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Featured Article

COVID-19: A Cloud with a Silver Lining for Renewable Energy?

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Abstract *COVID-19 has led to an unprecedented reduction in demand for energy for transportation and electricity, a crash in prices and employment in the fossil fuel industries and record-breaking reductions in global carbon emissions. This paper discusses whether this "demand destruction" could spell the beginning of the end for fossil fuels or a temporary recession and the imperative to recover from the current crisis by "building back better" and not the same as before. There are encouraging signs for the renewable energy industry that could make COVID-19 a cloud with a silver lining; whether this is the case will depend not only on the technological realities and social response to the crisis but also on political will and foresight.*

Key words: Carbon emissions, Creative destruction, Renewable energy.

JEL codes: Q21, A28, Q31, Q38.

Introduction

COVID-19, the disease caused by the new coronavirus named SARS-CoV-2, has led to a dramatic slowing down of economic activity around the world. After its presence was first noted by the World Health Organization on December 31, 2019, COVID-19 spread so quickly across the world that on March 11, 2020 it was classified as a global pandemic (WHO 2020). To slowdown the spread of this new coronavirus, governments across the world imposed shelter-at-home policies and forced most businesses to shut down or significantly scale back their operations. Many businesses switched to remote work, with their employees working out of their places of residence. These restrictions varied from country to country and from state to state within a country. Le Quéré et al. (2020) document that sixty-nine countries across the world had imposed some level of confinement measures between January 2020 and May 2020.

Forecasts indicate that the COVID-19 pandemic is expected to lead to a deep global recession with a 5.2% contraction in global GDP in 2020, despite governments spending trillions of dollars to counter its economic impact

(World Bank 2020). The shutdowns have also led to an unprecedented reduction in demand for energy for transportation and electricity; by mid-April energy demand in countries under full lockdown had fallen by 25% compared to average consumption in 2019 (International Energy Agency 2020a). This led to a crash in oil prices which declined by 85% between January 22, 2020 and April 21, 2020; oil futures even went negative briefly in May 2020. Despite a recovery in oil prices since then, they are still 43% lower than the peak in January and expected to remain low for some time due to high levels of inventories, restrictions on business travel imposed by employers, stay-at-home orders and the expected global recession. In the US, consumption of jet fuel and gasoline in 2020 is expected to be between 50% and 30% lower, respectively, compared to 2019 (Gillingham et al., 2020). Major oil companies expect the shock of the pandemic to reverberate for decades and some are writing down their holdings, indicating reduced book value of their assets while many are filing for bankruptcy. Global demand for coal and electricity have also been reduced in the periods with full lockdown but not as severely as demand for oil. In the US, electricity demand in 2020 is expected to be about 2.2% lower than in 2019, with increase in residential electricity demand partially offsetting the reduction in commercial and industrial electricity use (U.S. Department of Energy-Energy Information Administration (DOE-EIA) 2020).The amount of coal used for electricity in the US declined more than other fuels and its share is forecasted to be 20% in 2020 compared to 24% in 2019.

In the US, for the first time, more electricity was generated from renewables than from coal by June 2020 and the share of renewables is expected to increase from 17% in 2019 to 20% in 2020 (DOE-EIA 2020). In the UK, no coal had been burnt in the sixty days prior to June 10, 2020 (the longest period for this to occur since the start of the Industrial Revolution over 200 years ago) (Rowlatt 2020). Despite COVID-19-related bailout efforts by the US government and efforts to roll back environmental regulations, many utilities have announced plans to close several coal-powered generating stations in 2020 (Holden 2020; Niler 2020).

The steep reduction in demand for energy, transportation, and numerous services caused by COVID-19 is leading to the deepest recession experienced globally since the Second World War (World Bank 2020). Recessions such as this can emerge as times of "cleansing" when older, less profitable technologies are replaced by new production units embodying the most advanced technologies. This process has been referred to as "creative destruction" and its potential to be an engine for innovation was noted at least as far back as Schumpeter (1939). Several studies have since documented plausible examples of this effect in explaining the response of industries to cyclical variations in demand (see Caballero and Hammour (1994) and references therein). These studies show that industries accommodate cyclical variations in demand by altering the rate at which production units that embody new technologies are created and the rate at which outdated units are destroyed. The costs of adjustment in the process of creative destruction can slow down the process of technological change and lead to coexistence of production units of different vintages.

Can we expect a process of creative destruction to be induced by COVID-19? Will it spell the beginning of the end for fossil fuels and become an opportunity to increase the share of renewables? Can free market mechanisms lead to a transition from fossil fuels to renewables? What role can government policy play during and after the pandemic to aid this transition?

Since the start of the pandemic, electricity generation from renewable sources has been resilient to the COVID-19 confinement measures imposed

by countries. Global use of renewable energy in all sectors increased by 1.5%, while renewable electricity generation increased by almost 3% in the first quarter of 2020 relative to the same period in 2019 (International Energy Agency 2020b). This was because of new wind and solar photovoltaic projects completed over the past year and because renewables have low marginal costs of operation and are generally dispatched before other sources of electricity. As a result, the share of renewables in electricity demand increased in many regions under lockdown, including parts of Europe and the US.

However, growth in renewable energy capacity is expected to slow down in 2020 despite this resilience in current renewable energy generation. Additions to renewable electricity generation capacity are expected to be 13% lower in 2020 compared to 2019. This decline reflects delays in construction due to supply chain disruptions, lockdown measures, and social distancing guidelines, as well as emerging financing challenges (International Energy Agency 2020a). Beyond electricity, renewables have been less resilient. Reduction in demand for liquid fuels for transportation has lowered demand for biofuels, which are consumed as a blended fuel, and low oil and gas prices have made them less competitive.

The decline in fossil energy consumption since the start of the lockdown measures in response to the pandemic has led to an unprecedented decline in daily global carbon emissions. Le Quéré et al. (2020) estimate that carbon emissions decreased by 17% by early April 2020 compared with mean 2019 levels; about half of these reductions came from reductions in demand for surface transport. Global carbon emissions are expected to decline by 8%, or almost 2.6 gigatons, in 2020 to levels observed ten years ago (Hepburn et al. 2019; International Energy Agency 2020c). This decline is larger in absolute terms than in any other year on record (Le Quéré et al. 2018); annual carbon emissions fell by about 4% during the Second World War (1939–45), 3% during the 1991–92 recession, 1% during the 1980–81 energy crisis, and 1% during the 2009 global financial crisis (Boden, Andres, and Marland 2017).

What will be the long-term impact of this pandemic on carbon emissions, energy consumption, and the mix of fossil and renewable energy? Can we combine efforts for recovery from COVID-19 economic crisis with those to fight against climate change? Are there recovery paths that can address the megascale unemployment problem created by COVID-19 and keep the world on the path to meeting the goals of the Paris Agreement? Is COVID-19 going to halt or even reverse the unprecedented growth in renewable energy deployment globally or is there a silver lining for renewable energy as a path for sustainable economic recovery? What are the near-term social welfare and distributional effects of increasing renewable energy production and their policy implications?

This paper is organized as follows. Section 2 discusses the near-term impact of COVID-19 on the energy sector and carbon emissions. Section 3 discusses the case for strengthening investment in renewable energy to stimulate economic recovery. Section 4 discusses strategies for government investment and policy to stimulate a low carbon recovery. Section 5 concludes.

Near-Term Impact of COVID-19 on the Energy Sector and Carbon Emissions

The need for confinement to control the spread of coronavirus has led to large reductions in economic activity globally and reduced demand for

energy. Le Quéré et al. (2020) estimate that by early April 2020 the global aviation sector had the steepest decline with a 75% decrease in daily activity, followed by surface transport with a decline of 50%. Industry and public sectors saw their activity reduce by 35% and 33%, respectively. Power sector had a lower but still significant decline of 15%.

The COVID-19 pandemic has led to significant decline in production and employment in the fossil energy industry. Changes in production at several oil fields in the UK and in the mining, quarrying, and oil and gas extraction sectors in the US are expected to result in a substantial reduction in employment in these sectors in 2020. In the US lower demand for electricity, increased generation from renewables and natural gas, and declining export prospects led to the loss of mining jobs in the first quarter of 2020, even though coalmines were declared an essential business.

The pandemic has accelerated the trend in closures of coal-based power plants and reductions in coal-based power generation. In recent years, the share of renewable energy technologies has been growing in the global market for new power generation capacity due to declining costs. On average, new solar photovoltaic and onshore wind power cost less than keeping many existing coal plants in operation. According to the International Renewable Energy Agency (IRENA), solar photovoltaic and wind energy are expected to be fully cost-competitive within the next decade (IRENA 2019). The clean energy sector, particularly the solar photovoltaic industry, had been a fast-growing industry and a significant source of jobs for the last decade. In 2019, renewable energy generation increased more than the increase in electricity demand while fossil fuel electricity generation decreased; the first time this has occurred in a period when electricity demand is increasing.

Investment in renewable energy has been growing as investors, particularly in Europe, are putting pressure on oil companies to reduce carbon emissions. According to Goldman Sachs, capital availability for new oil development and drilling for shale gas has been tightening in recent years while financial institutions are redirecting financing towards renewable developments (Vigna et al. 2019). Foreign direct investment in renewable energy reached an all-time high in the first quarter of 2020, while investments in fossil fuels were plummeting. Foreign investors announced over $23 billion of cross-border renewable energy investment at the beginning of this year, the highest level recorded over the past decade (IRENA 2020).

Renewable energy generation has been impacted less than the rest of the energy sector due to lower marginal costs of electricity generation. Renewables receive priority in the grid and are not asked to adjust their output to match demand insulating them from the impacts of lower electricity demand (International Energy Agency 2020b). New capacity additions in the renewable energy sector, however, have not been left unscathed by the pandemic. Global investment in new renewables capacity is expected to fall by 10% in 2020 (International Energy Agency 2020a). The pandemic is leading to delays in bringing new capacity online, with investors becoming more cautious about investing in new projects. Most countries, including the US, are heavily dependent on China for many renewable components and raw materials, especially for the solar energy sector. Disruptions in supplies from China, as well as other challenges, including labor shortages and cancellation of install orders by homeowners due to COVID-19 are likely to slow down solar photovoltaics substantially in 2020 (Eckhouse and Martin 2020a). Continuing renewable energy investments will require re-establishing global supply

chains and strengthening existing renewable energy policies and investments.

As a result, the renewable energy sector is also facing substantial job losses. There has been a 13% reduction in employment in the renewable energy sector in the US, including solar and wind technicians, HVAC contractors, and thousands within the construction and installation fields. Conservative forecasts indicate that without government action hundreds of thousands of renewable energy workers would have filed for unemployment in 2020. Similarly, jobs in solar plant construction and maintenance in other countries like India and Bangladesh have also seen a decline this year (E2 2020).

The steep fall in demand for transportation fuel has also reduced demand for biofuels since these are consumed as a blend with gasoline. Global biofuel production is expected to be 13% lower in 2020 while renewable heat consumption is also likely to decline due to lower industrial activity. In the last two decades, global biofuel consumption had grown more than five times (Debnath et al. 2019). Biofuel production and renewable heat consumption were both expected to increase by around 3% in 2020 before the COVID-19 crisis emerged. This was due to Brazil's new biofuels policy, the wider implementation of China's ethanol blending mandates and continued biodiesel expansion in ASEAN member countries. Renewable heat consumption was expected to increase in the European Union due to new 2030 renewable energy goals. With reduction in demand, biofuel production plants have idled or reduced output (International Energy Agency 2020a). About half of the ethanol plants in the US had to become idle after the start of the pandemic and are expected to stay offline while the pandemic lasts. The demand could fall further if the blend rate mandate for biofuels is revised down because the competitiveness of ethanol as a source of octane was affected adversely due to decline in gasoline prices. With actual fuel demand less than projected otherwise, the biofuel volumes that can be consumed even with the current blend rate of about 10% will be lower than they would have been otherwise.

Demand for oil and biofuels in the future will also depend on the vehicle mix chosen by consumers. There has been a large decline in global car sales in 2020 and these are expected to be about 15% lower than in 2019. In contrast, the upward trend in electric car sales is expected to continue and to raise the share of electric cars in vehicle sales in 2020 to more than 3% and in the global car stock to 1% (Debnath et al. 2019). This is despite a substantial decline in electric car sales in China and the US and largely because of an increase in electric car sales in Europe; the latter has been driven by emissions standards and other policies to support electric car purchases (International Energy Agency 2020a).

The reductions in fossil fuel consumption due to the pandemic could be temporary since there are no structural changes in the economic, transport and energy systems due to Covid-19. With oil and coal likely to remain at historically low prices, there are risks the economics of energy production can again start leaning heavily in favor of fossil fuels over renewable sources. Even if COVID-19 were to lead to some long lasting shifts towards working from home, tele-conferencing and on-line education, these type of social responses alone would not be sufficient to keep global emissions on track to stay under 1.5 degrees C of warming in this century. The UN Environment Programme estimates that global carbon emissions must fall by 7.6% *every year* from 2020 to 2030 to keep temperature increases to less than 1.5°C (UNEP 2019).

Unlike other business cycles, such as the Great Depression, that have led to creative destruction, the economic impacts of COVID-19 are caused by restrictions on individual behavior rather than any fundamental changes in resource availability, technology or policy that would make renewable energy more profitable than fossil fuels. After the current crisis is over, individual behavior may revert back to business-as-usual before the crisis without leading to any structural changes in the economic, transport or energy systems; this will depend in part on how long the pandemic lingers. Based on past experience with economic slowdowns, it can be argued that the reductions in energy consumption could be short-lived and rebound back once mobility restrictions are lifted and economies recover, particularly if governments provide support to insulate the fossil fuel industry during the pandemic (World Bank 2020). The 2007–08 financial crisis and the subsequent economic slowdown led to a reduction in global greenhouse-gas emissions in 2009 by about 1%. However, carbon emissions grew by 5.1% in 2010 and hit a record high, in part due to governments' measures to stimulate economies that had limited considerations for environmental impact (Le Quéré et al. 2020). It is, therefore, critical to develop strategies to prevent a similar increase in emissions after the pandemic ends.

The Imperative to "Build Back Better"

Climate change and COVID-19 can represent existential crises for life as we know it, if they are not addressed appropriately; while the pandemic has been sudden and devastating with clearly visible impacts on human health, climate change is slow-moving and has wide-ranging impacts on the planet that are often less visible and directly attributable to the human activity. Climate change is expected to have a significant detrimental economic, environmental, and public health impact. Achieving the high levels of reduction in carbon emissions required while increasing societal well-being requires a shift to renewable energy rather than expecting a reduction in energy consumption observed during the pandemic to become permanent.

According to IRENA (2020), to reduce global fossil fuel use by 75% and energy related carbon emissions by 70% by midcentury, over half of the necessary reductions in emissions will need to come from renewable energy and around one-fourth from increasing energy efficiency. Continuing to invest in fossil-fuel energy infrastructure creates a path-dependence for decades to come and will make it more costly to meet goals of the Paris Agreement. Delaying the transition in the energy sector is likely to result in trillions of dollars in stranded assets in the future. The costs of this transition are expected to be high and will need to be sustained for a fairly long period. The IEA expects that investments of $1 trillion per year are needed for the next three years in the global energy system (International Energy Agency 2020b). In the long run, the IRENA (2020) estimates an investment need of $3.2 trillion annually each year till 2050 or a total investment of $110 trillion by 2050 to raise the share of renewables from 26% currently to 57% by 2030 and 86% by 2050. Of this investment, 25% would need to be in renewable energy, 23% in electrification and infrastructure and 34% in improving energy efficiency. The total investment required is twice as high as the historical investment in the energy sector of $1.8 trillion per year (IRENA 2020). Transformation of the energy sector would lead to not only benefits in the long run, in the form of reduced

externalities from indoor and outdoor air pollution and climate change but also be complementary with immediate goals of increasing job opportunities.

Government policy interventions and private capital are needed to sustain growth and investment in renewable energy and to prevent emissions from rebounding after the COVID-19 crisis is behind us; the process of creative destruction driven by self-interest in a market-based economy may not be sufficient. Creative destruction is driven by business cycles that make production technologies with an inferior technology unprofitable and, thus, private businesses have market-based incentives to scrap them and adopt newer more efficient technologies, without any government intervention. The extent to which the pandemic and the accompanying disruption in economic activity and reduction in demand can be expected to unleash a new wave of creative destruction and create a market-based imperative to shift towards renewable energy remains to be seen. It will depend, at least in part, on the competitiveness of renewable energy relative to fossil energy in the postpandemic world and the willingness of the private sector to mobilize capital for investment in new infrastructure.

In addition to solar and wind, a mix of renewable and clean energy technologies, including advanced nuclear energy, carbon capture and sequestration, and hydrogen energy will be needed to achieve the goal of restricting the global temperature increase to 1.5 degree Celsius by midcentury.[1] However, the market-driven incentives for expanding solar photovoltaics and onshore wind are high because their costs have declined significantly in recent decades. With economies of scale they are the cheapest source of new generation for at least two-thirds of the global population (Bloomberg New Energy Finance (BNEF) 2020). In many parts of the world solar and wind energy are competitive with existing coal-based electricity even without subsidies. Cost of battery storage have declined by 50% since 2018 with increasing project sizes, rapidly expanding manufacturing base and improvements in technology. The growing competitiveness of these renewable energy technologies with fossil fuels makes them promising options for expansion in the near term as compared to other renewable and low carbon energy sources, such as hydropower and nuclear energy. The latter are seeing declining trends in deployment and delays in approvals for new projects, planned maintenance, and construction (International Energy Agency 2020a).

The transition to renewable energy technologies will be aided by recognizing the environmental benefits they provide, such as improving air and water quality and mitigating carbon emissions. These benefits are often unpriced due to the absence of government policies. Incorporating a monetary credit for these external benefits in the pricing of renewable energy can improve their competitiveness relative to fossil fuels and aid the process of creative destruction. Low fossil fuel prices due to the pandemic could be offset by the imposition of a carbon tax that could make renewable energy more appealing. Additionally, governments around the world are spending trillions of dollars on rescue and recovery measures; the G20 nations (including most EU member states) had earmarked over US$7.3 trillion on rescue measures by April 2020 (Hepburn et al. 2020); this amount is estimated to be more than $10 trillion in May 2020 by McKinsey (2020). As discussed in the next section, recovery measures could be designed to promote renewable energy, which can also stimulate economic growth and jobs.

[1] *https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter2_Low_Res.pdf*

In the near term, since the start of the pandemic, the focus of governments has been on rescue measures. Hepburn et al. (2020) analyze 300 major policies implemented globally following the start of the pandemic and shows that the majority of these policies are rescue policies to protect workers and businesses. Their subjective assessment is that 4% of policies are "green" with potential to reduce long-run carbon emissions, 4% are "brown" and likely to increase net carbon emissions beyond the base case, and 92% are "colorless," meaning that they maintain the status quo. While most of these policies are to provide cash to individuals to meet basic needs, some policies also support emission-intensive firms, such as airlines that face bankruptcy or reduced revenue due to COVID-19 (examples include tax breaks for airlines in Russia, bailouts for US airlines and unconditional airline relief in Australia).

Fossil fuel industries facing low demand and prices are also seeking tax breaks and bailouts. In the US, the Coronavirus Aid, Relief, and Economic Security (CARES) Act passed in March 2020 has led to changes in tax restrictions and rebates that have benefited oil companies; SEC filings indicate that at least thirty-seven oil companies claimed more than $1.9 billion in CARES Act tax benefits (DeConcini and Neuberger 2020). Oil and gas companies have also benefited from extensions to loan repayment periods by the Federal Reserve Bank in the US and reductions in royalties to produce oil and gas on public lands. In contrast, access to tax relief provided to the renewable energy projects by the government has been impeded by supply chain disruptions, shutdown of factories, and the inability to do installations when social distancing is required. Efforts to insulate the fossil fuel industry from the effects of the pandemic can hamper the creative destruction process.

The longer-term impact of COVID-19 on renewable energy will depend on how long the crisis lasts, how widespread it is, and how deep the restrictions are. It will also depend on the recovery path chosen by the government, businesses and individuals, the speed of the recovery, the nature of the government spending to support and reinvigorate the economy, and the extent of rebound in consumer spending. It is possible that governments around the world may consider fossil fuel companies as too important to be allowed to fail and offer to bail them out and support industrial recovery by reducing environmental standards and slowing the growth in fuel efficiency standards. Countries may also take advantage of the low price of oil to increase fossil-fuel based consumption to aid economic recovery, particularly in emerging economics and scale back support for renewable energy (Fox-Penner 2020; Hepburn et al. 2020).

Implications for Plans for Recovery from COVID-19

The focus of the government interventions so far has been on rescue packages to protect lives and livelihoods and not on recovery packages. Recovery packages would need to address societal concerns related to poverty alleviation and inequality reduction and catalyze productive investments. They will seek to address the unprecedented scale of unemployment resulting from the global pandemic and make investments with high economic multipliers. An investment package focused on the energy transition can help to overcome the economic slump and create much-needed jobs, both for the short term and beyond. Renewable energy infrastructure is very labor intensive in the early stages—one model suggests that every $1 million in spending generates

7.5 full-time jobs in renewables infrastructure, 7.7 in energy efficiency, but only 2.7 in fossil fuels (Garrett-Peltier 2017). The global employment intensity of all energy transition-related technologies is about 16.5 jobs per million dollars, but regional values range from as high as about thirty jobs per million dollars in Latin America and the Caribbean and countries of the Association of Southeast Asian Nations (ASEAN) to around ten in EU-27 plus UK and North America, and five in Oceania. Analysis by IRENA (2020) shows that transition to clean energy can create 29.5 million jobs by 2030; among renewable technologies, solar energy and bioenergy have the greatest potential—11.7 and 10.9 million jobs, respectively, followed by wind energy jobs at 3.7 million (IRENA 2020). These job gains are expected to outpace the job losses in fossil fuels globally and in all regions. In the long run, these public investments offer high returns by driving down costs of the renewable energy transition (Henbest 2020). Investment in renewable energy technologies could stimulate innovation, job creation, and more environmentally sustainable growth, with spillovers that benefit the wider economy (Aghion et al. 2014). However, an increasing share of renewable energy can also raise electricity prices and this can be regressive, conflicting with the goals of poverty alleviation (Böhringer et al. 2017).

Investment in renewable energy has several advantages as a stimulus policy; it has a higher jobs multiplier in the near term, which boosts spending and increases short-run GDP multipliers. In the long run, renewable energy requires less labor for operation and maintenance, and this frees up labor and saves on fuel. This implies that as the economy returns to capacity, it enables more efficient use of labor and offers higher long-run multipliers as well (Hepburn et al. 2020). An overarching recognition of the need for a sustainable recovery from COVID-19 has led to a call from many government leaders, businesses, and major investors to transition to a low-carbon economy as a mechanism for economic recovery following COVID-19 (McKinsey 2020). Many CEOs from the banking and the insurance sectors, members of the European Parliament, business associations, and top executives at companies, nongovernment organizations, and others have joined the "green recovery alliance," launched in April 2020 at the initiative of the chair of the Environment Committee of the European Parliament. The green recovery alliance seeks to offer investment solutions to revive the economy after the crisis in ways that are aligned with climate commitments. In parallel to this private sector initiative, the European parliament in April 2020 called for making the European Green Deal an integral part the recovery from COVID-19. The Green Deal provides a comprehensive regulatory framework to achieve the European Union's targets of net-zero carbon emissions by 2050, and a 50% to 55% cut in emissions from 1990 levels by 2030. Similarly, in 2019, the US Congress proposed a Green New Deal, a nonbinding resolution calling on the federal government to wean the US from fossil fuels and reducing greenhouse gas emissions.[2] Continuing this convergence of private sector and government commitment to make the coronavirus recovery a time to move towards a more sustainable energy system will be critical to increase economic growth and jobs while limiting the harm to the climate.

These legislative initiatives are consistent with emerging public opinion on this issue. Two-thirds of survey respondents to a global survey of the public believe that government actions should prioritize climate change mitigation

[2]*https://www.nytimes.com/2019/02/21/climate/green-new-deal-questions-answers.html*

in the economic recovery after COVID-19 (McKinsey 2020). The International Energy Agency and the International Monetary Fund offer a roadmap for governments to stimulate economic growth, create millions of jobs, and put global emissions into structural decline by accelerating deployment of clean energy technologies and infrastructure and increasing energy efficiency (International Energy Agency 2020b). Governments have a profound opportunity to be farsighted, to set in motion a lasting shift in the global energy mix, and to allow the world to reap the multiple benefits of a cleaner energy system. Whether governments will heed the call of these agencies to use this historic opportunity to develop economic recovery plans that reduce investments in fossil fuels and accelerate the energy transition remains to be seen.

Conclusion

COVID-19 has created an economic and public health crisis for the world and the government and societal response to addressing it has substantially reduced energy consumption and had unprecedented negative effects on employment in the oil, gas and coal sectors. The pandemic has been a global experiment for the environment and shown the extent to which severe energy demand destruction can lower carbon emissions. It also highlights the challenge of maintaining these lower emissions in the future, as is critical to achieve the climate goals of the Paris Agreement, while expanding human well-being and standards of living that are dependent on energy consumption. The extent to which energy consumption will rebound back after the pandemic will depend on how long and widespread the effects of COVID-19 are and the extent to which there are structural changes in the form of increased reliance on telework, e-commerce, and shorter supply chains. These alone may not be sufficient unless we can decouple energy consumption from carbon emissions by transitioning to renewable energy in a major way.

The pandemic has occurred at a time when declining renewable energy costs, persistently low oil prices, rising debt in the fossil fuel sector and investor concerns about the impact of fossil fuels on carbon emissions and environmental regulations were already lowering capital investment in the fossil fuel industry while making renewable energy one of the fastest growing industries. The current crisis can now serve as a catalyst to significantly expand use of renewable energy and low carbon infrastructure as a path to stimulate the economy, increase employment and lower carbon emissions. A recent global survey of economic experts indicates that investment in clean infrastructure (such as renewable energy assets, energy storage, grid modernization, and carbon capture technology), renovations and retrofits to improve building efficiency, investment in education and training, and clean R&D spending rank as top-performing recovery measures from COVID-19 (Hepburn et al. 2020). The extent to which these investments will occur will depend on how policymakers prioritize job creation potential, cleaner air, and economic, energy, and climate resilience. Transforming the energy sector to one that is predominantly based on renewable energy will require a large and sustained investment of trillions of dollars globally as well as ambitious clean energy standards for the electricity and transportation sectors. These investment decisions need to be accompanied by appropriate policy incentives that are technology neutral, performance-based, and market-based. Additionally, in designing policies to stimulate investment in renewable energy, it will be important to consider various issues, including the

intermittency of renewable energy and its integration in the grid, the welfare economic costs and the distribution of those costs among consumers and producers of energy. The intermittency of solar and wind energy affects the extent to which it is cost-effective to include them in the mix of electricity generation (Hirth 2015; Hirth, Ueckerdt, and Edenhofer 1915). The welfare-economic effects of increasing renewable energy will depend on several considerations, including the extent to which regulatory incentives are needed to induce a shift to renewable energy, the type of incentives (renewable share mandates, low carbon standards, carbon taxes) that are provided and the relative cost of renewable sources of energy. Several studies show that low-carbon fuel standards and carbon taxes are more cost effective than renewable share mandates at achieving renewable energy and carbon mitigation goals (see Chen et al. 2014; Oliver and Khanna 2018). Renewable energy policies can raise the cost of energy and have adverse implications for low-income consumers. They also imply a shift in profits from fossil fuel producers to renewable energy producers. These distributional considerations have implications for the optimal mix and share of renewable energy in a region.

The COVID-19 has starkly highlighted the interdependent nature of the world we live in and the notion that governments can respond rapidly and cooperate globally to develop policies based on science when dealing with a global crisis. It has also shown that politics and short-term self-interest can act as a barrier to actions in the interest of the larger public. Whether the COVID-19 crisis will prove to be a silver lining for renewable energy will depend not only on the technological realities and societal response to the crisis but also on political will and foresight.

References

Aghion, Philippe, Cameron Hepburn, Alexandar Teytelboym, and Dimitri Zenghelis. 2014. Path Dependence, Innovation and the Economics of Climate Change. Centre for Climate Change Economics and Policy/Grantham Research Institute on Climate Change and the Environment Policy Paper & Contributing paper to New Climate Economy. http://www.lse.ac.uk/GranthamInstitute/publication/path-dependence-innovation-and-the-economics-of-climate-change/.

Bloomberg New Energy Finance (BNEF). 2020. Scale-up of solar and wind puts existing coal gas at risk. April 2020: https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/#_ftnref1

Boden, T.A., R.J. Andres, and G. Marland. 2017. Global, Regional, and National Fossil-Fuel CO2 Emissions (1751–2014). *DOE Data Explorer*. Oak Ridge, TN. https://doi.org/10.3334/CDIAC/00001_V2017.

Böhringer, Christoph, Florian Landis, A. Miguel, and Tovar Reaños. 2017. Economic Impacts of Renewable Energy Production in Germany. *Energy Journal* 38(SI 1): 189–209.

Caballero, Ricardo J., and Mohamad L. Hammour. 1994. The Cleansing Effect of Recessions. *American Economic Review* 84(5): 1350–1368.

Chen, Xiaoguang, Haixiao Huang, Madhu Khanna, and Hayri Onal. 2014. Alternative Fuel Standards: Welfare Effects and Climate Benefits. *Journal of Environmental Economics and Management* 67: 241–257.

Debnath, Deepayan, Madhu Khanna, Deepak Rajagopal, and David Zilberman. 2019. The Future of Biofuels in an Electrifying Global Transportation Sector: Imperative, Prospects and Challenges. *Applied Economic Perspectives and Policy* 41(4): 563–582. https://doi.org/10.1093/aepp/ppz023.

DeConcini, Christina, and Jillian Neuberger. 2020. *Oil & Gas Win, Clean Energy Loses in U.S. COVID-19 Response*. World Resources Institute. https://www.wri.org/blog/2020/06/coronavirus-stimulus-packages-clean-energy (accessed June 10, 2020).

DOE-EIA. 2020. Short Term Energy Outlook. U.S. https://www.eia.gov/outlooks/steo/report/electricity.php (accessed October 7, 2020).

E2. 2020. America Has Lost 594,300 Clean Energy Jobs; 850,000 Expected by June 30. E2. https://e2.org/releases/america-has-lost-594300-clean-energy-jobs-850000-expected-by-june-30/ (accessed May 13, 2020).

Eckhouse, Brian, and Chris Martin. 2020a. Coronavirus Crushing Global Forecasts for Wind and Solar Power. Bloomberg Green, March 27, 2020, https://www.bloomberg.com/news/articles/2020-03-27/global-solar-wind-growth-will-be-erased-this-year-rystad-says (accessed March 27, 2020).

——. 2020b. The Impact of the COVID-19 Crisis on Clean Energy Progress. https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress (accessed June 2020).

Fox-Penner, Peter. 2020. Will the COVID-19 Pandemic Slow The Global Shift to Renewable Energy? The Brink, Boston University. http://www.bu.edu/articles/2020/will-the-covid-19-pandemic-slow-the-global-shift-to-renewable-energy/ (accessed April 2, 2020).

Garrett-Peltier, Heidi. 2017. Green Versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy, and Fossil Fuels Using an Input-Output Model. *Economic Modelling* 61(February): 439–447. https://doi.org/10.1016/j.econmod.2016.11.012.

Gillingham, K. T, Knittel, C. R, Li, J., Ovaere, M., and Reguant, M. 2020. The Short-run and Long-run Effects of Covid-19 on Energy and the Environment. *Joule* 4(7): 1337–1341.

Henbest, Seb. 2020. The First Phase of the Transition Is about Electricity, Not Primary Energy. BloombergNEF. https://about.bnef.com/blog/the-first-phase-of-the-transition-is-about-electricity-not-primary-energy/ (accessed January 28, 2020).

Hepburn, Cameron, Ella Adlen, John Beddington, Emily A. Carter, Sabine Fuss, Niall Mac Dowell, Jan C. Minx, Pete Smith, and Charlotte K. Williams. 2019. The Technological and Economic Prospects for CO2 Utilization and Removal. *Nature* . https://doi.org/10.1038/s41586-019-1681-6.

Hepburn, Cameron, Brian O'Callaghan, Nicholas Stern, Joseph Stiglitz, and Dimitri Zenghelis. 2020. Will COVID-19 Fiscal Recovery Packages Accelerate or Retard Progress on Climate Change? | Oxford Review of Economic Policy. *Oxford Review of Economic Policy*. https://academic.oup.com/oxrep/article/doi/10.1093/oxrep/graa015/5832003.

Hirth, Lion. 2015. The Optimal Share of Variable Renewables: How the Variability of Wind and Solar Power Affects Their Welfare-Optimal Deployment. *Energy Journal* 36(1): 149–184.

Hirth, Lion, Falko Ueckerdt, and Ottmar Edenhofer. 2015. Integration Costs Revisited -an Economic Framework for Wind and Solar Variability. *Renewable Energy* 74: 925–939.

Holden, Emily. 2020. Fossil Fuel Firms Linked to Trump Get Millions in Coronavirus Small Business Aid. *The Guardian*. https://www.theguardian.com/environment/2020/may/01/fossil-fuel-firms-coronavirus-package-aid (accessed May 2020).

International Energy Agency. 2020a. The Impact of the COVID-19 Crisis on Clean Energy Progress. https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress (accessed June 2020).

——. 2020b. "Sustainable Recovery." World Energy Outlook Special Report. https://www.iea.org/reports/sustainable-recovery#Whiel (accessed June 2020).

——. 2020c. Global Energy Review 2020. https://www.iea.org/reports/global-energy-review-2020.

International Renewable Energy Agency (IRENA). 2020. *The Post-COVID Recovery: An Agenda for Resilence, Developmnet and Equality*. Abu Dhabi: International Renewable

Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Post-COVID_Recovery_2020.pdf.

IRENA. 2019. Falling Renewable Power Costs Open Door to Greater Climate Ambition. *International Renewable Energy Agency*. https://www.irena.org/newsroom/pressreleases/2019/May/Falling-Renewable-Power-Costs-Open-Door-to-Greater-Climate-Ambition (accessed May 29, 2019).

Le Quéré, Corinne, Robbie M. Andrew, Pierre Friedlingstein, et al. 2018. Global Carbon Budget 2017. *Earth System Science Data* 10(1): 405–448. https://doi.org/10.5194/essd-10-405-2018.

Le Quéré, Corinne, Robert B. Jackson, Matthew W. Jones, et al. 2020. Temporary Reduction in Daily Global CO2 Emissions during the COVID-19 Forced Confinement. *Nature Climate Change* 10(7): 647–653. https://doi.org/10.1038/s41558-020-0797-x.

McKinsey. 2020. Climate Math: What a 1.5-Degree Pathway Would Take. *McKinsey Quarterly*, April 30, 2020 . https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-math-what-a-1-point-5-degree-pathway-would-take (accessed April 30, 2020).

Niler, Eric. 2020. The Covid-19 Economic Slump Is Closing Down Coal Plants. *Wired*, June 12, 2020, https://www.wired.com/story/the-covid-19-economic-slump-is-closing-down-coal-plants/ (accessed June 12, 2020).

Oliver, Anthony.C., and Madhu Khanna. 2018. Spatial Distribution of Welfare Costs of Renewable Portfolio Standards in the United States Electricity Sector. *Letters in Spatial and Resource Sciences* 11: 269–287. https://doi.org/10.1007/s12076-018-0208-3.

Rowlatt, Justin. 2020. Could the Coronavirus Crisis Finally Finish off Coal? *BBC News*, June 9, 2020, https://www.bbc.com/news/science-environment-52968716 (accessed June 9, 2020).

Schumpeter, Joseph A. 1939. *Business cycles: A theoretical, historical, and statistical analysis of the capitalist process*. New York: Mc- Graw-Hill.

UNEP. 2019. *Emissions Gap Report 2019*. Nairobi: United Nations. https://www.unenvironment.org/resources/emissions-gap-report-2019.

Vigna, Michele Della, Zoe Stavrinou, Nikhil Bhandari, Neil Mehta, and Brian Singer. 2019. *Carbonomics The Future of Energy in the Age of Climate Change*. Goldman Sachs International. https://www.goldmansachs.com/insights/pages/carbonomics.html.

World Health Organization (WHO). 2020. Timeline of WHO's Response to COVID-19. https://www.who.int/news-room/detail/29-06-2020-covidtimeline (accessed June 30, 2020).

World Bank. 2020. *Global Economic Prospects*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1553-9.