is the Northeast Corridor from Washington, D.C., to Boston, particularly the high-speed Acela trains. Amtrak, the operator of U.S. passenger trains, is supposed to operate like a private company but is heavily subsidized and regulated at the state and federal level. The resulting political distortions inhibit adequate track, locomotive, and rolling stock investments and force multiple stops between the big cities of Washington, New York and Boston.[94] Although the Acela's designed top speed is 150 mph, it averages only about 84 mph.

Amtrak's basic business model is to use the revenue from the Northeast Corridor to cross-subsidize a national network of routes defined mainly by the preferences of powerful politicians. Amtrak comes close to covering operating expenses each year but has no profit margin available for capital investments.[95] As a result, its assets are always in poor condition, pending occasional and often inadequate injections of federal funds.

The poster child of the pro-train movement in the U.S. today is the California High-Speed Rail Network between Los Angeles and San Francisco. Although this project still has political support from some quarters, its history has been a disaster. The original budget for a downtown-downtown rail link between California's two major cities was $33 billion in 2008 with operations starting in 2020. The most recent estimate is $105 billion with initial operations in the mid-2030s. As of November 2021, only about 119 miles of the total 800-mile route were actually under development and not a single mile of track had yet been laid.[96]

The current estimate from the California High Speed Rail Authority (CHSRA) is that the project will carry 117 million passengers per year at a one-way fare of $55.[97] The passenger forecast should be compared to the current air system between Los Angeles and San Francisco which involves less than 10 million passenger trips per year.[98] Furthermore, the implied revenue of $6.4 billion would have to cover an expected $1.3 billion in annual operating costs and provide a return on $105 billion in total investment – not a promising P/L sheet.

As a final point, the CHSRA claims that the train will be powered by 100% renewable fuel. As discussed above, a 100% renewable grid is not sustainable. Even if the CHSRA constructed its own proprietary power system, it could not reliably supply the 3 TWh estimated to be needed each year.

This project has been bedeviled by politics from the outset. The original $9 billion bond issue approved by California voters plus several billion more dollars in federal funds have been used as a piggy bank by local interests demanding special conditions for right-of-way purchase, track and station construction and environmental mitigation.

The final approach offered by climate advocates to reduce jet-fuel use is for people to join Greta Thunberg in avoiding air travel altogether. Of all the climate proposals currently on the table, this one seems by far the least realistic.

Public transit is another favorite target of climate advocates. The American Public Transportation Association (APTA) claims, "To make progress in reducing our dependence on foreign oil and impacting climate change, public transportation must be part of the solution." Andrew Hawkins of *The Verge* claims, "Public transportation can save the world — if we let it."[99] The numbers say otherwise. Even before the pandemic, public transit accounted for 1% of passenger miles in the U.S. and only 2% in Europe.

There are four main types of public transit:

Heavy rail systems, like the New York subway, operate on a dedicated track either above or below road grade. Twelve U.S. cities[100] have such systems, but 63% of the passenger-miles are in the New York-New Jersey system, and 95% are in the six largest systems. The average number of passengers per rail car ranges from 29 in New York to eight in Baltimore. Costs range from $0.36 per passenger mile in San Francisco to $3.46 in San Juan. These systems can be very efficient in terms of convenience but make economic sense only if passenger loads are consistently high and the system is safe and well-managed.

Worldwide, 204 cities in 61 countries have heavy-rail systems, and 32 others are in the process of building them.[101] The policy question for CO_2 emissions is whether to seek opportunities to build even more systems or whether simply to try to increase passenger loads on the existing systems. In the U.S., all cities with sufficient population and density to support heavy rail systems already have them. In 2018, these urban systems accounted for less than 0.3% of U.S. passenger miles. Doubling or even tripling ridership would have a negligible impact on CO_2 emissions even if these passenger-miles directly replaced car travel.

Light rail systems have been a major focus of U.S. public transit spending in recent years. Unlike heavy rail systems, light rails have dedicated track at street level, usually by using existing road lanes. The U.S. has 23 such systems in cities from Los Angeles to Hampton Roads, Virginia. There are several hundred such systems worldwide, but many are antiquated streetcars rather than modern trains systems.

U.S. light rails accounted for 2.6 billion passenger miles in 2018, equal to 0.04% of total U.S. travel. Some light rail systems are attracting strong ridership with passengers per car averaging 34 in Phoenix and 30 in Seattle. Others, however, are struggling for customers, with Salt Lake City and Buffalo averaging about 13. In many cases, the light rail systems are a drain on municipal finances and often impede road traffic. Their energy efficiency depends to a large extent on the power generation mix of their electricity supply system and on ridership. The argument over light rail systems centers more on their impact on center city development and supposed alleviation of traffic congestion than their negligible impact on CO_2 emissions.

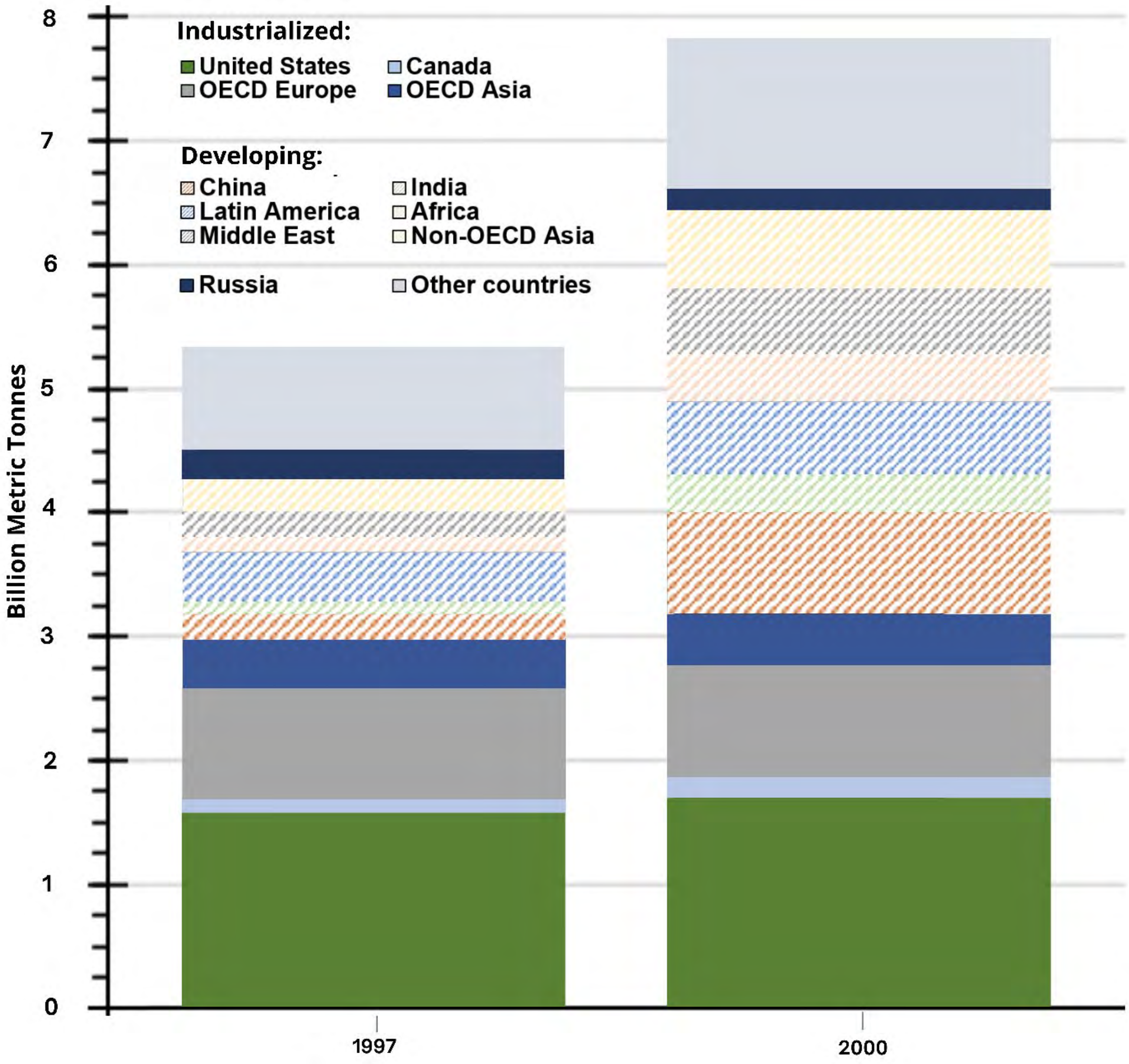
Commuter rail uses existing intercity track to move commuters from the suburbs to city centers. Passenger-miles in the U.S. totaled about 13 billion in 2018 – about 0.2% of total U.S. passenger-miles. Twenty-four U.S. cities have commuter rail systems. Sixty percent of the total passenger-miles are in the New York metropolitan area, and 86% are in New York, Chicago, Boston, Philadelphia and Los Angeles. These systems are based on an older urban model in which workers commute daily from the suburbs to city centers. Jobs are now more widely dispersed, and the pandemic has given a major boost to remote work. Both factors may limit the future development of commuter rail systems.

The most prevalent form of public transportation worldwide is the motorbus. In the U.S., 1,242 municipalities have public bus systems, which account for about 2 billion passenger-miles or 0.03% of the U.S. total. As with the other forms of public transit, ridership is concentrated in the big metropolitan areas with the 15 largest cities accounting for about half the total ridership. There are hundreds of other city bus services around the world.

City buses often have important social functions, such as easing traffic congestion or providing transport to poorer urban citizens who do not have automobiles. The economics and energy benefits, however, are often questionable. In the U.S., city buses tend to be full at rush hour, and rather empty the rest of the time. The average city bus ridership in the U.S. is eight passengers, and buses use about as much fuel per passenger-mile as private cars. Add in a union-scale bus driver and all the administrative overhead, and many city bus systems lose money and require constant subsidies, while contributing little to CO_2 reduction. Some municipal buses are run on natural gas, which reduces pollution, but the impact on CO_2 emissions is negligible.

Some cities around the world have other forms of public transit, such as intercity buses, ferries, cable cars, tourist buses, van pools and jitneys, but the total passenger-miles from these systems are negligible.

Figure 17: Comparison of CO_2 Emissions from Transportation Consumption in Industrialized and Developing Countries 1997 and 2020 (Gt)



Source: Our World in Data for 1997 and 2016, adjusted to 2019 per BP Statistical Review of World Energy, July 2021

In summary, transportation accounted for about a quarter of worldwide CO_2 emissions in 2019. As shown in Figure 17, the evolution of CO_2 emissions from the transportation sector has been similar to that of the power sector. The industrialized world has managed to stabilize CO_2 emissions, but emissions in the developing world continue to grow rapidly. Between 1997 and 2019, the increase in CO_2 from transportation in the developing countries was 10 times greater than the small increases in the industrial states.

PROSPECTS FOR THE FUTURE

Regardless of their views on climate science, most people would agree that the efforts to reduce CO_2 emissions have been less than successful over the last 30 years. The Paris Climate Agreement is now in its seventh year, urgent international meetings multiply, and the warnings of catastrophe grow louder and shriller, yet CO_2 emissions continue to rise. The stated objective of the global climate movement is now "net zero" emissions by 2050, meaning that any remaining CO_2 emissions must be offset or sequestered. So, what does the future actually look like?

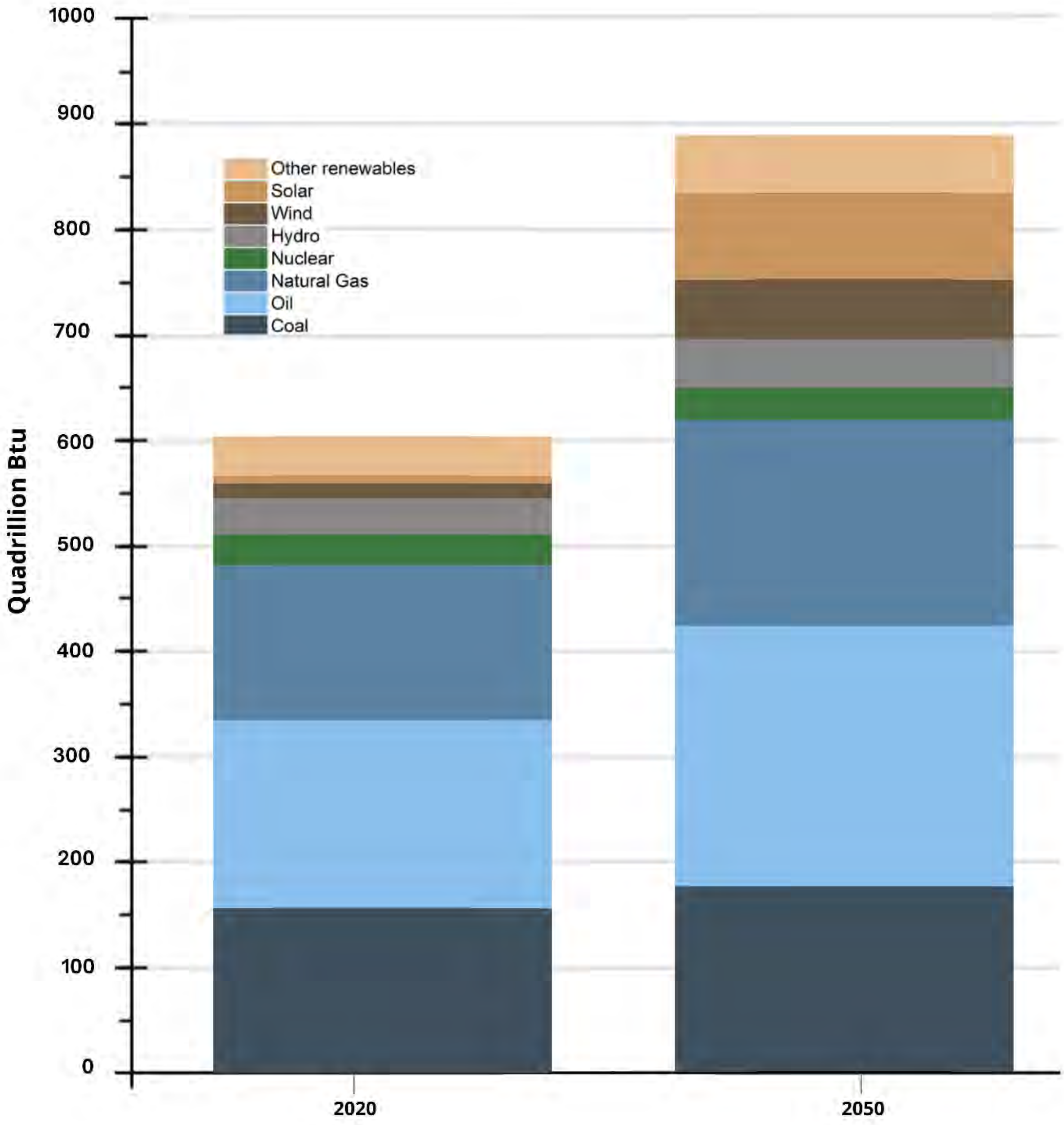
The EIA periodically produces an International Energy Outlook (IEO) that projects energy trends into the future. The most recent IEO (IEO2021), published in October 2021, received little public attention, but should be an eye-opener for climate advocates.

In fairness to the EIA, its outlook is not a prediction, but a set of projections based on specific assumptions. The Base or Reference Case projection shows a very different world in 2050. The global population is assumed to increase from 7.7 billion today to 9.7 billion in 2050. Global GDP increases from $122 trillion[102] in 2020 to $283 trillion in 2050 implying per capita income growing from about $16,000 today to $29,000 in 2050. The developing world accounts for over 90% of the growth in population and 70% of the growth in GDP, resulting in a substantial increase in discretionary spending. In China, for example, per capita income rises from about $19,000 today to over $50,000 in 2050. In India, per capita income increases from $7,000 to $29,000.

The U.S. population is assumed to increase 17% to 386 million, equivalent to adding another country the size of Spain to the U.S. U.S. GDP increases from $15.8 trillion in 2020 to $29.8 trillion in 2050, implying a per capital income rising from $47,995 in 2020 to $77,221 in 2050.

The world's 9.7 billion people with their dramatically improved living standards will want better food, better medical care, more mobility, more and better living space and consumer goods produced around the world and delivered to their door. All these activities require energy. Figure 18 shows the EIA's projection of how these energy needs are likely to be met. In IEO2021, the share of fossil fuels declines from 81% in 2020 to 70% in 2050, but all fossil fuels – coal, oil, and natural gas – are projected to increase in absolute terms. Although renewable energy is projected to grow over this period, wind and solar continue to supplement and not replace fossil fuels.

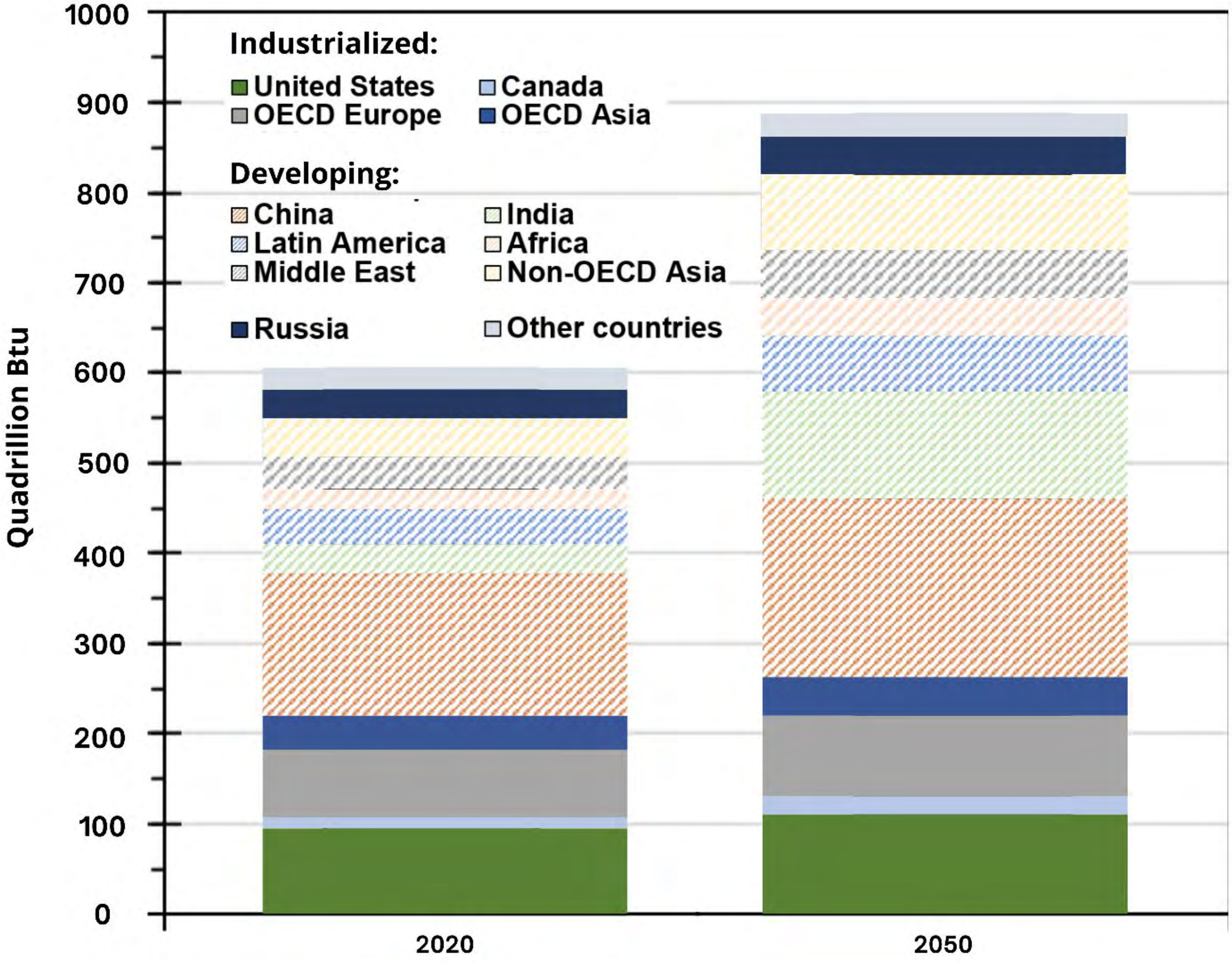
Figure 18: Projected Global Energy Consumption by Fuel, 2020 and 2050 (Quadrillion Btu)



Source: U.S. Energy Information Administration,2021 International Energy Outlook

Figure 19 shows the same energy balance but organized by region. Energy consumption follows the economic growth pattern: modest in the industrial countries – averaging only about 0.5% per year – and much stronger in the developing world – averaging about 2% annually. Over 80% of the energy demand growth between 2020 and 2050 is in the developing world.

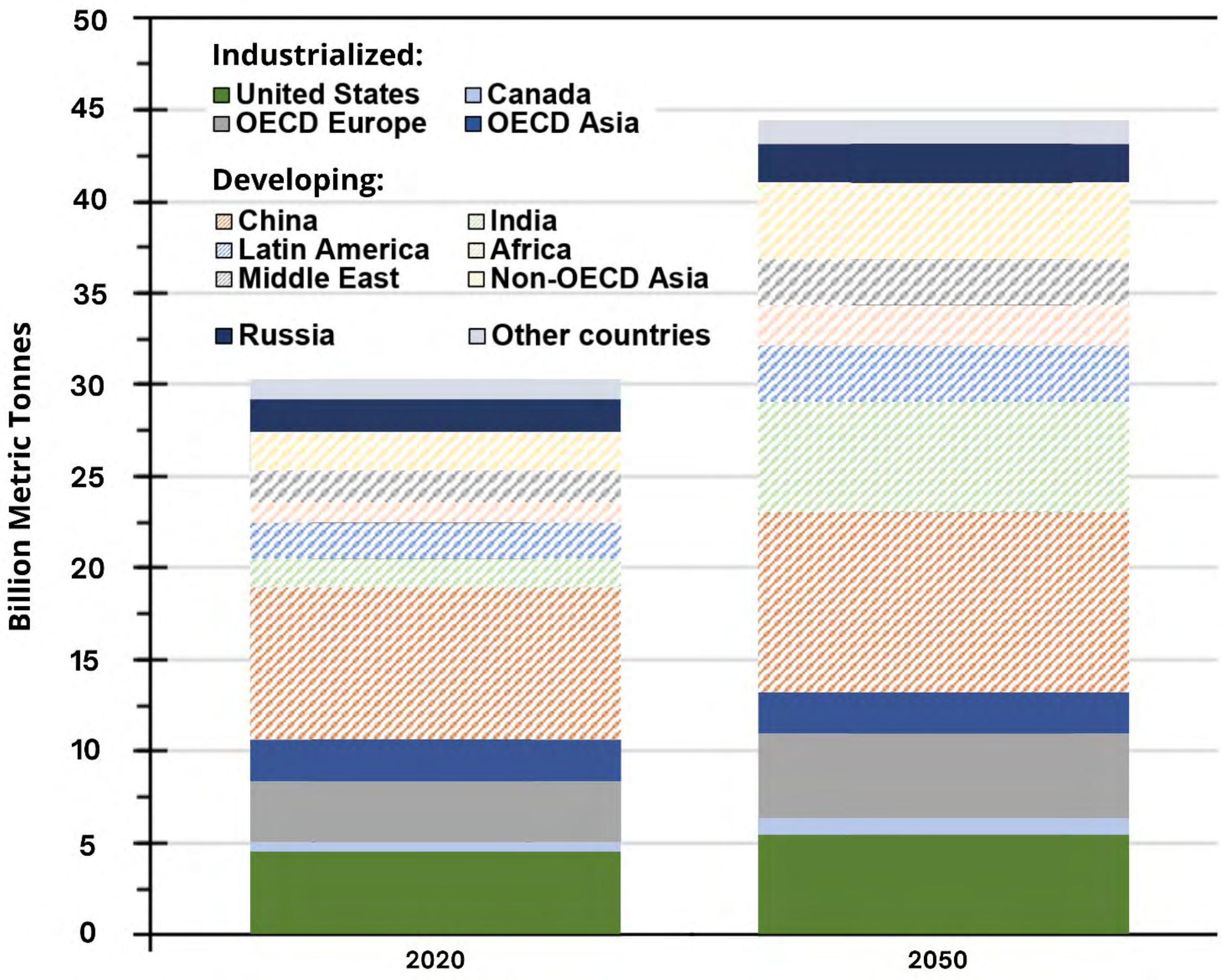
Figure 19: Comparison of Projected Energy Consumption in Industrialized and Developing Countries (Quads)



Source: U.S. Energy Information Administration, International Energy Outlook, 2021

Figure 20 shows the EIA's estimates of the CO_2 emissions associated with projected energy growth. CO_2 emissions, of course, depend on the amount of fossil fuel burned, not its share in the energy economy.

Figure 20: Comparison of Projected CO_2 Emissions in Industrialized and Developing Countries (Gt)



Source: U.S. Energy Information Administration, International Energy Outlook, 2021

The EIA projection implies that industrial countries will continue their struggle to reconcile the requirements of their economies with the demands of climate advocates, resulting in nothing more than a slowdown in the rate of growth in CO_2 emissions. The developing countries are projected to continue to grow their economies rapidly with whatever affordable energy is available to them, including large quantities of fossil fuels, regardless of any pledges made under the Paris or other climate agreements.

The EIA's Reference Case projection "includes existing laws and regulations as of spring 2021 and it reflects legislated energy sector policies that can be reasonably quantified."[103] The reference case also includes "Projected incremental cost and performance improvements in known technologies."[104]

The central conclusion of the EIA's analysis is that all the carbon reduction efforts to date, including the treaties, the pledges, the Conferences of Parties, the "Nationally Determined Contributions," the legislation, the political promises and the pleas for changes in social behavior are doing little to change human behavior or to move toward the goal of "net zero" emissions.

The difference between eliminating fossil fuels and "net zero" is an important loophole. "Net zero" allows carbon emissions to continue if they can be neutralized through Carbon Capture, Utilization and Sequestration, known as CCUS. Unfortunately for climate advocates, the technology to accomplish this task does not yet exist, despite considerable investment in research and development. A September 2020 report by the International Energy Agency (IEA) states categorically that "Reaching net zero will be virtually impossible without CCUS."[105] IEO2021 offers some insight into this problem in an obscure but powerful footnote to its Table A10 showing projected global CO_2 emissions out to 2050 which reads: "CO_2 captured by CCS [carbon capture and sequestration], accounting for less than 0.2% of the 2050 world total, is not subtracted."[106] In other words, the EIA assesses the loophole as having negligible value.

Without CCUS, reaching net zero by 2050 would require global CO_2 emission to decline by an average of 1,400 Mt per year between 2020 and 2050. The EIA Reference Case, however, projects an increase of about 275 Mt per year for the foreseeable future.

The EIA projections include some powerful assumptions about the future development of the U.S. energy economy through 2050:

- The U.S. light duty vehicle fleet increases by 6% from 257 million to 273 million vehicles. The share of electric vehicles (EVs and plug- ins[107]) increases from 0.5% to 7.7%.[108]

- The U.S. more than doubles wind generation from 343 TWh to 790. This increase is equivalent to adding 620 200 MW wind farms, each consisting of 100 large wind turbines and covering about 12 square miles of land. The total cost to American consumers (and/ or taxpayers) would be about $38 billion every year.

- Solar power increases eightfold from 132 TWh to 1,071 TWh, equivalent to adding 1,800 200 MW solar arrays or, alternatively, installing solar panels on every house in the United States. The total cost to American consumers (or taxpayers) would be $140 - 175 billion annually.

Even with these changes, however, U.S. CO_2 emissions are projected to increase over the next 30 years.

So, what else is on the current political table and what other U.S. actions would constitute a serious contribution to either reducing global CO_2 emissions or signaling to the rest of the world that the U.S. is serious? As a benchmark, the IEO2021 projects global CO_2 emissions of 42.8 Gt in 2050, of which the U.S. accounts for 4.8 Gt or about 11%.

The bipartisan Infrastructure and Jobs Act passed in November 2021, includes among its goals "tackle the climate crisis." According to the White House,[109] the specific provisions of the Act are:

- Deliver clean water to all American families and eliminate the nation's lead service lines. $55 billion. Understandable in light of the Flint Michigan problem, but no measurable impact on CO_2 emissions.

- Ensure every American has access to reliable high-speed internet. $65 billion. No material impact on CO_2 emissions other than perhaps a slight increase in electricity demand.

- Repair and rebuild our roads and bridges with a focus on climate change mitigation, resilience, equity, and safety for all users. $110 billion. Mitigation is not CO_2 reduction.

- Improve transportation options for millions of Americans and reduce greenhouse emissions through the largest investment in public transit in U.S. history. $39 billion. Public transportation may have benefits for commuters and center city development around the country but as discussed above, public transit is not a major component of U.S. travel. Assume that this investment (a) doubles the passenger miles on U.S. public transit, (b) all the additional miles are powered by carbon-free renewable electricity and (3) every new passenger mile replaces a mile in a private automobile carrying only the driver. The CO_2 reduction would be 54 billion passenger miles X 0.45 kg of CO_2 per automobile passenger-mile = 24 Mt of CO_2, equivalent to 0.5% of current U.S. emissions or 0.07% of global emissions.

- Upgrade our nation's airports and ports to strengthen our supply chains and prevent disruptions that have caused inflation. This will improve U.S. competitiveness, create more and better jobs at these hubs and reduce emissions*.* $42 billion. It is not clear how much jet fuel is wasted as a result of congestion or how much these dollars will reduce congestion but let us assume a 10% overall improvement in jet fuel use. IEO2021 projects U.S. jet fuel demand in 2050 of about 2 MBD or 30 billion gallons per year.[110] A 10% annual savings would be 3 billion gallons emitting about 30 Mt of CO_2, equivalent to just over 0.6% of U.S. emissions or 0.08% of global emissions.

- Make the largest investment in passenger rail since the creation of Amtrak. $66 billion. This provision promises to "create safe, efficient, and climate-friendly alternatives for moving people and freight." If Amtrak's history is any indication, this money will be allocated based on political rather than economic or environmental considerations. In any case, as noted earlier, U.S. intercity train travel accounts for only 6 billion out of 6,393 billion total passenger miles. Doubling the passenger miles on Amtrak's electrified trains would save at most 3 Mt of CO_2 emissions, equivalent to 0.06% of the U.S. total or 0.008% of the global total. Furthermore, although the Northeast Corridor is heavily traveled and electrified, most of Amtrak's routes are lightly utilized and diesel powered. Increasing and improving traffic on these routes would likely result in no emissions savings at all. In addition to passenger traffic, this provision targets rail freight movements. The EIA outlook shows only a modest 25% increase in rail freight between 2020 and 2050 entirely offset by efficiency improvements. Freight trains currently consume about 210,000 barrels per day of diesel, equivalent to 3.2 billion gallons per year. If the

Infrastructure Act's investments improve rail freight efficiency by 10%, the savings would be 320 million gallons per year X 10.2 kg of CO_2 per gallon totaling 3.3 Mt of CO_2 annually equal to 0.07% of U.S. emissions or 0.008% of global emissions.

- Build a national network of electric vehicle (EV) chargers. $7.5 billion. The White House calls this program to add 500,000 EV chargers a "critical step in the President's strategy to fight the climate crisis". It is not clear that $7.5 billion will cover half a million Level 3 charging stations, which can cost up to $50,000 each. As noted above, EVs currently total about 800,000 cars in the U.S. The primary problem with electric vehicles is their high cost, and this provision addresses only a secondary concern: range. Most EVs are charged at home at night. A network of Level 3 chargers provides an additional option for some long-range trips. According to the Department of Energy, about 60% of U.S. car trips are less than six miles.[111] Only 5% are over 30 miles. Furthermore, a gasoline automobile can refill in less than 10 minutes, while a Nissan Leaf with a 50-mile range would have to stop every 1-2 hours for a 30-minute recharge on a long trip. Even longer-range EVs like the Tesla Model 3 would have to stop every few hours for a 40–50-minute recharge. It is not at all clear how many more people would choose EVs as a result of this provision. IEO2021 projects EV sales averaging about 175,000 per year over the next ten years for a total of 1.75 million new EVs on the road by 2032. Assuming that this provision doubles the number of EVs on the road, since each EV replaces 4.5 tonnes of CO_2 per year compared to a gasoline vehicle, the net impact would be 7.9 Mt of CO_2 per year by 2032, equivalent to 0.14% of current U.S. emissions or 0.02% of global emissions.

- Make our infrastructure resilient against the impacts of climate change, cyber-attacks, and extreme weather events. $50 billion. Better control of floods and better response to weather-related disasters and cyberattacks may carry some significant benefits, but this provision does nothing to reduce CO_2 emissions.

- Deliver the largest investment in tackling legacy pollution in American history by cleaning up Superfund and brownfield sites, reclaiming abandoned mines, and capping orphaned oil and gas wells. $21 billion. No reduction in CO_2 emissions.

The White House description of the bipartisan Infrastructure and Jobs Act cleverly works the word "climate" throughout its text, but the actual impact of its provisions on CO_2 emissions, even with very optimistic assumptions, is likely to be small, totaling less than 100 Mt of CO_2, equal to 1-2% of current U.S. emissions or 0.3% of global emissions. By anyone's definition, these provisions hardly qualify as "tackling climate change".

Having abandoned the ambitious "Build Back Better" plan, the Democrats in Congress have passed a smaller reconciliation bill known as the "Inflation Reduction Act (IRA)". The Administration is facing a dilemma. On the one hand, taking decisive action against the "existential threat" of climate change means drastic near-term reductions in fossil fuel supply. On the other hand, keeping inflation down and consumer outrage over high energy prices in check means increasing near-term fossil fuel supplies. The two objectives are contradictory, and the IRA is an attempt to square this circle.

The IRA's supporters call the bill the "single biggest climate investment in U.S. history."[112] That, however, is a meaningless metric. The question is whether the bill will actually contribute to the solution of any problem. The bill proposes to spend $369 billion over ten years – equivalent to taking roughly $3,000 from the assets of each American household. What will Americans get in return for this money?

For context, as discussed earlier, let us do some simple math using the following steps:

1. As noted earlier, evidence does not support the view that CO_2 emissions represent an existential threat to the climate. Given the clear benefits of CO_2, emissions reductions may in fact have a negative impact on the climate.

2. If, however, one believes that CO_2 does present such a threat, then an effective climate policy must have a material impact on the amount of CO_2 in the atmosphere.

3. The U.S. currently accounts for less than 14% of global CO_2 emissions.

4. As outlined above, few countries in the world are making any effort at all to reduce CO_2 emissions. Europe has taken some steps in that direction but has backed off recently in light of the impact of reductions in Russian energy supplies as a result of the Ukraine war.

5. According to the International Energy Agency, global investment in energy supply, including fuel production, transport power generation and electricity generation total roughly $2 trillion per year or $20 trillion over the next ten years.

6. The IRA proposes to spend $369 billion over the next ten years to facilitate an energy transition away from fossil fuels – an amount equal to 1.8% of anticipated investment.

Spent carefully and efficiently, this sum is clearly inadequate to change the structure of global energy supply very much. The IRA, however, is neither efficient nor carefully targeted. Instead, like much federal legislation, it spreads money around to the various constituencies necessary to gather the required political support for the bill.

Half the expenditures are $161 billion in Clean Electricity Credits, based on a principle that has guided (or misguided) federal energy policy for several decades: subsidizing uneconomic technologies will ultimately make them economic. If this were true, wind and solar would long since have been weaned off their decades-old federal subsidies. Rather than just subsidizing wind and solar, however, the bill creates a complex mass of credits that may or may not promote renewable energy. For example, the bill extends and expands Production Tax Credits (PTC) and Investment Tax Credits (ITC) for renewable energy. These credits have been on and off for many years, but the IRA adds a new twist. The full credit would be available only for projects which satisfy prevailing wage and apprenticeship requirements – code for union shops. Projects that do not meet the union requirements would receive only 20% of the credit. Moreover, the project could increase its PTC by 10% if it also met certain domestic content requirements.

In addition to provoking extensive litigation and raising serious constitutional questions, these provisions might actually offset the subsidies and make renewable energy more expensive.[113]

Only about $60 billion of the Clean Electricity Credits is for solar and wind manufacturing. Another $60 billion is for assistance to disadvantaged communities – an adaptation step, not a mitigation step. $27 billion goes to clean energy R&D, which may or may not produce any actual results. Agricultural emissions reduction gets $20 billion, forest conservation $5 billion, drought funding in Western states $4 billion. There are also new battery manufacturing credits, stand-alone energy storage, hydrogen, carbon capture and storage, residential energy efficiency and other programs, none of which has near-term commercial prospects.

Some observers are applauding the inclusion of some funds for nuclear power. The main issues with nuclear power, however, remain political, not financial. Multi-billion-dollar government subsidies for the Vogtle 3 and 4 nuclear plants in Georgia resulted in the usual cost overruns and scheduling delays. Without resolution of the legal and political obstacles to nuclear power, there will be little near- to medium-term capacity additions.

One of the centerpieces of the bill is a $30 billion set of enhanced subsidies for EVs. That seems straightforward on the surface, but it is not. The basic provision is a refundable tax credit of $7,500 for qualifying EVs plus a $4,000 credit for "used clean vehicles."

It is not clear if the second of these provisions will have any impact at all. The credit is only for couples making $150,000 or less or single- filers making $75,000 or less and the vehicles purchased must be EVs or plug-in hybrids at least two years old. For all intents and purposes, no such secondary market yet exists. This provision seems to be an attempt to bring the middle class into a government program that has benefitted primarily the wealthy.

As discussed earlier, the U.S. currently has only about 800,000 registered EVs out of a fleet of 257 million vehicles. Assuming (1) the maximum tax credit of $7,500 per vehicle, (2) each credit results in the purchase of an additional EV and (3) that the entire $30 billion is devoted to this credit, the program would incentivize an additional 4 million EVs accounting for roughly 1.5% of the U.S. private vehicle fleet and saving about 4.5 Mt of CO_2 annually or less than 1% of U.S. emissions.

The IRA, however, puts some serious constraints on its own EV provisions. First, credits are not available to couples earning more than $300,000 annually or single-filers earning more than $150,000. Second, the credits are only available for vehicles that meet domestic content requirements for materials, including batteries. According to the Alliance for Automotive Innovation, 70% of current EVs available on the U.S. market would be ineligible for the credit.[114] In sum, the EV credits are limited for those people actually likely to buy them and for the vehicles actually on the market.

The total impact of all these provisions on U.S. CO_2 emissions is difficult to estimate, since the money is spread around to so many activities with so many strings attached. The Senate Democrats claim that the IRA "reduces carbon emissions by roughly 40% by 2030."[115] Although this number sounds impressive, it is measured against U.S. emissions in 2005 – 17 years ago.[116] This promise thus contains two clever tricks: (a) setting a target that does not need to be met while the President is still in office and (b) backdating the starting point.

According to British Petroleum's 2022 Statistical Review of World Energy,[117] total U.S. carbon emissions in 2005 were 5.9 Gt, which happened to be the peak year for the U.S. The promise, therefore, is to cut this number by 40% to about 3.6 Gt by 2030. After 2005, however, the substitution of natural gas for coal began to take effect, and 2021 emissions had fallen to 4.7 Gt. In other words, President Biden has already banked over half of his promised reduction without doing anything and needs only an additional 1.1 Gt reduction to meet his target.

Taking credit for history is an accounting trick with a strong pedigree. When the Kyoto Protocol was under negotiation in 1997, the U.K. and Germany insisted that the base year for measuring CO_2 reductions should be 1990. Since the European Union had a consolidated target, this clever twist allowed the E.U. to "book" both the switch of U.K. coal for North Sea gas and the shutdown of most of the East German lignite industry, both of which occurred during the 1990s. The E.U. had met most of its commitments before the treaty was even signed.

President Biden's political fortunes might improve if he could claim that he had kept his promise, but would it make any difference to the amount of CO_2 in the atmosphere? Checking back with Figure 20, the IEO2021 projects that annual global CO_2 emissions will increase from 34.5 Gt in 2020 to 42.8 Gt in 2050. The IRA impact of 1.1 Gt (assuming it actually happens) would represent a 2-3% reduction. Hardly a step toward "net zero."

These numbers put climate advocates in a serious bind. They can continue to argue, as many do, that the energy transition is well underway and that the world is cooperating fully to solve the "climate crisis," even though the numbers contradict this assertion. Alternatively, they can argue that the Biden Administration is now putting the U.S. on a path to serious CO_2 reductions, which will catalyze the rest of the world to action. Again, the numbers say otherwise.

It is worth noting that the IRA contains no provisions for tracking where the money goes or how much CO_2 reduction is actually achieved. If history is any indication, the money will simply dissipate through the economy without any accountability.

CONCLUSIONS

The two main sources of CO_2 emissions from fossil fuels are electric power generation and transportation.

Regarding electric power generation:

- Since electricity cannot be stored, modern electricity grids require a high proportion of dispatchable generating capacity. Too much intermittent power, like wind and solar, undermines the reliability and stability of the grid.

- When the costs of back-up capacity are included, wind and solar power are much more expensive than electricity generated by fossil fuels.

- The industrial countries are struggling to find a political balance between the need for a high-quality electricity grid and the demands of climate activists.

- In seeking this balance, politicians in the industrial countries will push renewable energy into the marketplace until they hit limits based on the voting public's willingness to tolerate high costs, unreliable electricity supply and national security risks.

- The developing countries are growing their electricity grids rapidly with whatever local and affordable sources are available, mainly fossil fuels and hydro.

- The growth in renewable energy in the developing world is largely an artifact of international lending institutions responding not to the needs of the poor but to the political demands of wealthy countries.

Regarding transportation:

- Automobile ownership in the industrialized countries is reaching a plateau. In the developing countries, however, the driving age population is growing rapidly, and they will demand mobility.

- Gasoline-powered vehicles provide that mobility at the lowest cost and best performance.

- Powered by heavy subsidies, electric vehicles have made slight inroads in the U.S. and some other countries, but these vehicles remain much more expensive than gasoline-powered cars, and the numbers are still small.

- The high cost and limited performance of batteries are the main obstacles to further market penetration by EVs. Battery technology is likely to improve, but there is no guarantee that the improvement will be sufficient to allow widespread adoption of EVs.

- In the U.S., EVs are a niche market serving mainly upper middle-class males in California.

- Aviation is a high growth segment throughout the world, and there are no viable substitutes for jet fuel in the foreseeable future.

- Public transport remains a small part of total travel throughout the world. Even major increases in travel on public transit would have a negligible impact on CO_2 emissions.

- The recently passed Infrastructure and Jobs Act and the proposed Build Back Better Act offer expensive, but largely symbolic carbon reductions in an effort to help President Biden fulfil his largely rhetorical 2030 promise.

- The current objective of the climate movement is “net zero” emissions by 2050.

- The technology for carbon capture, utilization and storage (CCUS) does not yet exist, implying that “net zero” must be accomplished entirely by reductions in CO_2 emissions.

- Climate politics are significant primarily in the industrial countries. The developing world “talks the talk” primarily to encourage financial flows from the rich countries.

- None of the pledges made by the developing countries in the various climate agreements has yet been translated into real actions, and nothing in the numbers suggests any trend toward “net zero” emissions.

- An “energy transition” away from fossil fuels may happen, but there is no evidence that it is happening now.

- According to the latest projections by the U.S. Energy Information Administration, the trends evident in the last 25 years are likely to continue. Specifically, the strong growth of CO_2 emissions in the developing world will probably overshadow any actions taken by the industrial countries. Even if the industrial countries reduced their CO_2 emissions to zero, total global emissions would still increase through 2050.

- The climate debate is not over pathways to “net zero” emissions, but rather about whether to spend large amounts of money in order to achieve modest reductions in the rate of growth in CO_2 emissions.

ENDNOTES

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13. 2020 is the latest year for which full information is available. It should be recognized, however, that economic activity, energy use and CO_2 emissions declined dramatically in this pandemic year before recovering somewhat in 2021.

14. A Btu, or British Thermal Unit, is the is the quantity of heat required to raise the temperature of one pound of liquid water by 1 degree Fahrenheit at 39 degrees Fahrenheit, the temperature at which water has its greatest density.

15. Carbon emissions will be presented in metric tonnes, using “t” for tonnes, “Mt” for million tonnes and “Gt” for billion tonnes.

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18. Source: https://www.statista.com/statistics/276480/world-carbon-dioxide-emissions-by-sector/

19. Abbreviations used in this article are as follows: kW (one thousand Watts), MW (one million Watts), GW (one billion Watts), TW (one trillion Watts). Similarly, kWh (1,000 Watt-hours), etc.

20. Source: Energy Information Administration at https://www.eia.gov/analysis/studies/electricity/batterystorage/ and https://www.eia.gov/electricity/annual/html/epa_04_03.html

21. Hydroelectric power can be dispatched over days or weeks, but annual availability depends on precipitation. For purposes of this analysis, hydropower will be treated as neither dispatchable nor intermittent.

22. For a more complete discussion of the Texas experience, see Gregg Goodnight, "The Feb '21 ERCOT Grid Failure and Lessons" at https://iogcc.ok.gov/sites/g/files/gmc836/f/documents/2021/po_-_iogcc_santa_fe_gregg_goodnight_final.pdf

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25. Buck, Alice: "A History of the Energy Research and Development Administration" March, 1982 at https://www.energy.gov/sites/prod/files/ERDA%20History.pdf

26. Load factor refers to the amount of time the generating plant is operating at full capacity. A 1 MW plant operating at 100% capacity would produce 24 X 365 = 8,760 MWhs each year.

27. U.S. Energy Information Administration, "Levelized Cost of New Generation Resources in The Annual Energy Outlook, 2021, Table 1, p. 8."

28. Source: The Planetary Society at https://www.planetary.org/space-policy/cost-of-apollo

29. See, for example Figure 5 on page xx of the Executive Summary of The Stern Review: The Economics of Climate Change at http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf

30. Inflation and interest rates are highly uncertain at this time. The conservative estimates used here are intended to avoid a bias against renewables and other capital-intensive technologies.

31. When the U.S. Department of Energy (DOE) was established in 1977, Congress saw the need for a truly independent statistical and analytical organization that could study global energy issues without political influence. The result was the Energy Information Administration (EIA), established within the DOE but with an unusual level of independence. The Department of Energy (DOE) Organization Act (P.L. 95-91, 42 USC 7135) states, "The Administrator shall not be required to obtain the approval of any other officer or employee of the Department in connection with the collection or analysis of any information; nor shall the Administrator be required, prior to publication, to obtain the approval of any other officer or employee of the United States with respect to the substance of any statistical or forecasting technical reports which he has prepared in accordance with law."

32. Source: Urban Institute, Housing Supply Chartbook, January, 2020.

33. Source: Energy Information Administration, 2021 Annual Energy Outlook assumptions at https://www.eia.gov/outlooks/aeo/assumptions/pdf/renewable.pdf

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36. National Renewable Energy Laboratory at https://www.nrel.gov/docs/fy21osti/79236.pdf

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76. Source: Forbes at https://www.forbes.com/sites/neilwinton/2019/04/04/eu-fuel-economy-rule-violations-could-cost-manufacturers-big/?sh=45dc8a8f7892

77. The Euro-to-dollar exchange rate as of this writing was 1.1.

78. Euronews at https://www.euronews.com/next/2021/12/14/germany-to-boost-electric-car-sales-by-extending-9-000-help-to-buy-subsidies

79. The pound-to-dollar exchange rate as of this writing was 1.3.

80. Source: Automotive News, Europe at https://europe.autonews.com/automakers/france-extends-ev-incentives-until-july-2022

81. Source: Forbes at https://www.forbes.com/sites/michaeltaylor/2021/10/18/france-to-throw-4-billion-to-regain-europes-ev-leadership-boostjobs/?sh=3eb383c963a2

82. Source: https://www.globalpetrolprices.com/gasoline_prices/

83. Source: https://www.oecd-ilibrary.org/environment/the-norwegian-co2-differentiated-motor-vehicle-registration-tax_ee108c96-en;jsessionid=R0Z49qaTltjEwUnWdYcqupSctLHXO27zcqBw0x-y.ip-10-240-5-23

84. Source: Reuters, January 5, 2022 at https://www.reuters.com/business/autos-transportation/electric-cars-take-two-thirds-norway-car-market-led-by-tesla-2022-01-03/

85. Source: International Energy Agency at https://www.iea.org/articles/global-ev-data-explorer

86. The yen-to-dollar exchange rate as of this writing was 0.0082.

87. Source: InsideEVs at https://insideevs.com/news/557284/china-plugin-car-sales-november2021/

88. Source: Bankrate at https://www.bankrate.com/insurance/car/average-car-weight/

89. Source: Car and Driver at https://www.caranddriver.com/news/a38748092/new-car-average-sale-prices-47100/

90. Complete data on diesel consumption are unavailable, since data sets combine diesel, home heating oil and industrial fuel oil, all of which are the same product used in different ways. Because of tax advantages, diesel passenger cars became popular in Europe for many years, but environmental concerns have led to decreased government incentives and a sharply declining market share for diesel passenger cars since 2015. At present, according to Statista, diesel cars represent only about 14% of passenger cars worldwide. Gasoline demand is therefore a reasonable proxy for passenger car use.

91. Commercial use only.

92. Source: https://www.forbes.com/sites/michaelgoldstein/2021/09/23/can-oil-industry-giants-like-shell-provide-sustainable-jet-fuel-by-2025/?sh=217ee96b3e00

93. Source: World Bank at https://data.worldbank.org/indicator/IS.RRS.PASG.KM?locations=EU

94. Acela makes 6 stops between Boston and New York and 6 stops between New York and Washington.

95. Source: “Amtrak’s $66 billion ticket”, August 6, 2021, Wall Street Journal at https://www.wsj.com/articles/amtrak-66-billion-dollar-ticket-senate-infrastructure-bill-joe-biden-11628181115?mod=article_inline

96. Source: Associated Press at https://apnews.com/article/business-california-san-francisco-4af722f953e89fa1d775f50aa891e620

97. Source: https://www.railway-technology.com/projects/california/

98. Includes all flights from LAX, Long Beach, John Wayne and Burbank airports to SFO, Oakland and San Jose.

99. Source: The Verge at https://www.theverge.com/c/22749305/public-transportation-covid-climate-buses-future

100. New York-New Jersey, San Francisco, Chicago, Washington, DC, Boston, Atlanta, Philadelphia, Los Angeles, Miami, Cleveland, Baltimore and San Juan.

101. Source: Wikipedia at https://en.wikipedia.org/wiki/List_of_metro_systems#List_by_country

102. All GDP numbers are in $2021 at purchasing power parity.

103. Source: https://www.eia.gov/outlooks/ieo/pdf/IEO2021_CaseDescriptions.pdf

104. Source: https://www.eia.gov/outlooks/ieo/pdf/IEO2021_Climate.pdf

105. International Energy Agency, “CCUS in Clean Energy Transitions, September, 2020 at https://www.iea.org/reports/ccus-in-clean-energy-transitions

106. Can be found on the Table listing at https://www.eia.gov/outlooks/ieo/tables_side_xls.php

107. Since plug-ins are assumed to drive half their miles on grid electricity and half on gasoline, each plug-in is counted as half an EV.

108. Counting each EV as one and each plug-in hybrid as half an EV.

109. All quotes in this section come from the White House, Fact Sheet: The Bipartisan Infrastructure Bill, at https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/06/fact-sheet-the-bipartisan-infrastructure-deal/

110. EIA, Annual Energy Outlook, 2021, Table 7 which you can see from the list at https://www.eia.gov/outlooks/aeo/tables_ref.php

111. Source: US DOE at https://www.energy.gov/eere/vehicles/articles/fotw-1042-august-13-2018-2017-nearly-60-all-vehicle-trips-were-less-six-miles

112. Source: https://www.democrats.senate.gov/imo/media/doc/summary_of_the_energy_security_and_climate_change_investments_in_the_inflation_reduction_act_of_2022.pdf

113. Source: https://www.natlawreview.com/article/inflation-reduction-act-includes-expansive-tax-incentives-clean-energy-investors-and

114. Source: Reuters at https://www.reuters.com/business/autos-transportation/us-auto-trade-group-warns-ev-tax-proposal-would-make-70-ineligible-2022-08-05/

115. Source: https://www.democrats.senate.gov/imo/media/doc/inflation_reduction_act_one_page_summary.pdf

116. Source: NPR, https://www.npr.org/2022/07/29/1114216967/climate-experts-experience-an-odd-sensation-after-the-manchin-budget-deal-optimi

117. Can be found at https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html