The Global Energy Transition: Where Do We Go From Here?

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Anticipated Changes in World Energy

By 2040, the world is projected to consume 24 percent more energy than today, with developing countries surpassing the industrialized world as the largest group of energy consumers. Fossil fuels, including oil, coal, and gas, will remain the dominant sources of energy, accounting for about 45 percent of the projected increase in energy demand according to the Stated Policies Scenario of the International Energy Agency (IEA) of Paris (2019). Owing to its relative abundance, ease of transport, and relatively low carbon footprint, natural gas will be the fastest-growing fossil fuel, estimated to increase in volume about 36 percent over the 2018-2040 projection period. Oil consumption will also continue to rise, with much of the increase in demand geared to the transport sector. Much of that growth will be for diesel fuel use in developing countries, essential for the poorest people in Africa and Southeast Asia to increase their standard of living via transport and trade. Renewable energy will increasingly contribute to electricity generation, and remain the fastest growing source of electricity supply.

Key Realities

A transition toward cleaner energy is underway, led by Europe and other signatories of the 2015 Paris Climate Accord and its implementation package, which promote significant reductions in CO_2 emissions. Renewables, increasing efficiency, electrification of end-use demand including electric vehicles (EVs) are driving the energy transition. The world is in an extraordinary period right now as renewable energy prices have dropped significantly since 2000, and use of wind and solar power has skyrocketed in many countries. And slowly but surely the world energy mix is changing.

In China, massive renewables growth is strategically important for the country as its economically recoverable coal to production (R/P) ratio is peaking and will begin to decline soon. The U.S., while seeking to be out of the Accord, does deploy some of the most energy efficient and advanced energy technologies in the world that can help countries slow their growth in energy consumption and carbon emissions, including, for example, waste-to-energy plants, super-efficient gas turbine power plants, liquefied natural gas floating storage and regasification units, and small modular nuclear reactors.

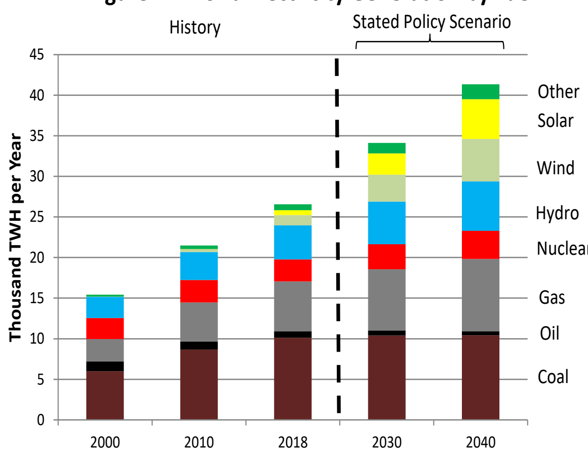
The global energy industry is one of the largest in the world, millions and millions of jobs are tied to energy extraction, production, processing, transportation, and use. Given the size and importance of the industry to the global economy, there are numerous players from the private sector, public sector, and academia that study and evaluate trends, but some of their results can be biased or misleading. We, therefore, describe key realities here as we see them, which we hope will prompt further dialogue and debate.

Future Mix of Fuels for Electricity Generation Will Be Vital

During the next two decades, the mix of fuels used for electricity generation will arguably be the most important variable in the world energy landscape. Developing countries will increasingly rely on renewables, natural gas, and possibly nuclear power rather than coal as the primary electricity generation fuel to meet this growing need during the next two decades, based on market and technology trends and international carbon emissions agreements that include these countries. India, for example, plans to rapidly boost its use of solar and wind to slow or reverse the growth of coal-fired generation as part of efforts to curb local pollution and carbon emissions (International Energy Agency, 2016; Gilblom et. al, 2018; and Krishner, 2019).

The International Energy Agency projects that world electricity generation will diversify and shift toward lower carbon sources by 2040, with renewables—wind, solar, geothermal, biofuels, and hydropower—

Figure 1: World Electricity Generation by Fuel



*Other includes biofuels, geothermal and marine
Source: International Energy Agency, World Energy Outlook 2019 and 2018.

probably overtaking coal in power output just after 2025 (International Energy Agency, 2019). Probably the greatest uncertainty in the future fuel choice for world electricity generation is the role that nuclear power will play, as many countries are now or soon will be facing a decision on what to do with an aging fleet. Figure 1 shows that the IEA expects that the output of nuclear will increase only slightly between today and 2040, as older nuclear power plants are retired and newly-built plants barely compensate.

Non-electricity uses for Renewables Remain Limited

Electricity accounts for only about 20 percent of the world's final energy use, so even if the world could fully decarbonize global power production, that only covers 20 percent of the problem and we still have 80 percent of energy use with few or no alternatives (Heinberg and Fridley, 2016). The other 80 percent of world final energy consumption includes, for example, aviation, shipping, steel and cement production, and plastics manufacturing—all economic activities that also need to be decarbonized if the world is going to meet ambitious carbon reduction targets. The optimal ways to begin decarbonizing these non-electricity sectors would be through efficiency improvements, and by increasing electrification of the various processes, where possible. How far this can go is uncertain.

We're Facing A Shift in Reliance from Oil and Gas to Metals and Minerals

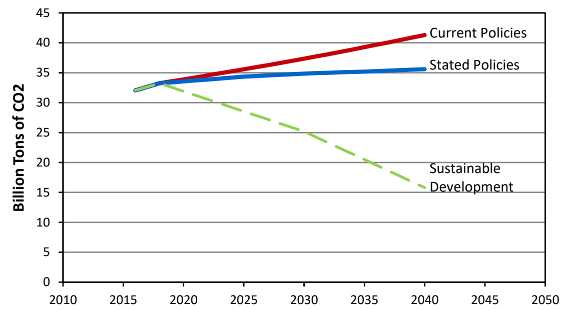
As the global energy transition proceeds over the next two decades, there will effectively be a gradual shift toward and increased reliance on metals and minerals in order to reduce reliance on fossil fuels, for example, the manufacturing and use of solar panels, windmills, and the associated transmission lines and battery storage. Arguably, the metals and minerals requirements for these new advanced energy technologies are a bigger problem than their current costs reflect. The World Bank recently assessed the metal and minerals requirement of a low-carbon world and found that compared to current extraction rates, future demand would soar to levels probably not possible with known reserves, and entail a huge amount of ecological destruction (not to mention the fossil energy required to extract and process all these ores) (World Bank, 2017).

Take copper for example. China uses, on average, about 45 tonnes of copper per MW of installed capacity (including the power plant and all associated cabling, transmission and distribution), and this will rise as solar and wind expands since they are 3-6 times more copper intensive than conventional power plants (and offshore wind the most copper intensive of all). Some studies projecting a total buildout of renewables in China to 15,000 GW by 2050 would thus require about 750 million tonnes of copper (compared to current world extraction of 19 million tonnes a year today). And this is just for China, not even taking into account that the amount of energy consumed per kg of copper produced has quadrupled in the last 8 years and the amount of water used the same, as the average ore concentration drops. Then we have nickel, cobalt, lithium, neodymium, along with a series of others that are all crucial to the manufacturing of renewable technologies

Why Even Discuss the 1.5 C Option?

The world energy economy is still largely carbon-based, with oil, gas, and coal accounting for about 81 percent of global primary energy consumption, and the majority of man-made greenhouse gas emissions. Every November the International Energy Agency (IEA) releases its annual *World Energy Outlook (WEO)*, projecting three scenarios for energy use and fossil fuel CO_2 emissions. The scenarios are the Current Policies Scenario; the Stated Policies Scenario, which includes policies enacted but not yet implemented; and the Sustainable Development Scenario, which reduces fossil carbon emissions to limit warming to about 1.5 to 1.65 C (see Figure 2). But is the 1.5 C scenario even remotely achievable, and if not, why still talk about it?

Figure 2: Scenarios for Fossil CO2 Emissions



Source: International Energy Agency, World Energy Outlook 2019.

At the November 2019 release of the *World Energy Outlook,* the head of the IEA observed that the Stated Policies Scenario falls far short of the Sustainable Development Scenario, and he exhorted governments to do more. The 1.5 C pathway is extremely difficult to achieve. We highlight some of the challenges here by examining the issue on a sectoral basis, and by examining the growing divergence in energy intensity between developed and developing economies.

The Power Sector

Currently the power sector accounts for 42 percent of world fossil carbon emissions. Within the power sector coal-fired power plants account for 73 percent of emissions and generate 38 percent of world electricity. Emissions from coal-fired power plants must therefore be sharply reduced to reach the Sustainable Development path.

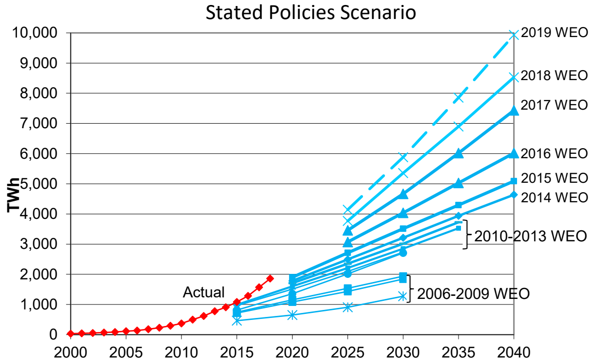
One proposal for reducing carbon emissions from coal-fired power plants is to capture and use or store some of the CO_2 through a technology called carbon capture utilization and storage (CCUS). This technology requires equipment to capture carbon at the plant, pipelines to transport the captured gas, and underground reservoirs into which high pressure CO_2 can be pumped. Progress on CCUS has been slow. Although there is some potential for using CCUS in enhanced oil recovery, in the absence of a high carbon price penalty, few utilities want to incur the extra costs and suffer the reduction in plant efficiency that goes with CCUS. There is also public concern about leakage, based on the toxicity of concentrated CO_2. Given its poor track record, counting on CCUS to contribute significantly to reaching the Sustainable Development pathway is a risky bet. The anticipated contribution of CCUS continues to drop in the WEO projections.

Nuclear power is nearly carbon free but has been losing momentum in recent years, because of very high development costs, cost overruns and fear of accidents. These and other factors have halted most construction in OECD countries. From a climate perspective, early retirement in some OECD countries will reduce generation at a time when carbon free sources are most needed. Developing Asia has seen the largest growth in nuclear generation, but even there the enthusiasm is waning, such as in China and India. The Stated Policies Scenario projections for nuclear generation in 2040 have declined from 4,600 TWh in the 2014 WEO to 3,500 TWh in the 2019 WEO. Although nuclear advocates hope that new designs will calm public fears and reduce costs leading to a resurgence of nuclear, as with CCUS, we cannot count on it.

The best news from the power sector is that the capital cost of solar and wind have declined to the point where they are competitive with fossil fuels in a number of regions, thus spurring rapid expansion of their capacity and generation. Figure 3 shows a series of forecasts of wind plus solar photovoltaics (solar PV) by the *World Energy Outlook* from 2006 through

Figure 3: Wind + Solar PV Electric Forecasts, World

Stated Policies Scenario



Source: International Energy Agency, World Energy Outlook, 2006 through 2019.

2019. Actual generation (in TWh) is shown in red on the left. The upward fan of blue lines shows successive revisions of the WEO electricity generation forecast in the Stated Policies Scenario through time. Clearly these renewable technologies are making inroads to generation faster than the modelers at the IEA can keep up. In the Stated Policies Scenario wind plus solar PV are now projected to provide 24 percent of world electricity generation in 2040, up from 7 percent today.

Complications arise as the penetration of solar and wind grow. One concerns system reliability as large amounts of power must be provided by backup sources on short notice as the sun goes down and the wind falters. This requires careful weather forecasting, the ability to ramp up fossil generation, other renewables, or electricity from battery storage, and the transmission capacity to wheel massive amounts of power where needed. Another complication arises when the capacity of solar and wind grow large enough to compete with one another on a windy, sunny day. This degrades the economics of both. There is also the question of public willingness to tolerate large tracts of land devoted to windmills, solar farms, and power lines.

Despite the good news on solar and wind we cannot run a power grid solely on them and it remains to be seen how far they can penetrate and how fast. The record of WEO projections shows the difficulty of forecasting renewable electricity generation. So far the revisions have all been upward but it is possible for the IEA to overreach. The state of California now has about the same penetration of solar and wind as projected for the entire world in 2040. California can do this is by wheeling power from fossil plants in neighboring states. However it is not clear that the rest of the world can replicate this.

The IEA has expressed some angst over the existence of a large number of relatively new coal-fired power plants, suggesting that these may emit carbon dioxide decades into the future. Coal-fired plants are now sometimes used in load-following mode, which reduces the time they run. If at some point natural gas plants or batteries become a less expensive source of backup power than coal plants, then coal plants will be closed for economic reasons regardless of whether they are still within their design lifetimes. (Similarly, perfectly good buggy-whip factories were probably closed with the advent of the automobile.) Unfortunately, indigenous coal is quite cheap in China and India, and coal mining bolsters employment, which suggests that the decline of coal will be long and slow in that region.

Battery backup for electric utilities is a complicated subject because there are different time-frames for battery storage. Batteries are already cost effective in some seconds-long applications for power conditioning. Batteries are not generally economic for day-long electricity storage or longer. There is much optimism on cost reductions for batteries but still lots of uncertainty on how low the prices will fall, and whether large-scale production might increase the price of critical metals.

Adding other renewables (hydro, geothermal, biofuels) to wind and solar, the share of renewable electric generation is projected to reach 44 percent by 2040 in the Stated Policies Scenario. If we include nuclear power, then non-fossil generation is projected to reach 52 percent by 2040. Despite the rapid projected progress of non-fossil generation, this still falls far short of the Sustainable Development pathway. Why is the Sustainable Development pathway so difficult to achieve in electric generation? In brief there is a great deal of embedded capital, it takes a long time to replace, and some parts of the world still have strong cost and employment incentives to continue with fossil generation.

Transportation

Currently the transportation sector accounts for about 24 percent of world fossil CO2 emissions. Economic and population growth, particularly in developing countries, translates into significantly higher future demand for transportation. More than 1 billion cars and trucks are on the road today and that number will increase to over 2 billion by 2040. Higher efficiency of gasoline and diesel powered vehicles, while useful, cannot satisfy the carbon goals set forth in the Sustainable Development Scenario.

Although EVs have made significant technical progress in the past decades and are beginning to penetrate the market, a variety of drawbacks limit their potential growth and their ability to reduce carbon emissions. Drawbacks include limited range, poor cold weather performance, long charging times, small size, the need for hundreds of millions of charging stations, availability of key metals for large scale implementation and the fuel sources for nighttime charging.

The driving range of EVs has increased substantially since General Motors first rolled out its EV1 in 1996 with an advertised range of 70 to 100 miles. The 2019 Chevrolet Bolt has an advertised driving range of 238 miles, while the Tesla model S gives a range of 370 miles. These ranges are for ideal driving conditions—the range can drop as much as 40 percent in the coldest weather according to AAA (2019). However, even when facing less favorable driving conditions they are still long enough for most round trip commutes. This opens up a substantial market as a commuter vehicle, provided that home or workplace charging is available.

The fuel source for electricity is a key issue for EVs. If the millions of Chinese EVs are charged using coal-fired electricity then the CO_2 emissions may be higher than those from an efficient gasoline-based vehicle, for example one with 35 mpg fuel economy. When vehicles are charged at night the absence of solar means a greater chance of the fuel source for electricity being carbon-based. The real push for EVs should probably wait until after the world moves toward cleaner electricity sources.

Biofuels have been used as a supplement to gasoline and diesel for years. In a low carbon world they could serve as fuels for niche applications, such as long distance trucking, but have a large land footprint and so cannot be scaled up significantly without competing against food. They also have a poor energy balance and very high costs.

Air travel and shipping have unique needs. Although low carbon advances are possible they are probably decades away.

The bottom line for transportation is that the lag times needed for further technology development, tooling up for production, and replacement of the existing global vehicle fleet is in the order of a few decades – too slow to meet the Sustainable Development pathway.

Industry

Many industrial processes use fossil fuels as either a feedstock (as in plastics) or a heat source (as in cement manufacturing). Biological feedstocks are being researched but few are economic at this point.

Industrial heat demands can be lessened by improving equipment and process efficiency. Sometimes a different process can be used to achieve the same end, as in freeze drying to reduce moisture instead of heating. In this example the fuel switches from natural gas to electricity, which can hopefully be powered by cleaner sources. Many industrial processes run 24 hours per day, meaning that even if powered by electricity there is the issue of what is used to generate the electricity, especially at night.

Although industry has been improving its efficiency for decades, it is not clear that carbon emissions can be reduced as far and as fast as required by the Sustainable Development pathway. The embedded capital stock of industrial plants is enormous, and takes time to change.

Residential and Commercial

Although super-insulation for buildings has been technically feasible for decades, governments have been timid in revamping building codes accordingly. Super-insulation is one of the least expensive ways to reduce CO_2 emissions. Such insulation reduces heating and cooling demands 24 hours per day so reduces the need for electricity generation, transmission and storage.

In many parts of the United States however tradesmen have little understanding on how to build double-wall construction and home builders refuse to oversee such a requirement, even if requested by the buyer, given the expense of minutely supervising the tradesmen. Building codes could force the issue, but local jurisdictions have little incentive to change them. Building codes are much stricter in some European countries, such as Denmark.

Combining super-insulation with on-site generation (primarily solar) and effective passive solar design can lead to homes that are close to net zero energy. Retrofitting existing buildings to achieve net zero energy performance is much more expensive than building new.

In developed countries the enormous installed stock of buildings along with the expense of retrofitting to higher standards means it will take decades of building stock turnover to reach the full potential of carbon emissions reductions.

The developing world has a unique opportunity to sharply reduce building energy use as new buildings are constructed. Will this happen, or will future buildings in the tropics compensate for poor insulation with larger air conditioners?

Developed versus Developing Economies

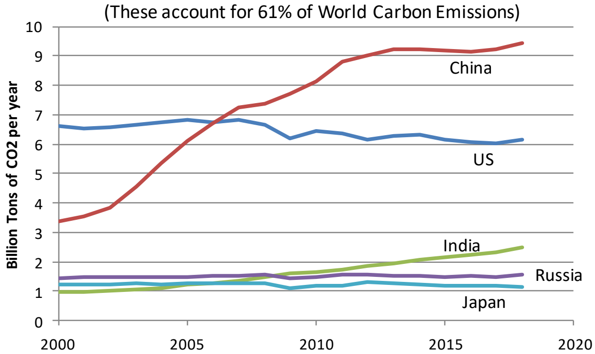
The developed economies have more economic resources than the developing countries, but face an enormous embedded capital stock of electric generation, factories, homes and fleets of vehicles. To reach the Sustainable Development path put forward by the IEA, this embedded stock must be retrofitted or prematurely scrapped--waiting for natural turnover takes too long.

The developing economies have less capital stock so they have an opportunity to install the best sources of electric generation, the most efficient factories, homes, and vehicles at lower cost than retrofitting. Unfortunately these countries have fewer economic resources and there are typically fewer economic incentives to grow on a low carbon path.

Figure 4 shows the top five CO_2 emitting countries in the world, accounting for 61 percent of global emissions. China tops the list and its emissions are still growing. Indian emissions are also growing,

Figure 4: The Top Five CO2 Emitters

(These account for 61% of World Carbon Emissions)



Source: BP Statistical Review of World Energy, June 2019

although from a smaller base. This growth is typical of developing countries. In contrast, the U.S., Japan and Russia show slowly declining or level emissions. In order to transition from the Stated Policies CO_2 path to the Sustainable Development path, the emissions from developing countries would have to start declining very soon. This would need to happen without sacrificing economic growth.

So Where Do We Go From Here?

So where do we go from here? How much further can renewables be pushed? What economic, technical, political, and environmental challenges lie ahead?

Several questions have to be addressed regarding the future of the world energy transition:

- Have renewables now reached a critical inflection point, where their use will accelerate even further in the future, as called for by the International Renewable Energy Agency (2019). Or, will penetration growth rates slow down, as predicted by the Oxford Institute of Energy Studies (2019).
- Are there applications where renewables cannot or should not fully replace fossil fuels or nuclear power? For example, plastics manufacturing, marine transportation, aviation, iron and steel manufacturing, and food production? What about the applicability of renewables in mega cities where 10 million persons or more reside? And what about the use of renewables in military theaters where reliable and consistent energy supplies often means saving lives?
- And finally, can the world thrive on 100 percent reliance on renewables, or 90 percent, or 80 percent, or 70 percent, as is being proposed in many countries, regions, and localities, and at what cost? And with what land requirements?

Here's What We Know

Here is what we know: how far and at what speed the global energy transition will evolve will likely depend on three extremely critical factors: renewable energy penetration rates; EV penetration rates, and energy efficiency gains in industry, transportation, and buildings.

Renewable energy penetration rates

Deployment of renewable energy, in particular solar power, continues to grow faster than industry analysts assess, driven by sharp cost reductions and policy support, such as subsidies and tax credits. This growth in renewable energy use has prompted the International Energy Agency and other energy-forecasting bodies to revise their long-term projections upward each year since 2006, as was highlighted in Figure 3. This graphic demonstrated how fast the uptake in the use of renewables has been over the past decade, far exceeding projections from leading analysts. Nevertheless, as was highlighted in Figure 1, renewables penetration in world electricity generation is less than 30 percent today and is projected to still be slightly less than 50 percent of total generation in 2040.

EV penetration rates

The expected growth in oil consumption for transport use in coming decades could be slowed with the further penetration of advanced transportation technologies, including pure EVs, gasoline-powered electric hybrids such as the Toyota Prius and advanced diesel engines, though governments worldwide will need to take unprecedented policy actions to promote their use. Ultimately clean diesel-powered hybrids may offer even greater fuel efficiency and reduced carbon emissions, as such, we argue that more research and development should focus on heavy duty diesel hybrids and not heavy duty long haul EVs. Longer term, hydrogen fuel cell vehicles including trucks will offer long-distance driving ranges, an ability to carry heavy loads, and a very flexible fuel source. The overall emissions of both hydrogen fuel cell vehicles and EVs can vary greatly, depending on the original energy source used to make the hydrogen and electricity.

The lack of sufficient charging infrastructure for all-EVs is currently an upper bound on just how fast such cars can penetrate world markets. Other challenges include continued efficiency improvements in conventional petroleum-based vehicles, long EV charging times, and EV range anxiety.

Critically, most of the world's population reside in cities or urban areas, largely in apartment dwellings, implying that charging stations would need to accommodate this population category. Any judgment about future EV penetration rates should be based largely on the ability for apartment dwellers to recharge their car batteries. Homeowners with garages are a much smaller segment. We believe that until apartment dwellers are able to charge their EVs either near their residence or at work, there will be an upper limit on EV sales worldwide. With the major source of worldwide electricity generation still from fossil fuels, EVs can have higher overall emissions than high efficiency petroleum-based vehicles.

Energy efficiency gains

Energy efficiency encompasses all changes that result in lower energy use for a given energy service (for example, heating, cooling, and lighting) or level of activity. This reduction in energy consumption can be related to technical changes—such as improving insulation effectiveness for walls and windows—or better practices, management, and organization. Reduction of energy use for specific services or activities can be achieved by various means including energy efficiency improvements, demand-side management, and performance contracting.

The most effective energy efficiency programs—such as in Japan—typically involve a combination of approaches, including mandatory measures and regulations, tax and fiscal incentives, and public education. A worldwide ramp-up in energy efficiency improvements is technically possible if financial barriers—including risk exposure and the inadequacy of traditional financial mechanisms for energy efficient projects—are eased and consumer apathy reduced. Other potential barriers include lack of enforcement of building codes and standards and regulatory biases.

The biggest potential for reducing CO_2 emissions is through energy efficiency improvements in industrial, residential, and commercial applications, as well as in transportation. In its outlook for energy to 2040, ExxonMobil (2019) concludes that global energy demand will grow by only about 20 percent from 2017 to 2040 because of continued energy efficiency improvements that will result in large energy savings and a slowdown in growth of carbon emissions. Global energy demand would soar significantly higher—closer to a 100 percent increase by 2040—without the anticipated efficiency gains across the global economy, according to ExxonMobil (2019). Moreover, by 2040, the combined effects of lower energy intensity and less carbon-intensive energy sources could result in a nearly 45 percent reduction in the carbon intensity of the worldwide economy (ExxonMobil, 2019). As such, investments to boost energy efficiencies are likely to increase over the next two decades to help offset the need for new energy production and reduce emissions.

Still, There Are Great Uncertainties

--EV penetration rates:

As discussed previously, the lack of sufficient charging infrastructure for EVs is an upper bound on just how fast such cars can penetrate world markets. Another challenge is the source of the electricity that those EVs use for charging. EVs in China for many years will have significantly higher overall emissions than an equivalent gasoline hybrid electric vehicle due to the use of mostly coal-based electricity. The advantage of EVs for China today is they provide a means of shifting air pollution out of the cities (while regrettably increasing CO_2 emissions).

--Will there be 'clean' coal:

Many recently built European coal-fired power stations are dubbed carbon capture utilization and storage, or CCUS, capable, implying that when CCUS technology becomes economically viable, the stations can add the equipment to reduce or eliminate the carbon emissions. While no immediate breakthroughs with CCUS technology are expected, should the technology become viable and widely available, it could favor continued coal development in the developing world, where electricity needs are projected to continue rising at a robust pace through 2040. However, CCUS is very site specific and will be limited to areas with large nearby safe deep underground CO_2 sequestration. Moreover, adding CCUS to an existing plant would significantly reduce the net power plant capacity and efficiency—by as much as 1/3 if fuel rates are constant—while adding substantially to net unit capital costs.

While carbon trading is intended to help signatories move towards their CO_2 reduction targets, in the end, their ambitious targets will probably only be achieved through a major curtailment of use of coal, a continued ramp-up of renewables, some reliance on nuclear power, and major efficiency and conservation gains.

--Nuclear power phaseout?

There are 443 operating nuclear power plants in the world, accounting for about 10.3 percent of world electricity consumption (World Nuclear Association, December 2019). France relies on nuclear energy for the greatest share of its electricity output, about 72 percent, although the government plans to reduce that reliance to about half of the country's electricity mix by 2025. The United States has the largest nuclear power plant fleet—96 operating units—whereas China has the most plants now under construction, at 12. Importantly, as many as half of the world's existing nuclear power plants are expected to end their life cycles over the next 15 years, and numerous countries such as the UK will have to decide what to do with their nuclear power industries—extend the lives of the existing plants, replace the plants with other energy sources such as natural gas and renewables, or build new nuclear power plants using state of the art designs. Retiring nuclear plants face high decommissioning costs as well as long-term storage challenges for highly radioactive components and spent fuel.

Clearly, it should be recognized that any large-scale global retreat from nuclear power will almost certainly make global climate change goals more difficult to achieve, which rely on accelerated use of low-carbon energy technologies by 2030. Nuclear power is one of a few nearly carbon free sources of energy, as extracting uranium, processing it into nuclear fuel, and constructing plants release only a modest amount of emissions. Countries such as Brazil, France, Sweden, and Switzerland, along with regions such as Ontario, have decarbonized their electricity supplies by using nuclear power with other low carbon sources. Yet, in many countries nuclear power is not officially linked in with clean energy initiatives, or even ignored entirely.

--Confronting cyber threats to grids:

As the world becomes increasingly electrified including a rapid push toward EVs and charging stations, cyber threats will become more widespread and commonplace. Greater digitalization of renewables-based electricity grids, including the "smart" grid, will certainly increase cyber threats and raise prospects for remote hacking and disruption from adversary sources. How will governments and country leaders respond? Will protection technologies and software be able to keep pace with increased cyber threats?

--How far can solar and wind really be pushed?:

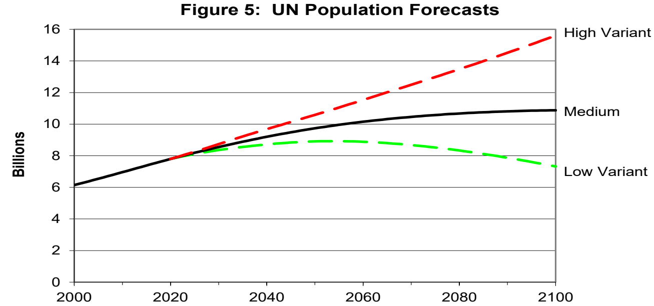
Relatively low capacity factors for wind and solar power imply that large land areas will be required to generate large volumes of electricity and compete with baseload generation provided by fossil fuels and nuclear power. For example, we calculate that to replace the electricity generated by a 1-gigawatt nuclear power plant running at 80 percent capacity factor would require over 1,000 3-megawatt windmills with a 25 percent capacity factor. Such wind capacity would require over 2,000 acres of land. As more and more large-scale wind farms and solar arrays are contemplated, it is possible that communities will begin pushing back, as they already are in parts of the United States and Europe.

Land requirements matter not only in terms of acreage needed, but also in terms of opportunity costs. In Culpeper, Virginia, for example, there is a proposal to cut down more than 800 acres of forested land, to build a "solar power farm" of 270,000 solar panels, to produce 80 MW of electricity. (For perspective, in nearby Chesterfield, Virginia, there is a coal-fired power plant that generates 1640 MW.) In Spotsylvania, Virginia, there is a second proposal to cut down 6,500 acres, to locate 1.8 million solar panels, producing up to 500 MW. Nearby communities are pushing back, and asking if clear cutting makes sense from an environmental perspective. We ask whether such projects would be economically viable without the tax credits, subsidies, and mandated renewable portfolio standards, and why wouldn't such large solar arrays be more appropriate in desert climates or other open space environments?

With wind, we believe that over the long term the most probable areas for large scale deployment will be offshore, which can take advantage of generally advantageous wind regimes and not necessarily become an eyesore. Offshore wind unit capital costs are much higher compared to onshore facilities, but have higher annual load factors to help cover the higher capital costs.

We're Downplaying Other Potential

Figure 5: UN Population Forecasts



Source: United Nations, World Population Prospects 2019.

Solutions for Global Warming

Most solutions being discussed by energy and climate advocates are supply-oriented, that is, how do we produce and use more renewable energy? Other possible solutions that are mentioned only briefly, if at all, include slowing population growth rates, further boosting energy efficiencies, and assessing geoengineering opportunities.

Current population forecasts call for an increase from 7.7 billion people today to about 10.9 billion people in 2100 despite gradual reduction in the population growth rate (United Nations, 2019). Speeding up the reduction in population growth rate by even a small amount can greatly reduce the 2100 population, as demonstrated in Figure 5. This can probably be achieved non-coercively through improved education and empowering women in developing countries according to some demographers (Bongaarts, J. et. al, 2012; Worldwatch Institute, 2012). This is a win-win approach as it helps eradicate poverty while reducing climate pressure associated with population.

Energy efficiency improvements are the least costly and yet most meaningful ways to curb energy consumption growth and, as a result, greenhouse gas emissions. Major efficiency improvements reduce energy use and emissions per unit of GDP thus enabling GDP growth while at the same time reducing fuel, emissions, and costs. Although energy efficiency is referred to in the aggressively in some sectors in some scenarios.

Solar geoengineering is deemphasized by some in the climate community for fear that it could have unintended consequences. However, some of the geoengineering ideas are inexpensive and relatively easily reversible, which means we can experiment with them with minimal cost or risk. If the costs of climate change are high, why are we not experimenting more with geoengineering to at least bridge the time gap needed to fully implement renewables, efficiency changes and other measures? Current funding for solar geoengineering is very small.

Conclusions

The world is currently in a transitional, and sometimes turbulent, period for energy. Although renewables and other new technologies promise far lower carbon emissions in electricity generation and transportation, there are major uncertainties and challenges in how far the world can push and how quickly. Climate scientists have warned repeatedly that time is of the essence. Yet the amount of capital needed to replace existing carbon intensive technologies is enormous, while at the same time the world economy and population are growing, requiring more and more energy services.

The 1.5C to 1.65C Sustainable Development pathway proposed in the *World Energy Outlook* is quite impractical, as was shown in Figure 2 and discussed at length. However, despite the large gap between the desired trajectory and the Stated Policies Scenario, energy analysts and governments cling to the notion that the aggressive pathway is within reach simply with greater efforts. We argue that the energy community is too narrowly focused on increasing the supply of renewables and other low-carbon energy sources, rather than also having a serious focus on demand-side management. By broadening the scope of the global energy transition to include options for greater emphasis on efficiency, the use of solar geoengineering and other technological means to reverse carbon levels, and slowing population growth rates, we can greatly increase the chances of averting serious climatic consequences while the new energy economy is being established.

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