International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

International Science Council

Transformations within reach:
Pathways to a sustainable and resilient world

RETHINKING ENERGY SOLUTIONS

Available at: **pure.iiasa.ac.at/16820**

First published in January 2021.

Cover illustration assets: © Pavlo Syvak | Dreamstime
Cover design: © Adam Islaam | IIASA

Transformations within reach:
Pathways to a sustainable and resilient world

Rethinking energy solutions

Lead Authors
Behnam Zakeri, Katsia Paulavets, Leonardo Barreto-Gomez, and Luis Gomez Echeverri

Contributing Authors
Shonali Pachauri, Joeri Rogelj, Felix Creutzig, Diana Urge-Vorsatz, David Victor, Benigna Boza-Kiss, Caroline Zimm, Sarah Alexander, Morgan Bazilian, Steffen Fritz, Dolf Gielen, Harish Hande, David McCollum, Clay Nesler, Michaela Rossini, Varun Sivaram, and Leena Srivastava

Table of contents

About the authors

Lead Authors:

Behnam Zakeri, International Institute for Applied Systems Analysis (IIASA), Austria

Katsia Paulavets, International Science Council (ISC), France

Leonardo Barreto-Gomez, Austrian Energy Agency (AEA), Austria

Luis Gomez Echeverri, International Institute for Applied Systems Analysis (IIASA), Austria

Contributing authors:

Shonali Pachauri, International Institute for Applied Systems Analysis (IIASA), Austria

Joeri Rogelj, International Institute for Applied Systems Analysis (IIASA), Austria, and Imperial College London, UK

Felix Creutzig, Technische Universität Berlin, Germany

Diana Urge-Vorsatz, Central European University, Hungary

David Victor, UC San Diego, USA

Benigna Boza-Kiss, International Institute for Applied Systems Analysis (IIASA), Austria

Caroline Zimm, International Institute for Applied Systems Analysis (IIASA), Austria

Sarah Alexander, SELCO Foundation, India

Morgan Bazilian, Payne Institute/ Colorado School of Mine, USA

Steffen Fritz, International Institute for Applied Systems Analysis (IIASA), Austria

Dolf Gielen, IRENA Innovation and Technology Centre, Germany

Harish Hande, SELCO Foundation, India

David McCollum, Electric Power Research Institute (EPRI), USA

Clay Nesler, Alliance to Save Energy, USA

Michaela Rossini, International Institute for Applied Systems Analysis (IIASA), Austria

Varun Sivaram, ReNew Power, India

Leena Srivastava, International Institute for Applied Systems Analysis (IIASA), Austria

Acknowledgments

This report is a joint effort between IIASA and ISC. We appreciate the continued support from the two institutions, especially Leena Srivastava (IIASA) and Flavia Schlegel (ISC). We would like to sincerely thank Hans Olav Ibrekk, Policy Director of Section for Energy, Climate, and Food Security, Norwegian Ministry of Foreign Affairs and Co-Facilitator of the SDG7 Technical Advisory Group, as the Chair of the Sustainable Energy Theme. We would also like to thank Keywan Riahi, Director, Energy Program, IIASA, who served as an Advisor to the energy team. We demonstrate our sincere appreciation to all participants in three consultative meetings for their valuable comments and contributions on which this report is based (see the list of participants on page 50). The views represented in this report is not the official position of IIASA and ISC, nor represents the views of supporting organizations. The team also sincerely acknowledges the assistance of Anastasia Aldelina Lijadi (IIASA) for the administrative and logistic support throughout the project. In addition, we would like to express our sincere appreciation for the support of the IIASA communications team, Adam Islaam, Philippa Baumgartner, and Ansa Heyl in the finalization of this report, as well as the editing and formatting services provided by Kathryn Platzer and Ingrid Teply-Baubinder.

Executive Summary

The COVID-19 pandemic has caused multiple disruptions to the global economy, and the energy sector is no exception. Among the key developments taking place in the energy sector over the last months have been: a drastic fall in energy demand due to reductions in economic activities and traveling; lifestyle changes; reduced oil prices; disruptions in the supply chain of energy technologies; and a decline in energy investments. The COVID-19 crisis has also exacerbated global inequality in access to basic energy services, with the most devastating impacts falling on vulnerable groups and the urban poor.

As a result of reduced energy demand, energy-related carbon emissions are expected to fall in 2020. However, most of the reductions observed in energy consumption, carbon emissions, and air pollution in 2020 are likely to be short-lived if no systemic changes take place in the economic, transport, or energy sectors. The long-term impacts of the pandemic on human well-being, the economy, and the environment, in addition to the energy sector, are still uncertain, raising questions and concerns as to how the post-COVID-19 recovery will advance or undermine efforts to achieve the Sustainable Development Goals (SDGs) and to meet the Paris Agreement pledges on climate change.

Decisions made today will either accelerate the transition toward a more sustainable and resilient energy system or slow it down. Choices made concerning the energy system will also increase or decrease vulnerability in other key systems, such as health, food, cities, etc. It is thus important for recovery efforts and stimulus packages in the wake of COVID-19 to avoid the emission rebounds that would arise from a return to business-as-usual energy use. However, the latest data show that the recovery packages of the G20+ countries benefit fossil fuels more than clean energy. This trend has to be reversed. Policy signals should be given to stimulate a reallocation of investments toward clean energy projects, otherwise the world will lock itself into an insecure and high-carbon energy future which would significantly jeopardize the achievement of the SDGs and climate neutrality goals.

To meet the global goal of the temperature limit "well below 2 degrees," global emissions must have peaked by 2020. This means that sustainable energy transitions must accelerate. This will require structural changes in the economy, lifestyles, production and consumption practices, transport, buildings, agriculture, and industry. This report outlines three priority areas for intervention that provide high potential for reducing energy demand and accelerating energy transformation, including:

- Decarbonizing economy and redirecting excessive consumption to sufficiency through a circular and sharing economy;
- Reinventing urban spaces, infrastructure and mobility through compact urban development with reduced car dependency, and a low-carbon and resilient built environment; and
- Advancing decentralized, efficient, and resilient energy systems.

Justice and equity considerations should be central to these interventions in order to increase the resilience of disadvantaged and vulnerable groups and to ensure that they have a voice in energy transition.

Science has a key role to play in assessing the effects of the COVID-19 pandemic on energy demand and supply, governance, innovations, investments, and social equity and justice. Moreover, understanding how the pandemic will influence individual behavior, lifestyles, consumer choices, and social practices in relation to

energy, mobility, and sustainable consumption in the longer term will be key. Science can provide a valuable contribution in identifying and designing sound energy policy options in the short, medium, and long term in the face of uncertainty.

The work presented in this report aims to identify areas where scientific approaches can support policy, rather than dictate policy choices. For instance, interdisciplinary scenario work combining technology, economics, and social sciences could demonstrate the multiple benefits of sustainable recovery pathways and accompanying societal transformations to enable a more equitable, resilient, and sustainable post-COVID–19 world. In addition, an assessment of the effects of digitalization on energy demand in transport, buildings, and industry, as well as options for making digitalization more sustainable and just, should be undertaken.

We identify cities and urban spaces as another key area for transdisciplinary research. The way our cities are designed significantly affects their energy consumption, livability, and resilience. In response to COVID-19, air pollution, and climate change, cities will need to adapt their public spaces, infrastructure, services, and governance systems to become more resilient, healthier, and equitable. To this end, a more holistic and systemic approach to urban planning based on context-specific evidence and nuanced analysis of urban processes is essential. One of the key priorities for science is to examine how low-carbon buildings, multimodal mobility services, decentralized renewable energy–based solutions, combined with flexibility options such as end-use energy storage, social innovations, behavioral change, and citizen engagement can reduce energy demand and improve urban resilience.

Synergies with the other key themes of the IIASA–ISC Consultation Platform (core frameworks of governance, science systems, and food systems) could also be explored to identify and develop the transformations that are within reach. Some examples for further investigation include: designing smart, multiscalar governance approaches for the energy sector; strengthening science–policy–society dialogues with an energy and climate focus; and examining systemic responses to the energy–water–food nexus challenge under the influence of climate risks such as heatwaves, droughts, floods, and other systemic risks. Last, but not the least, considering that the lockdown and containment measures may continue in several waves, the recommendations of this report can be generalized beyond the initial response to the pandemic and the related recovery packages.

1 Impact of COVID-19 on Energy Systems

The global COVID-19 pandemic and its economic and social impacts have altered life as we know it around the world (Canales and Berman-Vaporis, 2020). Reductions in industrial activities, global travel and tourism, consumption of goods and services, and use of local transport have affected every sector of the global economy, including the energy sector. The ongoing experience of COVID-19 has revealed the vulnerabilities present in energy systems as well as their inherent opportunities.

1.1 COVID-19 and vulnerabilities in energy systems

This subsection reviews key developments in the energy sector over the last months, including the critical lockdown periods of 2020. These developments include growth in energy inequality, reduced energy demand, low oil and gas prices (*The Economist,* 2020), disruptions to the supply chain of energy technologies and materials, and a decline in energy investments.

Exacerbated energy inequality

The lockdown measures and the associated abrupt changes in lifestyles (e.g., working and studying remotely) have challenged populations everywhere, particularly those that were already vulnerable. During times of lockdown, regular access to modern energy services is essential, not only for everyday needs, but also for access to information, remote social interaction, home office, home-schooling, and accessing health services. Many low-income populations are now at a higher risk of poverty because of loss of jobs or regular incomes due the economic slowdown or containment measures (The World Bank, Global Prospects 2020). A lack of access to affordable modern energy services is intensifying inequalities because of the ways in which population groups are being impacted by the virus and the measures taken to contain it. The physical distancing and stay-at-home measures being adopted in many countries can only function if the population has access to reliable, affordable electricity to stay connected and perform remote work. Although access to electricity has improved in the past few years, COVID-19 has put a brake on efforts to achieve electricity access, and the lack of a reliable electricity supply is still a significant problem for many people.

Remote work has meant higher home energy bills for many (Drehobl, 2020). For those facing income losses, thermal comfort and well-being at home may be compromised if energy for heating/cooling becomes unaffordable (End Fuel Poverty Coalition, 2020). Working from home has obliged parents to juggle family care with job commitments, placing a disproportionate burden on women (Power, 2020). The combination of all these stress factors due to the pandemic has compromised the productivity of adults and the education of young people. Importantly, access to a reliable electricity supply is crucial for health facilities to provide services for people affected by COVID-19 (Van Leeuwen and Tubb, 2020). A higher reliance on digital solutions for so many aspects of life (e.g., work, studies, social interaction, shopping, services, etc.) has underlined the value of reliable and affordable electricity for the provision of digital services (UN News–Tech Agency, 2020). There is increased concern for families relying on traditional cooking methods, as indoor pollution exposure inside homes increases vulnerability to the most serious COVID-19 health effects (Wu X et al., 2020).

Many already disadvantaged populations now bear a disproportionate burden of the pandemic's fallout. Policies and measures for the energy transition, as well as an inclusive approach to digitalization, must take into account that the gap between the rich and poor has widened due to the economic crisis triggered by the current pandemic.

Shock for global oil industry

Reduced economic activities and energy demand, coupled with a supply-side price war at the start of the pandemic, brought oil prices to their lowest level in 20 years—although there has been some recovery since. Several oil and gas companies around the world have slashed investment and announced job cuts in an effort to reduce costs. Since the beginning of the pandemic, the oil field services sector in the United States (USA) has shed more than 99,000 jobs (Offshore Technology, 2020). The oil and gas industry in the United Kingdom (UK) has also announced 30,000 potential job losses (Kean 2020). If the economic slowdown and the decline in energy demand continue, energy-producing sectors and sectors with intensive energy consumption will be further affected, with an uncertain future ahead for their workers. The drop in oil prices has led to a large fall in oil revenue, damaging the economies of many oil-dependent countries (IEA, 2020). The countries affected may thus have difficulty meeting their policy targets and implementing the fiscal stimuli needed to support transition to a more sustainable energy system.

Uncertain landscape for sustainable energy transitions

The share of renewables in world electricity generation reached a record of 25% in 2019, with significant growth in developing countries such as Vietnam, India, and China (IEA, Renewables, 2020).

COVID-19 has had short-term impacts on the renewable energy sector, marked by decreased manufacturing and disruptions to the supply chains of green technologies, such as solar panels and batteries, especially in major manufacturing countries like China. However, those disruptions seem to have been relatively short-lived. The investment capacity of some private and state-owned utility companies is also declining due to lower energy demand, and some consumers are delaying payment of energy bills because of the pandemic. The delay in construction projects due to the lockdown measures, limited international trade, and reduced workforce availability can increase the capital investment needed for such projects. This economic uncertainty has resulted in a 10–15% decline in new investments in clean energy in Europe compared to 2019 (Eurelectric, 2020). This has resulted, for example, in a decline in wind energy installations in 2020 compared to industry forecasts (WindEurope, 2020.)

At the global level, however, the renewable energy sector has proven remarkably resilient to the crisis. According to Bloomberg NEF (2020), "overall investment in new renewable energy capacity (excluding large hydro-electric dams of more than 50 MW) was $132.4 billion in the first half of 2020, up 5% from a revised $125.8 billion in the same period of 2019. Onshore wind investment slipped 21% to $37.5 billion, while investment in solar fell 12% to $54.7 billion. China was the largest market, investing $41.6 billion, up 42% from the same period in 2019 thanks to its offshore wind boom."

More of a concern, however, is the risk that long-term economic recessions could tighten public expenditure on climate-friendly solutions and clean energy investments in different countries of the world. This may result in a decline in international development funds and cooperation to support access by low-income and developing countries to the capital, technology, innovation, and skills required to facilitate sustainable energy transitions.

According to the Tracking Report (2020) on Sustainable Development Goal (SDG) 7, "significant progress had been made on various aspects of SDG 7 prior to the start of the COVID-19 crisis," including a significant decline in the number of people lacking access to electricity globally, accelerated uptake of renewable energy, and improvements in energy efficiency. However, the progress in some regions like sub-Saharan Africa is still not on track to meet the SDG 7 targets. The pandemic has increased the risk of further lags in progress. The 2020 tracking report introduces a new indicator (7.A.1) for tracking international financial flows to developing countries in support of renewable and clean energy, highlighting that only 12% of international financial flows reached the least-developed countries in 2020, a number that will likely be further at risk after COVID-19 budgetary constraints (WHO, 2020).

1.2 Pandemic and opportunities for sustainable energy transitions

Demand for transportation fuels and electricity has been reduced by up to 20% in many regions of the world as a direct result of the lockdown measures (EIA, 2020; ENTSO-E Transparency Platform, 2020; Indian National Load Dispatch Center, 2020) with the largest impacts being felt in service-based economies. Renewable-based electricity showed an increasing share in electricity generation in some regions, for example, in Europe, mainly due to lower electricity demand during the COVID-19 outbreak and lower generation of baseload fossil fuel power plants (Twidale, 2020). Reduced economic activity and lower energy use has led to short-term improvements in air quality and greenhouse gas (GHG) emissions (Le Quéré et al., 2020; Liu et al., 2020). Daily estimates of country-level CO2 emissions for different sectors based on near-real-time activity data show an abrupt 8.8% decrease in global CO2 emissions (−1551 Mt CO2) in the first half of 2020 compared to the same period in 2019 (Parker and Elder, 2020). The reduction in energy demand compared to previous forecasts may last for a few years until a full economic recovery can take place (The World Bank, Global Outlook 2020).

The COVID-19 crisis has clearly shown the urgent need to act swiftly and decisively as soon as the responses to a future imminent global crisis have been clarified scientifically. Climate change, as a global problem, is best addressed by a global consensus to trigger collective solutions to urgent problems. Some researchers compare aspects of the COVID-19 pandemic and climate change, highlighting the lessons that can be learned from climate change to tackle the pandemic, namely, early actions, citizen engagement, alleviation of inequality, global collaboration, and reliance on scientific policy advice (Klenert et al., 2020). Many people have shifted to working from home, and millions of consumers have started to shop online, overcoming any entry barriers that they may have faced previously. Digitalized services and businesses have advanced at an unprecedented pace, resulting in innovations and job opportunities.

Governments around the globe are responding to the COVID-19–related economic crisis with unprecedented economic recovery packages. Low-carbon investments to put the world on an ambitious track toward net zero carbon dioxide emissions by mid-century are being outstripped by the COVID-19 stimulus funds currently being announced (Andrijevic et al., 2020). Green stimulus responses to the COVID-19 crisis can contribute to and accelerate the pace of this transition. Analyses have shown that with an economic recovery tilted toward green stimulus and reductions in fossil fuel investments, it is possible to avoid future warming (Forster et al., 2020).

The COVID-19 crisis represents both a challenge and an opportunity to put the necessary instruments in place to lead the world toward a resilient and environmentally benign energy system for all (Sovacool et al., 2020). The post-COVID–19 recovery will need energy to drive the economy and society, but in a sustainable manner. The economic recovery must thus take into account the targets of SDG 7 on energy, including equal energy access for all, promoting renewable energy, and energy efficiency. This can be achieved by grasping the opportunities presented in the aftermath of the pandemic, including the positive behavioral and lifestyle changes that can also be practiced in a post-pandemic world. Figure 1 summarizes the main impacts of Covid-19 on the energy sector.

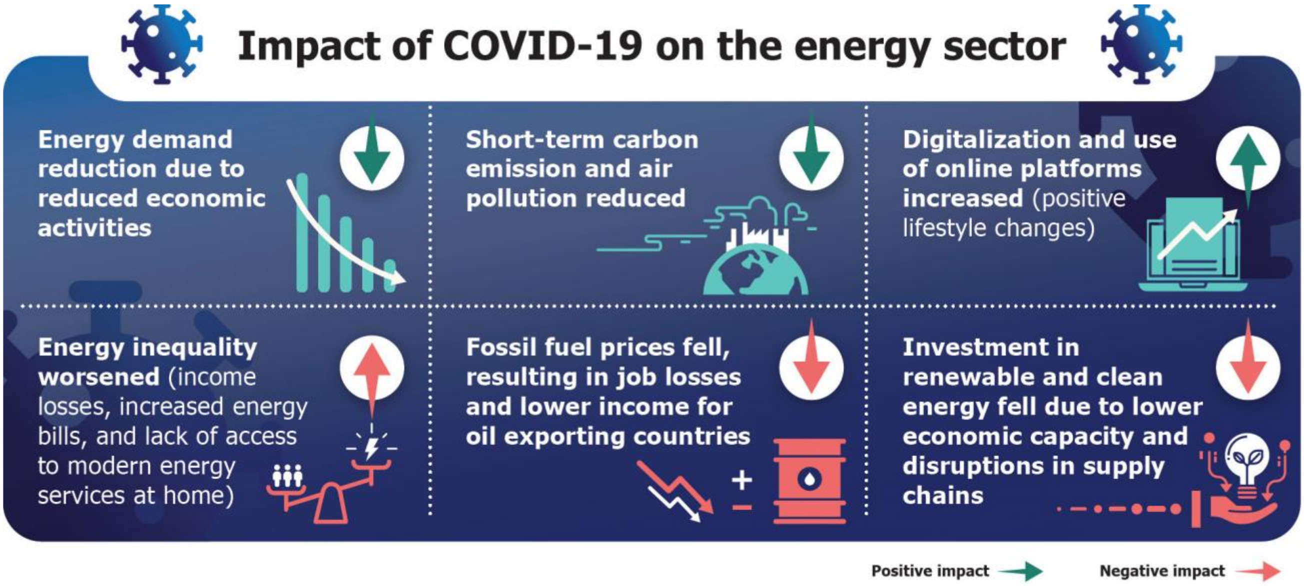

Figure 1: The impact of Covid-19 pandemic on the energy sector

2 Transition to a Resilient and Sustainable Energy System: Rationale and Enablers

SDG 7 calls for three critical actions to ensure that the world moves toward a sustainable energy pathway, including ensuring access to modern energy for all, moving decisively toward renewable energy, managing energy demands, and doubling the rate of energy-efficiency improvements. While progress has already been made in promoting renewable energy, we are still not on track to achieve SDG 7 by 2030 on all three sub-goals (IEA et al., 2019)

To keep the world on track to limit average global temperature to below 1.5 degrees Celsius above pre-industrial levels, the Intergovernmental Panel for Climate Change (IPCC) has estimated that coal and oil consumption should be almost have been phased-out by the year 2050, compared to 2010 levels, if the peak temperature limit is not to be exceeded (IPCC, 2018). The IPCC SR15 report estimates that for the same target, final energy demand in 2050 should decrease by one-third relative to 2010 levels, while the share of renewable energy sources in total electricity supply mix should reach 77%. More importantly, several studies have estimated that "declining carbon emissions after 2020 is a necessity for meeting the Paris Agreement temperature goal of 'well-below 2 degrees'" (Rahmstorf and Levermann, 2017). This means that fossil energy consumption should start to decline significantly from 2020 onwards.

While planning and decisions in the energy sector are being driven by the emergency response of governments and markets to the pandemic, the long-term resilience of supply is gaining in importance (Gordon, 2020). Long-term issues such as the transformation of the energy system toward net-zero-carbon emissions and mitigation of climate change—some of the benefits of which are future benefits—should be linked, to the largest extent possible, to short-term pressing concerns such as jobs, healthcare, and economic recovery to gain political traction (Hanna et al., 2020).

The long-term impacts of the pandemic on human well-being, the economy, and the energy sector are still uncertain, raising questions and concerns as to how the post-COVID-19 recovery will either advance or undermine efforts to reach the Sustainable Development Goals (SDGs) and to combat climate change. This section outlines key enablers and priority areas in sustainable energy transitions in a post-COVID world:

- Diverting support and investments from fossil fuel to clean energy
- Cities as a driving force for the energy transition
- Digitalization and digital divide

Advancing energy efficiency and decentralized renewable energy systems[1].

- Harnessing the power of collective responsible behavior
- Science and technology
- Ensuring a just energy transition

[1] In this report, decentralized energy is broadly used as a term covering both decentralized, community-level and distributed energy systems.

2.1 Diverting support and investments from fossil fuel to clean energy

The fossil fuel industry enjoys a subsidy of 370 billion USD per year, while the renewable energy sector is subsidized to the tune of 100 billion USD (Bridle et al., 2019). If the support for fossil fuels continues, the climate impact is likely to lead to extreme events, as identified in the Fifth Assessment Report of the IPCC (IPCC, 2014).

It is thus critical for post-COVID-19 recovery packages to incentivize a green recovery and to accelerate the large-scale deployment of renewables and energy efficiency. However, the latest data show that many national responses to COVID-19 continue the pre-pandemic path in supporting the production and consumption of fossil fuels. The Energy Policy Tracker shows that the recovery packages of G20+ countries favor fossil fuels over clean energy. Since the beginning of the pandemic, G20+ countries pledged 52% of all public money committed to the energy sector to fossil fuels (222 billion USD) and only 3% to clean energy (Energy Policy Tracker, 2020).

Unless this trend is reversed, the transformation toward a more sustainable global energy system and the achievement of SDG 7 and the goals of the Paris Agreement will be significantly jeopardized. In addition to public support, mobilizing private investment is essential to reach the large levels of investments required for the clean energy transition. The available volumes of public and blended finance are not sufficient to meet energy services under SDG 7. Stimulus packages need to leverage private investments and promote public–private partnerships. Policy signals should be given to stimulate a reallocation of investments toward clean energy projects, and a solid bankable project pipeline for sustainable energy investments needs to be built. Developing countries will need significant climate financing to palliate the costs of eliminating barriers associated with the energy transition, and this financing should supplement Official Development Assistance (ODA) flows and not be a substitute for them.

This becomes even more relevant, given that oil and gas are losing their competitiveness in key markets and becoming an increasingly unstable asset. Major investment reallocations toward clean energy projects would reduce the risk of stranded assets (Carbon Tracker, 2017). Policy interventions to minimize assets stranding, for instance, through a diversification of investments into low-carbon assets, such as clean energy equities and green bonds, and increase transparency through corporate climate disclosures are necessary (Baron and Fischer, 2015). An increasing number of countries are now considering putting a moratorium on new coal-fired power plants. Moreover, development financing institutions are now debating the conditions in which they will allow future financing of new gas-fired power infrastructure. Most of them already account for the risk of stranded assets when examining investment decisions. Some, like the European Investment Bank will phase out support to energy infrastructure directly associated with unabated fossil fuels (UN Habitat, 2020).

2.2 Cities as a driving force for the energy transition

Cities are the epicenter of the COVID-19 pandemic. According to UN Habitat, more than 1430 cities are affected by the pandemic in 210 countries, and well over 95% of the total cases are located in urban areas, with the most devastating impacts being on the urban poor (UN Habitat, 2020).

Cities have to deal with the impacts of climate change and with air pollution, which have been linked to higher COVID-19 death rates (Xiao et al., 2020). Cities are not only vulnerable to climate change, but also contribute to it by consuming 60–80% of global energy, and producing a significant share (more than 70%) of carbon emissions. As the world continues to urbanize, with 70% of the world population projected to live in urban areas by 2050, promoting energy efficiency, integrating renewable energy technologies into urban energy systems, electrical mobility, and active travel modes will be critical. Setting renewable energy targets is an important component of cities' efforts to boost deployment of renewables. A growing number of cities have set renewable energy targets, but more than 80% of them are in Europe and North America. Meanwhile, cities in Asia and Africa are falling behind in renewable energy target setting, even as their energy demand is expected to grow (IRENA, Renewables, 2020).

As the pandemic has demonstrated, securing access to affordable and clean energy services for all is an urgent priority for cities to ensure adequate healthcare services, online education, remote working, heating, cooling, and a safe environment. This is especially so for cities in low-income and lower-middle-income countries where the pace of urbanization is projected to be the fastest.

The way our cities are designed significantly affects their energy consumption, livability, and resilience. Two current dominant urban forms—dense developments with large concrete structures and urban sprawl— are characterized by the large presence of cars and extensive road infrastructure for motorized traffic, resulting in high levels of air pollution, CO_2 emissions, heat island effects, and noise levels. Furthermore, the use of public space by motorized traffic leads to lack of green space, poor social links, and reduced physical activity (Neiuwenhuijsen, 2020).

The travel restrictions imposed in response to COVID-19 have significantly affected people's mobility behavior. Global road transport activity was almost 50% below the 2019 average by the end of March 2020 (IEA, Global 2020). The use of public transport has almost stopped; for instance, the travel restrictions in the UK have led to a 95% reduction in underground journeys in London (Azzam Abu-Raysh et al., 2020). Most of the changes in travel demand have been driven by the adjustments that individuals have made to their daily travel activities, such as working from home, online education, and online shopping. Consequently, many cities have experienced cleaner air and a reduction in road traffic and noise.

Recognizing these positive changes, many cities have started to rethink urban planning and use of public space by promoting a more integrated approach that allows the virus, climate change, and air pollution crises to be dealt with simultaneously. Many cities are limiting vehicle traffic and converting street space from cars to cycling and walking by expanding sidewalks and cycle lanes. Some examples include Milan's open streets plan, San Francisco "slow streets" campaign; the introduction of 80 kilometers of temporary bike lanes in Bogota; and the conversion of over 100 streets for pedestrian use in Buenos Aires. The success of these initiatives should encourage city governments around the world to convert more roads for similar purposes, especially given that a large number of car trips in cities are less than 5 km and that for 96% of the time cars are parked (Neiuwenhuijsen, 2020). These measures will not only help reduce the energy intensity and carbon footprints of cities, but also make cities more livable and healthier as physical activity increases and air pollution goes down.

Despite the positive examples, the use of private cars in many cities is on the rise again since the lifting of lockdowns. This trend will likely continue, at least in the short-term, as people seek to avoid using public transport to minimize the risk of infection. However, without a significant amount of shared mobility, it will be challenging for many countries to meet their longer-term climate goals. The post-COVID–19 recovery should therefore aim to reverse the trend in reduced shared mobility by making it more convenient and less expensive than private car travel. Governments could use recovery packages to improve public transit quality, frequency, cleanliness, and safety. Additional measures to reduce private car travel demand include: removal of on-street parking spaces; increased parking fees; introduction of car-free days; creation of temporary cycle lanes following metro line routes; distance-based vehicle insurance; congestion pricing, etc. Normalizing and institutionalizing remote working practices provides another opportunity to reduce travel demand and associated carbon emissions and air pollution.

Promotion of innovative multimodal mobility services and e-mobility can also make urban mobility less carbon-intensive. Advancing electrification of the transport sector would require policies that stimulate investments in e-mobility vehicles (e.g., direct subsidies for electric vehicle purchase, road tax exemption, free city center parking for electric vehicles [EVs]). Installing charging infrastructures and implementing innovative business models such as smartphone-based transportation network companies will be important.

To reduce demand for mobility and increase resource efficiency, some cities have started to redesign cities into urban villages and compact neighborhoods that provide access to all amenities within walking distance. For instance, Paris promotes self-sufficient neighborhoods, with all the amenities needed (shops, offices, schools, etc.) within a 15-minute radius. Several other cities around the world like Melbourne with its "20-minute neighborhoods" and Copenhagen’s Nordhavn "5-minute neighborhood" are promoting a new standard for the use of space and sustainable mobility.

A shift to working from home has led to increased electricity consumption in residential buildings and higher electricity bills, severely affecting low-income households. The building sector and the construction sectors combined are responsible for over one-third of global final energy consumption and nearly 40% of total direct and indirect CO2 emissions (IEA, Buildings, 2020). Demand for energy in buildings is projected to further increase due to rapid growth in the floor area of buildings globally and the growing use of household appliances and air conditioning to deal with extreme heat. The creation of a built environment that is low-carbon is thus critical for addressing sustainable urban development challenges (Cabeza and Ürge-Vorsatz, 2020). This transformation would require a combination of new technologies, innovative urban design, enabling policies and regulations, new processes for planning and managing urban development, and demand-side changes in consumer attitudes and practices for urban living related to energy (Newton and Rogers, 2020).

Given that the world has significant infrastructure needs—90 trillion USD of infrastructure investment is needed for 2015–2030 mainly in developing countries (Meltzer and Constantine, 2018—it is important to ensure that the COVID-19 recovery measures stimulate the construction of new buildings that are less resource- and carbon-intensive, as well as the renovation of the existing building stock to ensure it meets the same standard. Unless the new infrastructure is low-carbon and climate-resilient, the world will be locked into a high-carbon pathway and will miss the Paris Agreement’s goal of keeping the global average temperature increase well below 2 degrees Celsius by 2050.

COVID-19 has also highlighted the need to design buildings for flexibility of future use. As the pandemic has spread, new emergency facilities like hospitals, quarantine centers, and testing sites have had to be created. The shifts to remote working and the virtual delivery of essential services will also reduce the demand for office space. The current crisis is thus accelerating the need for flexible buildings where the space can be adapted depending on need, and be capable of providing different accommodations: offices, residential, and other functions. Such mixed-use buildings not only utilize resources and space more efficiently but can also provide city dwellers with neighborhoods that integrate work, home, shopping, and green spaces. Converting vacant office buildings into more affordable housing can also help to reduce travel demand. Reducing car dependence and improving energy efficiency in the building and transportation sectors should be a key priority for cities going forward.

2.3 Digitalization and digital divide

Because of the COVID-19 crisis, many organizations have been forced to adopt new working practices and have felt a strong pressure to offer products through digital channels. Companies have experienced profound changes and, in a very short time, have implemented solutions based on digital technologies. A significant proportion of the world population have shifted to working from home and millions of consumers have been going shopping online. This rapid migration to digital technologies driven by the pandemic will continue into the recovery, making it critical to explore the opportunities provided by digitalization to advance the energy transition (Hossein Motlagh et al., 2020). Digital technologies and innovation are forming new economies as well as creating new platforms for connectivity and collaboration, substituting digital (online and streaming) platforms for physical service provision and replacing traditional physical meetings with digital forms of communication (tele-working, online meetings), thus reducing demand for mobility.

Digitalization has the potential to make consumption more sustainable and reduce its carbon footprint, as it offers opportunities to use resources more efficiently. It can contribute to transparent information flows to support sustainable consumption. Digital applications can guide consumers to make sustainable choices or to use existing products for longer or more efficiently or put pressure on producers to reduce the environmental footprint of their products (Umweltbundesamt, 2019). Digitalization also provides opportunities to the energy sector in particular, by advancing the decentralization and decarbonization of energy systems. Digitalization contributes to changes in energy market design, enables new business models, and drives the development of smart cities, factories, communities, buildings, and mobility. Digitalization also leads to enhancements in the ability to collect and analyze relevant data to better coordinate energy planning, investment, and operational decisions. In industry, for example, digital technologies are being used to improve safety, increase production, and make product manufacturing more flexible (IEA, Digitalization, 2017).

Digitalization is also essential to integrate various renewable energies into the electricity grid and thus ensure a high-quality power supply. It enables smart grids and virtual power plants that aggregate output from distributed power plants. It also enables better forecasting (e.g., wind speeds), intelligent predictive maintenance of assets and outage prevention, and plant optimization, among other things. Digital technologies are reshaping the energy system by the massive collection and analysis of data (big data), enhancing remote control of assets (which enables demand response), behind-the-meter generation, home energy management, and vehicle-to-grid technologies, as well as unlocking flexibility from different sources, such as battery management systems, heat pumps, and appliances (IRENA, 2019).

Digitalization also enables more efficient use of built infrastructure. A smart-ready built environment can enable energy-system-responsive buildings, which at the same time provide better indoor environmental quality and comfort for the occupants. For example, artificial intelligence in Building Management Systems (BMS) can improve building operations, making buildings more energy-efficient, helping them participate in energy markets, improving comfort control, and enabling predictive maintenance (IoT for All, 2018).

In the mobility sector, the combination of Autonomous driving, Connectivity through the Internet-of-Things (IoT), Electrification and Shared mobility (so-called ACES) can accelerate the uptake of new mobility options (McKinsey & Company 2019). These technologies provide opportunities to improve mobility and reduce car ownership, car traffic, and parking needs but should be integrated with public transport in multimodal strategies to obtain better gains (Sanvicente et al., 2018).

Digitalization of the economy through technologies like teleworking, e-mobility, intelligent building management systems, industry 4.0, etc., offers the potential to increase energy efficiency and drive a reduction in energy demand. At the same time, the total electricity demand for information and communications technologies (ICTs) could increase substantially, making the green growth of ICT technology essential (Ökoinstitut and Technical University Berlin, 2014).

In this context, it is necessary to understand and quantify the effects of digitalization on energy demand (e.g., potential rebound effects), how it enables new business models, what the socioeconomic impacts of digital technologies are, and what policy and regulatory frameworks are required. The deployment of digitalization also requires careful consideration in terms of its impact on jobs and socioeconomic development. Although it can deliver economic benefits through greater productivity and job creation in advanced manufacturing and support services, digitalization can also reduce physical tasks (European Commission, 2019).

Research and development with respect to digitalization should be increased, as it offers substantial opportunities for innovation**,** including standardization and interoperability. The latter is critical to enabling smart appliances and flexibility sources such as electric vehicles, heat pumps, and batteries to exchange data with each other and thus facilitate the uptake of new business models related to renewable energy self-consumption, intelligent energy management, and demand response services (SolarPowerEurope, 2018).

The scale of the digital divide is enormous. For example, there are massive inequalities within schools and homes in terms of internet access and the technologies needed to participate in home-schooling via the internet. This problem is not restricted to developing countries and disadvantaged regions. Depending on the type of community in question, different focuses are needed to address these problems. A systematic upscaling effort is needed in regions where most of the population is lagging behind with digitalization or where digital illiteracy deters citizens and students from moving to an online-based lifestyle; it is also imperative to ensure leap-frogging for more expeditious dissemination of modern solutions. In developed regions, where the majority of the population are well-equipped, the individuals and families lagging behind digitally can face educational gaps and miss out on job opportunities. Such groups need to be identified and supported. It is vital to facilitate digital inclusion for low-income communities and citizens to improve their economic opportunities: digitalization can increase skills and literacy, community organization, knowledge exchange, and civic engagement. Digital inclusion requires collaboration across the public, private, and civil society sectors, awareness-raising, and the granting of subsidies to give people access to digital tools. Efforts are needed to include different population segments in the expansion of the digital economy, including women, youth, elderly, micro-, small- and medium-sized enterprises, and rural inhabitants (EU, 2018; Global Forum on Sustainable Energy, 2020).

2.4 Advancing energy efficiency and decentralized renewable energy

Energy efficiency offers multiple benefits including job creation, increased industrial productivity and self-sufficiency, reduction of impacts of volatile energy prices, poverty alleviation, and climate change and energy security. Therefore, measures to improve energy performance as part of green stimulus packages will lead to faster economic and social recovery and bring social, economic, and environmental benefits.

While access to electricity has improved in the past few years, lack of access is still a significant problem in many countries, and this situation has been further exacerbated by COVID-19. The pandemic has highlighted the importance of relying on local solutions, such as decentralized, renewable-based energy services; this increases the resilience of the system in coping with disruptions in supply and accessing modern energy services, especially in developing countries. Electrification plans should give priority to health facilities and other essential energy services using local decentralized energy solutions. Decentralized renewable energy can offer cost-effective and rapidly deployable modular solutions. In Kenya, for example, solar PV provides health clinics with reliable electricity for medical equipment use and the ability to safely store vaccines (Chen et al., 2019). Reliable electricity improves the quality of healthcare and also enables the working hours of healthcare facilities to be extended.

Decentralized renewable energy solutions can also increase the resilience of energy systems to natural and anthropogenic disasters and secure the provision of crucial services and infrastructure, such as healthcare facilities, in the event of an energy service interruption. As extreme weather events such as heatwaves, tornados, floods, droughts, and fires, caused by climate change, become more frequent, resilience will become a more important factor in energy planning. This also applies to the linkages between the energy sector and, for example, the water sector. Electricity and water systems are inextricably linked through water demands for energy generation, and through energy demands for using, moving, and treating water and wastewater. The energy demands of climate adaptations on the water sector could significantly affect future electricity system needs, and this requires planning to be coordinated between the energy and water sectors to achieve mutually beneficial solutions for climate resilience (Szinai et al., 2020).

Variable renewable energy (VRE), namely, solar photovoltaic (PV) and wind, have been the main pillars of renewable energy transitions (IRENA, Global, 2020). With the capital cost of PV declining, the uptake of distributed solar PV has increased significantly in recent years, with an annual average growth rate of about 50% between 2010 and 2020 (SEIA, 2020). Solar PV generation in many countries does not completely coincide with household electricity demand, which reduces the self-consumption of generated electricity. To balance the intermittency and variability of electricity generation from wind and solar PV, a number of flexibility options, such as energy storage, are needed to match energy supply and demand reliably (Lund et al., 2015).

Energy storage systems can contribute to the integration of high shares of VRE, minimizing the need for fossil fuel–based peak generation and backup power capacity and resulting in lower carbon emissions and reduced electricity prices (McPherson et al., 2018; Staffell and Rustomji, 2016). Moreover, by increasing the self-consumption of distributed renewable energy, energy storage can reduce possible grid contingencies in peak times, lowering system-wide generation costs and potentially avoiding the need for the grid network reinforcement (Goutte and Vassilopoulos, 2019). Energy storage is also a viable solution for islanded and off-grid locations. As the cost of distributed energy storage, like home batteries, is typically higher than the benefits for consumers under current market conditions (Schmidt et al., 2017; Zakeri and Syri, 2015), policy intervention is needed to increase the deployment of the storage systems. The policies for supporting energy storage can be combined with renewable energy policies to ensure the uptake of distributed energy generation in an optimal manner reducing the curtailment of clean energy (Castagneto et al., 2019; Gissey et al., 2020).

Improving the reliability and climate resilience of the electricity system also necessitates a modernization of existing electricity grids through the implementation of smart and flexible grids, capable of integrating a higher share of decentralized renewable energy and e-mobility, storage, and demand response. A sound load management in extreme weather situations and approaches to quickly isolate failures are fundamental to ensure the power system's ability to withstand disturbances with the minimum acceptable service disruption.

Decentralized energy systems also enable the participation of local actors such as cities and communities, and small- and micro-enterprises in the provision of energy services, thus changing the structure and governance of the energy sector toward a multi-actor arrangement. Through open and participatory processes, decentralization also empowers communities to choose energy sources and technologies that provide energy services with the most benefits to their community. Given the multiple benefits offered by decentralized renewable energy solutions, their deployment should be at the center of a long-term recovery strategy.

While efficiency policies have traditionally focused on technical requirements, there is still much room for improvement. The pandemic has shed light on the value of social norms and behavioral change related to energy-using products, services, mobility, and their upstream impacts. The pandemic is also changing the design and operation of energy-efficient buildings toward the incorporation of more stringent health criteria (e.g., in heating, ventilation, and air conditioning [HVAC] and air filtration systems) thus necessitating the introduction of building codes that incorporate energy efficiency criteria and COVID-19 mitigation criteria (U.S. Environmental Protection Agency, 2020). Even today, less than one-third of countries globally have mandatory energy-related codes for new construction (International Energy Agency and International Monetary Fund, 2020). In the other countries, energy efficiency building codes do exist, but they still have to be enforced (Global Alliance for Buildings and Construction et al., 2019).

New policy instruments may push energy performance gains as part of recovery packages aimed at people-centered, multi-beneficial energy-demand changes. These policies include: i) promoting energy-saving obligations (whereby energy utilities/suppliers are obliged to save a few percent of their total energy sales per year); ii) promotion of one-stop shop solutions for residential building refurbishment (thus reducing the renovation hassle for homeowners and tenants) iii) new mobility services (such as mobility as a service solution) or stimulation of energy neighborhoods; and iv) reduction of the upstream energy and resource impacts of energy demand, etc.. In the long term, energy-related building codes can be successively tightened toward nearly-zero energy building standards. Besides reducing energy bills, energy-efficient buildings offer great potential for job creation (e.g., local construction jobs and manufacturing jobs due to increased demand for building materials and equipment).

Energy transitions can affect local communities significantly, resulting in job losses and reducing incomes, for instance, after the closure of large fossil fuel plants and coal mines. Thus, a fair and equitable energy transition that addresses the social and economic effects of transition is required. Fair transition mechanisms focusing on the people, regions, and sectors most affected by the energy and climate transitions can help create new jobs and new economic activities through a combination of worker education and retraining, social support, local economic development tools for communities, and support for the creation of new businesses, among other thing (Henry et al., 2020).

2.5 Harnessing the power of collective responsible behavior

COVID-19 has demonstrated the critical role of individual and collective responsibility and actions in achieving positive social outcomes in the face of the pandemic. Hundreds of millions of individuals, armed with the knowledge of how to protect their own health and the health of others have isolated themselves in response to the virus, often at great personal, social, and financial cost. Throughout the pandemic, the focus has been on individual responsibility. The collective impact of individual behavioral changes has been sudden and dramatic. Almost immediately, people have changed their daily routines and altered their household consumption patterns (Budd and Ison, 2020).

Public information campaigns that explain to citizens, individually and collectively, the effects of their behaviors on themselves, others, and the environment, and that encourage more sustainable energy and transport practices, can similarly be an effective option for governments seeking to create long-term shifts in energy and travel demand. Citizens play a critical role in advocating and helping to make public institutions more transparent, accountable, and effective, and contributing innovative solutions to complex development challenges (World Bank, 2020).

Bottom-up pressure from the public (i.e., individuals taking greater responsibility for their own actions and involving themselves in the development of policies and plans) can encourage governments to create the political, financial, and physical infrastructure required to transform energy and mobility habits and decarbonize those same sectors.

People should be at the center of the energy transition (see Figure 2). The energy transition is leading to various forms of social innovation, defined as new ideas (products, services, and models) that simultaneously meet social needs and create new social relationships or collaborations (European Commission, 2013). Examples of social innovations are energy cooperatives, energy "prosumers" consuming and producing energy, living labs, citizen science, and new participative forms of decision-making, such as citizen assemblies and local energy forums (GFSE, 2020; Wittmayer et al., 2020). Citizen engagement must be strengthened. Approaches to citizen participation should also involve underrepresented social groups and be inclusive of age, gender, race, minorities, and geography (Haf and Robison, 2020).

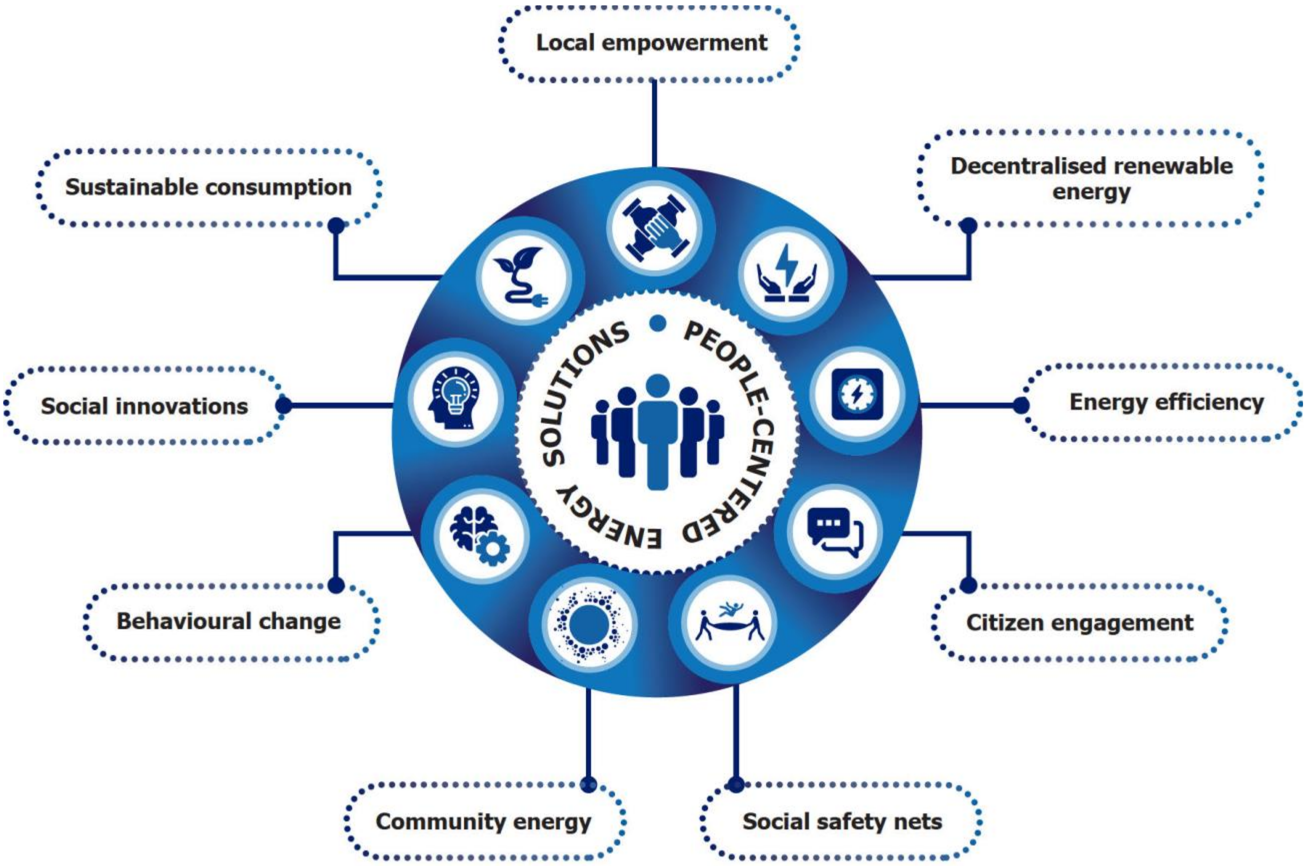

Figure 2: People centered energy solutions

2.6 Science and innovation

The Covid-19 crisis and the global lockdowns have had a profound effect on the energy sector. The long-term impact of the pandemic is still unknown and will be determined by how long the restrictions last and what recovery measures will be taken around the world. The recovery packages that governments are putting in place will shape the energy sector for years to come.

Science will be critical to understanding the long-term impacts—on energy systems and for clean energy transitions across various regions—of both the COVID-19 crisis and the measures taken by governments. Specifically, it will be important to assess the lasting effects of the COVID-19 pandemic on energy demand and supply, governance, innovations, and investments. Understanding how the pandemic will influence individual behaviors, lifestyles, and social practices in relation to energy and mobility in the longer-term will also be key. Science can make a valuable contribution by identifying policy options to incentivize positive behavioral changes and to discourage unsustainable practices. It is also critical to assess the impact of the pandemic on energy demand in transport, buildings, and industry and, to identify options for making digitalization more sustainable, as its development gathers pace.

Research and innovation will be critical elements in achieving the objectives of numerous governments and companies to reach net-zero carbon emissions in the coming decades as part of global efforts to meet long-term sustainability goals and the Paris Agreement on climate change. Among the various stimulus spending options for both positive economic and environmental benefits and long-run multipliers, "clean energy R&D" and "clean energy infrastructure investment" score the highest (IEA, Clean Energy Innovation, 2020). However, the latest data on the scale and focus of public budgets for energy R&D around the world indicate that budgets are not in line with ambitious international climate and sustainable energy goals.

Limiting global warming to 1.5°C and the sustainable energy transition will require rapid and deep alteration of attitudes, norms, incentives, and politics. To answer some of the key climate-change and energy-transition puzzles, there will be strong reliance on contributions from the social sciences. However, these are precisely the fields that receive least funding for climate-related research. Between 1990 and 2018, the natural and technical sciences received 770% more funding than the social sciences for research on issues related to climate change. Only 0.12% of all research funding was spent on the social science of climate mitigation. This underinvestment in social sciences undermines the possibility of tackling the most urgent question: how to change society to mitigate climate change (Overland and Sovacool, 2020).

The role of architecture and urban design will also be of critical importance in ensuring that future cities are more sustainable, healthier, and resilient. A portfolio of innovations is required for the transformation toward sustainable and affordable energy services. Innovations refer not only to new technologies, which must be advanced to enable net zero energy systems (Azevedomm et al., 2020) and new policy measures, for instance, reorganizing energy markets. Innovation cycles must be accelerated to stimulate technological learning and bring efficiency improvements and cost reductions. Granular innovations such as decentralized, small-scale, renewable energy technologies and energy-efficient appliances, which are typically smaller and more modular, may have higher learning and diffusion potentials and may be more suitable for a rapid transformation (The World in 2050, 2020). In the global electricity sector, for example, innovations are emerging across four key dimensions: enabling technologies, business models, market design, and system operation (IRENA, 2019).

Enabling technologies such as storage, technologies that facilitate electrification of end-use sectors, digital and ICT technologies, and smart grid technologies, together with novel system operation to handle the volatility of wind and solar resources, play a key role in facilitating the integration of renewable energy. For example, the coordinated planning and operation of electric vehicles and renewable energy power generation in the future is a key link in achieving decarbonization in the power and transportation sectors. Smart charging strategies for electric vehicles can also provide flexibility to the power system and increase the share of renewable energy (Li et al., 2020).

New business models (Glachant, 2020), for instance, facilitating peer-to-peer trading, which allows consumers and producers to trade electricity directly without the need for an intermediary, and adaptations to the design of the electricity market can enhance the affordability, system flexibility, and value of new grid services (Anisie and Boshell, 2020).

Investment priorities should be scrutinized with respect to, among other things, their potential to increase the adoption of innovative technologies and their spillovers into other innovative technology solutions necessary for the energy transition. Accelerating innovative technology solutions in recovery packages can align near-term investment with the long-term energy transition and create a multiplier effect in the medium to long term (IRENA, Recovery, 2020).

Beyond technology, understanding the dynamics of human behavior can help policymakers to complement traditional energy policy measures with behaviorally informed ones. We must identify, design, and implement the policies that can help produce the behavioral changes required for the energy system transformation (Bouman et al., 2020; IEA, World Energy, 2020).

Social innovations in the energy sector must also be examined in detail: specifically, the conditions that facilitate their emergence, their contribution to the development of new business models and greater acceptance of the transition toward net-zero, climate-resilient energy systems. Identifying effective approaches to facilitate citizen engagement in energy transitions to make them just, democratic, and sustainable, and to identify solutions to urban development challenges is essential (Chilvers et al., 2018).

Overall, given the complexity of sustainable energy transitions, the involvement of different actors and the power dynamics in play, research practice will also need to shift toward a more collaborative mode of knowledge production—transdisciplinary research that integrates the diversity of scientific and societal views of the problems and helps to increase the use of scientific evidence as a basis for energy policy development and practice. The ability of the science, policy, and governance systems to rapidly respond to newly emerging and rapidly unfolding shocks at national and international levels should be significantly enhanced. The transformation of the energy systems toward sustainability may have to be undertaken under the influence of dangerous climate change, massive shocks to global socioeconomic systems, and increasing human impacts on nature.

2.7 Ensuring a just energy transition

An explicit focus on equity and justice in immediate recovery efforts and medium and longer-term transition policies is essential in order to reduce growing disparities and inequities, increase the resilience of disadvantaged and vulnerable groups, and ensure that the latter have a voice in energy and climate governance. Policies and efforts to help people with limited resources, and those that are more vulnerable to shocks, need to be prioritized. An explicit focus on the social aspects of energy transitions is as important as the traditional techno-economic focus. This will determine specifically how society embraces, encourages, and supports transitions to low-carbon futures.

The pandemic has had an enormous economic fallout, with significant negative social repercussions for employment, income, and access to energy services, which increases the need protect low-income and vulnerable populations. Working from home has a very different meaning for the poor who have lost their livelihoods and are trapped in debt and unable to repay it. Many of these populations have also struggled with a lack of access to reliable electricity and internet services or are unable to afford these services. This has exacerbated the already deepening digital divide and the ability of many to participate in the new COVID-19–mediated digital life, including home schooling. Energy and other social safety nets are required now more than before to help improve access to essential energy services for the poor and vulnerable to make such services affordable for all (OECD, 2020). In the longer term, energy safety nets could be linked to energy efficiency programs, for instance, through soft loans and subsidies for low-income populations to enable them to buy energy-efficient, easy-to-repair appliances that will reduce the impact of energy price increases on welfare and consequently reduce energy poverty (SEforall, Safety, 2020).

The effects of COVID-19 have exacerbated existing inequalities for women and girls, specifically, and threaten the progress that has been made on gender equality and women's rights. Yet, women can make a substantial contribution to the energy transition (GWNET, 2020). More effort is needed through regional and national initiatives to involve women in the design and implementation of energy-efficient and renewable energy policies and in local value chains, for instance, by training them as entrepreneurs, engineers, and technicians on energy efficiency and renewable energy technologies.

Energy efficiency and renewable energy value chains offer employment opportunities (Kane and Shivaram, 2020). Regional and national initiatives to develop skills and create jobs for young people in local value chains for renewable energy and energy efficiency must be pursued vigorously, through increased collaboration between the private sector and educational institutions, and improvements, too, in the quality and accessibility of training, among other things, through digital knowledge transfer platforms.

Populations living in slums and low-income housing and those with shelter that is temporary, inadequate, or of poor quality have been particularly impacted by the ongoing pandemic and are at higher risk of contracting the virus. Efforts to provide access to adequate shelter and a comfortable and clean indoor environment must be accelerated. Recovery and stimulus packages could be designed to deliver co-benefits for these targets, too. In the short term, measures that provide rental assistance and prevent evictions, for example, through a moratorium on evictions and foreclosures, and measures that provide emergency funds for the homeless or those unable to afford utility bills, may be needed. Stimulus packages and longer-term efforts, however, need to target the provision of affordable and sustainable housing infrastructure (Dalton and Pope, 2020; Ellen et al., 2020). New construction and refurbishment projects that aim to provide affordable and low-carbon housing infrastructure can also provide jobs and employment.

In low- and middle-income nations, policies and programs to provide universal access to clean cooking and heating have been impacted by the crisis as well. Leveraging social assistance mechanisms to help poor families afford clean cooking and heating services and thermal comfort in the home can drive efforts toward enhancing universal access and achieving SDG 7. An intersectoral approach to recovery plans can also reap additional benefits for health and equity (Batchelor and Brown, 2020).

The COVID-19 crisis has revealed significant weaknesses and, in some cases, a complete absence of safety nets for the less privileged. Addressing prevailing vulnerabilities and inequities exacerbated by the Covid-19 pandemic is imperative for building resilience and overcoming long-standing gaps in existing policies and efforts toward equitable and just energy transitions. There is a risk of excluding the vulnerable from access to essential energy services unless strong policies to support them are implemented, like energy safety net functions (SEforall, Safety, 2020), programs to guide off-grid companies to protect and support customers, and provision of financial assistance for energy access companies (ECREEE, 2020; SEforALL, Off-Grid, 2020).

3 Areas for Policy Intervention

This document puts forward three areas for policy intervention toward a sustainable energy transition in the light of COVID-19 impacts:

1. Reimagine consumption through the advancement of a circular and sharing economy and citizen engagement;
2. Reinvent urban space, infrastructure, and mobility through: i) the promotion of compact urban development with reduced car dependency and easy access to key services, including public, shared and active mobility; and ii) acceleration of the transformation toward a low-carbon, flexible, and resilient built environment; and
3. Advance decentralized and resilient energy systems, including energy efficiency improvement measures.

The justice and equity considerations should be central to these interventions to increase the resilience of disadvantaged and vulnerable groups and to ensure that they have a voice in the energy transition.

3.1 Reimagining consumption: Circular and sharing economy and citizen engagement

There is a need to shift toward more sustainable and responsible modes of production, distribution, and consumption of energy products, energy technology, and energy services. At the same time, actors in the energy systems need to change to more sustainable and resilient norms and practices. This requires a systemic change in the way we produce and consume so that resource consumption remains within planetary boundaries and our consumption footprint is reduced. Efficiency improvements that allow more services to be delivered using fewer resources to satisfy human needs and improve well-being should be complemented by sufficiency considerations, that is, efforts to consume less in absolute terms, taking into account the limitations of resources and respecting Earth's ecological boundaries (The World in 2050, 2020; Wiedmann et al., 2020).

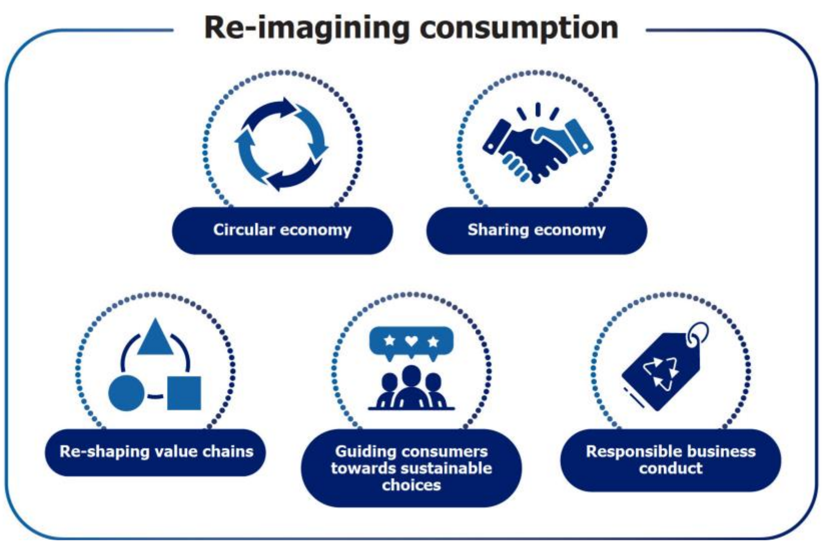

Figure 3. Main elements for rethinking consumption

The concept of consumption needs to be transformed toward responsible, sustainable, and sufficient ways of meeting human needs. Technologies and policies can encourage behavior and lifestyle changes leading to a new "consumerism of sufficiency," characterized by high resource-use efficiency, digital convergence, and increasing importance of the circular and sharing economy (Bocken and Short, 2019; Millward-Hopkins et al., 2020). Figure 3 depicts the main elements of a re-thought consumption that are discussed in this Section.

Sustainable consumption through circular economy and sharing economy

Shifting toward a circular economy is a key priority in that it allows products and materials to be kept in use, thereby reducing waste and pollution and enabling the regeneration of natural systems. For example, after energy efficiency is improved, energy systems should become more integrated to deliver low-carbon and resource-efficient energy services and to reuse waste streams such as industrial waste heat and bio-waste for energy purposes (European Commission, 2020). Product durability, reusability, and reparability must also be improved, and the energy and resource efficiency of products should be increased. A coordinated approach to sustainable consumption between different policy areas is necessary, ranging from research, innovation, energy, and industrial policies to education, health, welfare, and trade. This would allow consumers to adopt more sustainable lifestyles and make products and materials longer-lasting, more energy-efficient, and less environmentally damaging.

Promoting a sharing economy allows goods, appliances, and equipment to be used by many, instead of owned and used only individually, which makes better use of their capacities. There is a wide range of business opportunities along the interface of the sharing economy and the energy sector, that has attracted growing interest and could be further promoted. Shared mobility, sharing electricity generated from intermittent renewable energy, community-owned solutions, city spaces, and shared appliances reduce overall resource use. Implementation of regulatory frameworks that promote a fair and effective sharing economy and reduce social and other risks must be implemented. These could, for example, protect consumer interests, adapt existing tax frameworks to ensure a fair share of value added is captured by the state, and shape labor laws to ensure that companies adhere to legitimate rules (a-connected, 2020). In the light of poverty and inequality considerations, the limitations to sharing need to be addressed. Fair use of shared systems and "things" need to be resolved. As the access of disadvantaged populations to these services may be precarious, specific solutions for these people are also needed.

Sustainable consumption strategies should also aim to make sustainable consumer choices accessible and affordable, protecting people's rights along the whole value chain (IBON International, 2020).

Special attention thus has to be given to ensure that healthy, sustainable, and safe products and services are made available to poor and vulnerable populations at affordable prices.

Resilient supply chains

Trade and investment agreements have enabled a system of production and consumption based on interlinked economies. These global value chains have been substantially affected by the COVID-19 crisis and should be reshaped to make them more resilient. Governments should encourage more responsible business conduct. Companies should map social and environmental risks in their international supply chains and take measures to prevent or mitigate them. Traceability systems that show where products originate and how they move through the supply chain would help to identify sustainability risks (Roy, 2019).

Awareness raising and education

To help change behavior and positively influence the decision-making process, information needs to be freely available to raise people's awareness and motivate them to act. If properly designed, targeted awareness-raising campaigns and education will encourage attitudes and practices that will lead to fair and green public procurement and to circular economy approaches that will bring about a better use of materials and a reduction in wastage and emissions (European Economic and Social Committee, 2020). Policies should strengthen consumer protection against greenwashing and premature obsolescence and incentivize innovative business models, such as product-as-a-service, whereby producers retain ownership of a product and are responsible for its performance throughout its lifecycle (European Commission, 2020).

Societal and behavioral change and citizen engagement

Communities and civil society play a central role in supporting sustainable consumption initiatives when they engage in policy dialogues on sustainable consumption and production, support behavioral change processes, and facilitate awareness raising. Encouraging citizens to actively change their consumption habits, which is an important element of sustainable consumption, improves energy efficiency. Understanding behavioral changes and consumer beliefs, motivation biases and choices, and feeding the resulting insights into energy policy measures can help guide consumers to make lifestyle changes geared toward greater energy- and resource-efficiency and low-carbon consumption patterns.

Prosumers (professional consumers) have an important role to play in improving the sustainability of goods and services. Prosumerism enables people to become more self-sufficient, to generate income and choose environmentally benign technologies and products. Empowering citizens and local communities as prosumers generates benefits for the communities themselves. Electricity prosumers, for example, are consumers that generate their own electricity and inject excess production into the grid (Lavrijssen and Carrillo Par, 2017). Encouraging their active participation in electricity markets requires regulatory frameworks that allow them to self-generate, self-consume, store, and sell their electricity without facing unnecessary barriers (ECRB, 2020)

Encouraging industrial energy, resource efficiency, and circularity

Industry can substantially improve its energy and resource efficiency by optimizing processes and introducing circular economy approaches for energy purposes, such as the use of industrial waste heat and waste streams, recycling of scrapped metals and other materials to remanufacture products, and improving water use efficiency etc. (Rissman et al., 2020). Industrial energy and resource efficiency, for example, could be stimulated by direct financial incentives, tax deductions, and government-backed credits. There is a particular need to support capacity building for energy and resource efficiency in Small and Medium Enterprises (SMEs), which are job engines in many economies.

Enforcing Ecodesign for sustainable products

Rules for improving the lifecycle environmental performance of products must be introduced and enforced. Decisions made at the design phase influence the use and end-of-life phases of products (European Commission, 2019). Ecodesign allows products and services to become more energy- and resource-efficient, durable and reusable, and improves recyclability and waste-handling at the end of their lifetimes. Ecodesign also contributes significantly to circular economy objectives. For example, Ecodesign standards and labeling for lighting, appliances, and clean cookstoves can contribute significantly to improving their energy and environmental performance. Their implementation requires technical assistance, fiscal instruments such as rebates for purchasing new energy-efficient appliances, and market incentives for supply-chain actors to stimulate market uptake. Ecodesign also requires capacity building for standards bureaus and accreditation bodies, as well as testing facilities and systems for adequate disposal and recycling.

Promote regional and international cooperation

Regional and international cooperation for energy efficiency, decentralized renewable energy, and sustainable consumption are essential for achieving the levels of innovation and societal change necessary to increase the uptake of clean energy technologies and sustainable products and services. Cooperation facilitates knowledge exchange, the strengthening of institutions, creation of markets, awareness raising, training of the workforce, and support to companies. Regional policy frameworks for energy efficiency and renewable energy, including the setting of national targets and requiring the development of action plans, increase the confidence of the private sector and its readiness to invest (Agrawala, 2014).

The necessary economies of scale can be achieved through common regional markets and standards. For this, alignment of national and regional levels is required. One example of this is the development of guidelines for Minimum Energy Performance Standards (MEPS), Energy Labeling and Eco-design at the continental level in Africa—an initiative of the African Union Commission (AUC) in collaboration with the European Union Technical Assistance Facility (EU TAF), Regional Economic Communities (RECs), Regional Bodies, and regional centers for renewable energy and energy efficiency (ECREEE, RCREEE, SACREEE, EACREEE), which enables the creation of regional markets for energy-efficient appliances and equipment. The initiative supports member countries in the implementation of the MEPS and labels of appliances at the continental level; there is a harmonized regional approach to the implementation in order to create a larger and more homogeneous regional market with an effective control system and the establishment of regional appliance testing laboratories. The initiative facilitates is a part of the Strategy and Action Plan for a Harmonized Electricity Market in Africa (African Union, 2019). Table 1 summarizes the policy recommendations for reimagining sustainable consumption.

Table 1. Actions and objectives for policy recommendations for re-imagining sustainable consumption.

Action	**Objective**	**Timeframe**[a]
Implement policies to promote sustainable consumption and production	- Encourage responsible business conduct and mitigate social and environmental risks in supply chains - Coordinate approaches to sustainable consumption in different policy areas (e.g., research, innovation, energy, and industrial policies to education, health, welfare, and trade) Strengthen consumer protection	Short to medium
Promote circular economy	- Improve product durability, reusability, and reparability - Increase energy and resource efficiency of products - improve circularity of energy systems to deliver low-carbon and resource-efficient energy services and reuse waste streams - Develop and implement sufficiency-orientated business models (e.g., closed-loop recycling-based business models augmented with design for longevity, repair, and reuse)	Medium to long term
Apply policies to trigger behavioral change	- Guide consumers to make lifestyle changes toward more energy- and resource-efficient and low-carbon consumption patterns.	Medium to long term
Implement regulatory frameworks to promote sharing economy	- Promote business opportunities in the sharing economy, while protecting consumer, societal, and workforce interests	Medium to long term

Reshape value chains to improve sustainability	- Mitigate social and environmental risks in supply chains - Identify sustainability risks through traceability systems	Medium to long term
Promote regional cooperation for energy and resource efficiency	- Create regional markets for green products and services - Facilitate regional exchange of knowledge and training	Short to medium
Promote digital innovations	- Encourage producers to reduce the environmental footprint - Facilitate disclosure of information about products to market actors - Guide consumers to make sustainable choices - Enhance traceability systems that show where products originate and how they move through the supply chain to identify sustainability risks	Medium to long term
Making sustainable products and services accessible and affordable to low-income and vulnerable populations. (European Economic and Social Committee, 2020).	- Link sustainable consumption to agendas on nutrition, poverty and inequality - Achieve a better balance of access to resources and strengthen resource justice - Ensure that consumers benefit from a right to repair - Ensure that the healthier, more sustainable, and safer products are affordable to low-income citizens	Medium to long term

[a] Short: months to 1 year, medium: 1–3 years, and long: more than 3 years

3.2 Reinventing urban space, infrastructure, and mobility

Given that the cities account for more than 70% of global carbon emissions, how we transform our cities will determine whether we manage to achieve the SDGs and the commitments under the Paris climate agreement. The predicted 70% rate of urbanization highlights that the sustainability of the urban environment will be a key factor in building long-term global resilience to future crises. There is an urgent need to rethink and transform cities to respond to the reality of COVID-19 and potential future pandemics and to recover better, by building more resilient, inclusive, and sustainable cities. It is important to move away from a siloed to a more holistic and systemic approach to urban planning and management that would allow us to address health, livability, sustainability, climate change, and equity simultaneously.

Improving current cities will require strong collaboration between urban and transport planners, architects, scientists, and health professionals, to name a few. Furthermore, to ensure that future cities are people-centered will require strong citizen involvement to understand local needs and preferences. As cities are becoming decisive actors in shaping future sustainability, local governments should be empowered to take action. As the COVID-19 pandemic unfolds, local and regional governments are demonstrating innovative solutions that can address structural weaknesses exposed by the pandemic. Local governments should be further empowered financially, politically, and technically to take transformational action to make cities more sustainable and resilient. To this end, it will be important for national governments to support tailored local responses and enhance local governments' budgetary capacity. Recovery packages should enhance local and regional governments' ability to sustain critical public services and raise and control their own finances (for example, through local taxes, charges, and fees), while preventing additional financial pressure on poor and vulnerable groups. Furthermore, ensuring collaboration across different levels of government and promoting participatory, multilevel governance should be at the heart of local responses. For instance, stimulus funding for weatherization assistance programs can improve energy affordability, create jobs, benefit public health, and advance equity (Ayyagari and Glassman, 2020). The main pillars for re-inventing urban space, infrastructure and mobility are illustrated in Figure 4.

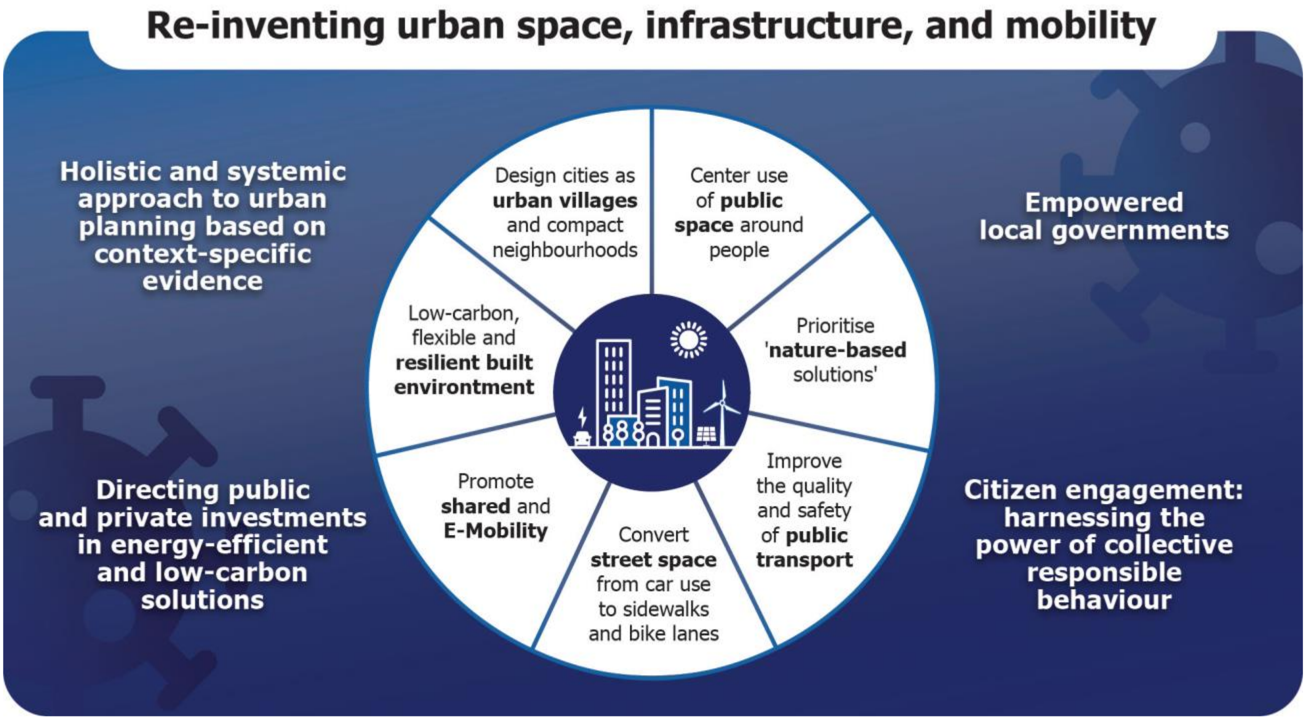

Figure 4: Re-inventing urban space, infrastructure and mobility

Building on the evidence provided in 2.1.2, two policy recommendations are put forward to make cities more sustainable and resilient:

1. Promoting compact urban development with reduced car dependency and with access to key services, including public, shared, and active mobility; and
2. Accelerating transformation toward a low-carbon, flexible, and resilient built environment.

A set of actions and measures relevant to these two key areas are presented in Table 2 and Table 3.

Table 2. Policy recommendation for promoting compact urban development with reduced car dependency and with access to key services, including public, shared, and active mobility.

Action	Objective/Measures	Timeframe[a]
1. Apply a holistic and systemic approach to urban planning	- Tackle multiple challenges simultaneously	Medium to long
2. Design cities as urban villages and compact neighborhoods with access	- Reduce travel demand and associated emissions	Medium to long

to essential services within short distance	- Reduce energy intensity and carbon footprints of cities - Improve transportation services for different target groups, including underserved low-income populations	
3. Reduce car-dependency in cities	- Rethink the use of public space to center around people - Convert street space from car use to sidewalks and bike lanes - Enhance the quality and safety of walking and biking infrastructure - Make private car travel in cities less attractive by raising parking fees; introducing car-free days; distance-based vehicle insurance; congestion pricing - Institutionalize remote working practices	Short to long
4. Promote shared mobility services for different target groups, including underserved low-income populations	- Improve the quality, cleanliness, and safety of public transport - Ensure that mobility solutions are affordable to low-income populations	Medium to long
5. Promote e-mobility and energy efficiency in transport sector	- Provide subsidies for an electric vehicle purchase, road tax exemption, free city center parking for EV - Install charging infrastructure - Implement innovative business models such as smartphone-based transportation networks - Introduce intelligent traffic management - Promote EV-based ride-hailing as part of a holistic set of solutions to make diverse forms of mobility accessible, safe, and affordable for all (Kammen, 2020).	Medium to long

[a] Short: months to 1 year, medium: 1–3 years, and long: more than 3 years

Table 3. Policy recommendation for accelerating transformation toward low-carbon, flexible and resilient built environment.

Action	**Objective/Measures**	**Timeframe[a]**
1. Promote built environment that is low-carbon, flexible, and resilient to multiple hazards	- Direct investments in the construction of new buildings that are less resource- and carbon-intensive, and renovate the existing building stock - Adopt and enforce the Minimum Energy Performance Standards (MEPS) and energy-efficient building codes, increasing the use of bio-based, traditional low-carbon materials - Invest in home weatherization to improve energy affordability and public health, and advance equity - Design buildings with future flexibility of use the space in which can be adapted depending on need and provide different services	Medium to long

	- Prioritizes "nature-based solutions" such as parks, green roofs, green walls, blue infrastructure - Create mechanisms that can mobilize citizens to invest locally in low-carbon infrastructure and services - Build capacity of local authorities, architects, civil engineers, and construction workers in energy- and water-efficient systems and use of sustainable materials - Implement sustainable housing for low-income population by improving their access to housing finance, promoting wide-scale housing affordability, strengthening the construction value chain - Support the development of net zero-energy communities through a holistic approach to energy- efficient building renovation and construction of new buildings, considering energy interactions between individual buildings and the broader energy system at local level.	

[a] Short: months to 1 year, medium: 1–3 years, and long: more than 3 years

3.3 Advancing the role of decentralized and resilient energy systems including energy efficiency

In response to the challenges and opportunities revealed in the wake of the COVID-19 pandemic, and to the call for transition to a resilient and sustainable energy system, a number of recommendations are listed below. We divide the recommendations into two groups: decentralized energy systems and energy efficiency. The key recommendation for transition to decentralized energy systems and main actions are summarized in Table 4.

Table 4. Actions and policy recommendations for advancing decentralized and resilient energy systems.

Action	**Objective**	**Timeframe[a]**
Reduce or eliminate fossil fuel subsidies	- Offer fair competition between different energy sources Reduce dependence on fossil fuels (e.g., through coal phase-out initiatives)	Short to medium
Promote diversification of investments in low-carbon assets, such as clean energy equities and green bonds, and increase transparency through corporate climate disclosures	- Minimize fossil asset stranding - Account for the risk of stranded assets when examining investment decisions - Monitor fossil fuel exposures in investment portfolios and audit their carbon intensity - Phase out support to energy infrastructure associated with unabated fossil fuels	Medium to long
Remove barriers to renewable energy and green technologies	- Amend existing market or system regulations that favor central solutions - Promote distributed energy generation and energy storage through subsidies and supportive policies	Short to medium

Prioritize decentralized energy solutions	- Facilitate access to energy for the underprivileged - Reduce stress on the grid and the need for grid expansion - Reduce the need for backup, central capacity - (applicable to off-grid [no access], fragile grids [low access], and modern grids)	Short to medium
Develop local value chains for renewable energy	- Create jobs and develop green skills - Make up the job loss in the fossil fuel industry	Medium to long
Promote community-based governance and business models (especially in developing regions and areas with no access to modern energy services)	- Empower local communities - Ensure smaller financial burdens but greater benefits for community - Enhance resilience (health, energy, and engagement)	Medium to long
Expand and strengthen energy safety nets to enable vulnerable low-income populations access to essential modern energy services (SEforall, Safety, 2020)	- Close the affordability gap between market prices and what low-income customers can afford to pay for essential energy services. - Link energy safety nets to energy-efficiency programs, for instance, through soft loans and subsidies for low-income populations to buy energy efficient, easy-to-repair appliances that reduce the impact of energy price increases on welfare, and consequently reduce energy poverty - Link energy safety nets to initiatives for financial inclusion and digital technologies for cash transfer payments - Energy safety nets should include mechanisms to promote gender equality and benefit women, taking into account women's particular needs and abilities to pay for energy.	Short term
Develop special recovery packages for small and medium enterprises providing decentralized energy services in developing countries (energy SMEs)	- Implement recovery packages for energy SMEs, which may include fiscal measures such as tax breaks, tax cuts, reduction of interest rates and restructuring of credits, - Guarantee funds and credit facilities for SMEs as well as enabling frameworks to increase private sector involvement in renewable energy, energy efficiency, and energy access businesses	Short term

[a] Short: months to 1 year, medium: 1–3 years, and long: more than 3 years

When incorporated into stimulus and recovery plans, the transition toward decentralized renewable energy systems represents a sound investment. An investment package focused on such an energy transition can help to overcome the economic crisis and create jobs, both for the short-term and beyond. Policy measures and investments for stimulus and recovery can drive a wider structural shift, fostering the energy transition at national and regional levels as a decisive step in building resilient economies and societies. Moreover, investment portfolios, for instance, those of institutional investors, could be reoriented toward sustainable and resilient assets, including renewable energy investment projects to secure the mobilization of the necessary funds (IRENA, Recovery, 2020; IRENA, Capital, 2020).

Similarly, energy efficiency needs to be at the heart of building resilient energy systems and be part of stimulus and recovery plans (Emtairah, 2020) (see Figure 5).

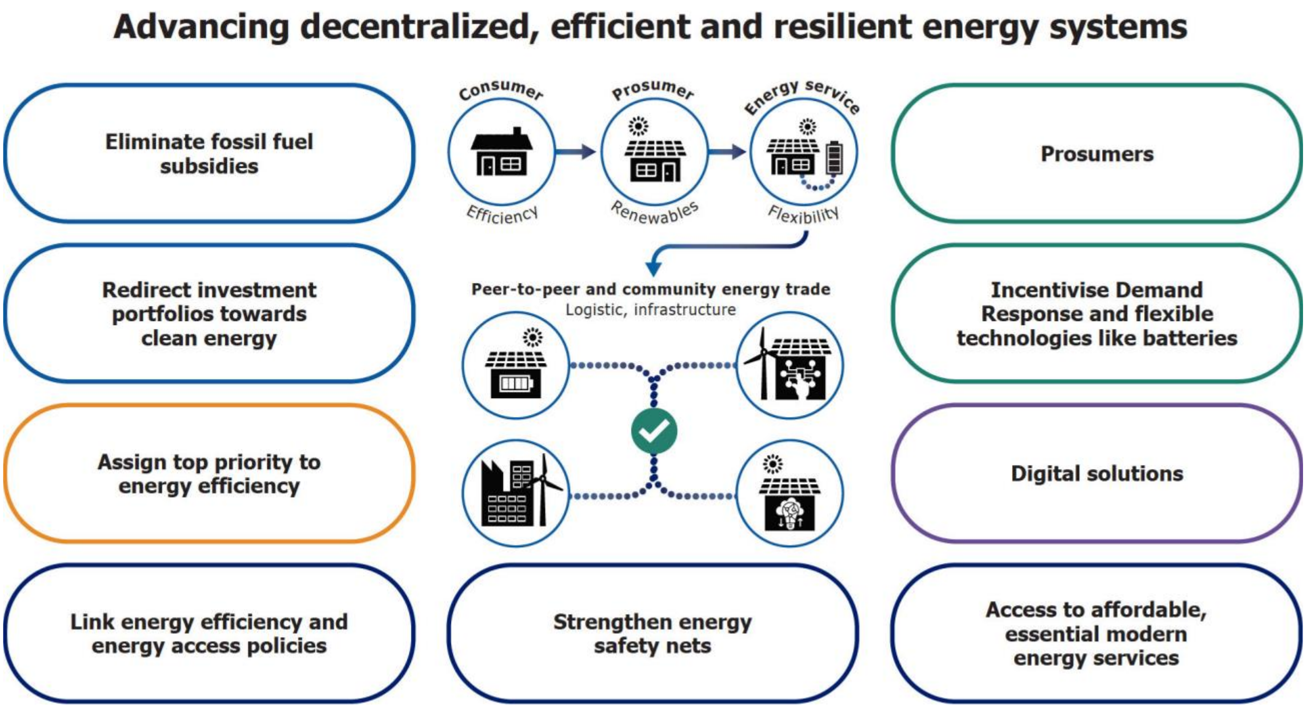

Figure 5: Solutions for advancing decentralized, efficient, and resilient energy systems

In addition to measures mentioned in the sections above, other policy and regulatory frameworks that stimulate energy efficiency include:

Stimulating utility-funded energy efficiency

By reducing energy consumption, utilities can delay or avoid the need to build new infrastructure like power plants and distribution grids. Thus, energy efficiency contributes to ensuring that electricity reliability is maintained and improves affordability and service quality by reducing load-shedding or blackouts. Energy utilities have easier access to funding and can facilitate on-bill financing to customers. Policy frameworks are needed that encourage utilities to invest in energy efficiency by allowing them to earn a return on energy-efficiency expenses and facilitate revenue decoupling to make up for lost revenue caused by energy savings (IEA, Recovery, 2020).

Promoting market-based approaches to improve energy efficiency

The Energy Service Company (ESCO) concept in combination with Energy as a Service (EaaS) models, is a framework whereby customers pay for an energy service without having to make any upfront capital investment and energy efficiency financing credit lines (Resources for the Future, 2019). For instance, Cooling as a Service (CaaS) is emerging as a business model, whereby building and business owners pay for the cooling service instead of investing in the infrastructure that delivers the cooling. The technology provider owns the cooling system, maintains it, and covers operational costs (Cooling as a Service Initiative, 2020).

The ESCO approach could also be a vehicle for implementing COVID-19 mitigation strategies such as surface disinfection and suspended particulate air filtration to improve indoor air quality in facilities such as schools and government buildings (Walther, 2020).

Phasing out fossil fuel subsidies to level the playing field for renewable energy and energy efficiency

The economic downtime triggered by COVID-19 has led to lower energy prices than those forecast a year before. This reduction in final energy prices may put policies for clean energy and for improving energy efficiency and its role in achieving SDG7 at risk. It is essential to phase out fossil fuel subsidies to level the playing field for renewable energy and energy efficiency. As a complementary measure, in the long-term carbon taxes can be introduced and a significant fraction of carbon revenues can be reinvested in energy efficiency. This could help advance energy efficiency while ensuring that energy-poor households are not adversely affected by carbon taxation (Wang et al., 2019). According to Mintz-Woo *et al.* (2020), carbon pollution is already increasing health and environmental costs, and these are disproportionately borne by the most vulnerable parts of society. Therefore, making those generating the costs pay for them could lead to fairer production and consumption. Revenues from a carbon price could contribute toward government spending on social safety nets, fund green projects, support the development of green skills and green jobs, or be returned as credits to taxpayers.

Incentivize demand response to increase the flexibility of electricity grids

Besides energy efficiency, demand response must be incentivized**,** that is, short-term reduction in energy demand, triggered by price signals, during periods when electricity demand threatens to outpace the electricity supply (McPhail, 2015).

Demand response provides much needed flexibility to the power grid in case of extreme temperatures, leading to peak demand in air conditioning, but also in situations of power-line damage or scheduled maintenance, and it contributes to the integration of volatile renewable energy sources. The development of demand response services incentivizes consumers to be more active in the electricity market. Regulatory frameworks for electricity markets are necessary to allow demand response to compete on an equal footing with other forms of network flexibility and encourage new business models for the provision of flexibility to the electricity grid through demand response such as aggregators, that is, energy service providers, which can increase or reduce the electricity consumption of a group of consumers, and sell the resulting flexibility to the electricity market (IEA, Demand Response, 2019).

Digitalization strategies for energy efficiency and decentralized renewable energy

Advancing digitalization will contribute to modernizing energy efficiency and increasing its value. Measures to boost energy efficiency using digital technologies include smart meters and smart grids, intelligent building management systems, which optimize energy consumption and allow for demand flexibility of buildings, smart energy management systems and smart factories in the industrial sector, internet-connected devices that facilitate demand response, digitally enabled shared mobility, and smart cities. Policy and regulatory frameworks, which facilitate new business models, stimulate the development and market uptake of smart efficient products, address data privacy, set industry standards and promote interoperability are needed, among other things, to realize the potential of digitalization. The main actions for the recommendations discussed in this section are summarized in Table 5.

Table 5. Actions and objectives for key recommendations in energy efficiency and flexible demand.

Action	**Objective**	**Timeframe[a]**
1. Assign top priority to energy efficiency	- Implement energy efficiency improvements when these are more cost-effective than supply-side solutions and take account of co-benefits - Anchor energy efficiency as a key priority in energy policies, planning instruments, and energy investment decisions	Short to medium
2. Link energy efficiency policies to energy access policies	- Enable the best use of available energy and financial resources by implementing energy efficiency and energy access hand in hand - Support the use of high-performing, quality appliances to reduce costs/bills and improve reliability of off-grid solar power systems and community-level mini-grids, enabling customers to run more appliances for longer	Short to medium
3. Empowering citizens and communities as prosumers	- Adapt policy/regulatory frameworks to allow prosumers to generate, sell, store, and share energy	Short to medium
4. Incentivize demand response to provide flexibility to the power grid	- Adapt regulatory frameworks to encourage new business models for the provision of flexibility to the power grid through demand response (e.g., through aggregators)	Short to medium
5. Advance digitalization to increase the value of energy efficiency and renewables	- Adapt regulatory frameworks and strategies for guiding consumers in sustainable choices, energy efficiency, and enable decentralized energy - Facilitate new business models, stimulate the development and market uptake of smart efficient products, address data privacy, set industry standards, and promote interoperability of digital solutions	Medium to long term
6. Accelerate innovation cycles to improve energy efficiency	- Advance the portfolio of innovations required for the transformation toward efficient, sustainable, and affordable energy services.	Medium to long term
7. Improve the affordability of energy efficient appliances to low-income population (UNIDO, 2020).	- Address logistical and production factors supporting the supply of affordable products to the market - Reduce taxes and duties, and introduce rebate schemes and implement bulk procurement for efficient appliances - Provide economic incentives to low-income populations to support the purchase of energy-efficient products when possible or appropriate. - Make energy efficiency products equally affordable to both women and men	Short to medium
8. Promote affordable, resilient energy access, and clean cooking solutions	- Improve information about people's willingness to pay and market dynamics to guide investment decisions on energy access and clean cooking - Provide debt finance, tax cuts, and other support to energy-access companies - Support diversification of clean cooking technologies beyond improved cookstoves (e.g., electric and solar cooking, biogas) - Implement funding and risk mitigation mechanisms to alleviate risk for private sector investors (SEforALL, Finance, 2020).	Short to medium term

References

a-connected (2020). Regulatory implications of the sharing economy. Accessed 25 November 2020. [https://www.a-connect.com/knowledge/regulatory-implications-of-the-sharing-economy/]

Abu-Raysh, A., & Dincer, I. (2020). Analysis of mobility trends during the COVID-19 coronavirus pandemic: Exploring the impacts on global aviation and travel in selected cities. Energy Research & *Social Science*, Volume 68, October, 101693. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S2214629620302681?via%3Dihub]

African Union (2019). Guidelines for Minimum Energy Performance Standards (MEPS) Energy Labelling and Eco-Design at the Continental Level. Technical Paper. The first ordinary session of the African Union Specialized Technical Committee on Transport, Transcontinental and Interregional Infrastructures, Energy and Tourism (Stc-Ttiet). 14–18 April 2019. Cairo, Egypt.

Agrawala, S., Klasen, S., Acosta Moreno, R., et al. (2014). Chapter 14 - Regional development and cooperation. In: *Climate Change 2014: Mitigation of Climate Change*. IPCC Working Group III Contribution to AR5. Cambridge University Press.

Andrijevic, M., Schleussner, C.-F,. Gidden, M., et al. (2020). COVID-19 recovery funds dwarf clean energy investment needs. *Science* 370 (6514): 298-300. Accessed 25 November 2020. [https://science.sciencemag.org/content/370/6514/298.full]

Forster, P.M., Forster, H.I,. Evans, M.J., et al. (2020). Current and future global climate impacts resulting from COVID-19. *Nature Climate Change.* Accessed 25 November 2020. [https://www.nature.com/articles/s41558-020-0883-0]

Anisie, A., & Boshell, F. (2020). The benefits of Peer-To-Peer Electricity Trading for communities and grid expansion. Energypost.eu. 13 November. Accessed 25 November 2020. [https://energypost.eu/the-benefits-of-peer-to-peer-electricity-trading-for-communities-and-grid-expansion/]

Ayyagari, S. & Glassman, J. (2020). The Wonders of Weatherization: Improving Equity through Stimulus Funding. Rocky Mountains Institute, 26 August. Accessed 25 November 2020. [https://rmi.org/the-wonders-of-weatherization-improving-equity-through-stimulus-funding/]

Azevedomm, I., Davidson. M.R., Jenkins, J.D., et al. (2020). The Paths to Net Zero: How Technology Can Save the Planet. *Foreign Affairs*. May/June. Accessed 25 November 2020. [https://www.foreignaffairs.com/articles/2020-04-13/paths-net-zero]

Baron, R., & Fischer, D. (2015). Divestment and Stranded Assets in the Low-carbon Transition. Background paper for the 32nd Round Table on Sustainable Development, 28 October. OECD Headquarters, Paris, France.

Batchelor, S., & Brown, E. (2020). Cooking Health Energy Environment and Gender (CHEEG) - guiding Covid recovery plans. Working Paper 19/June/2020 V1.1, MECS, Modern Energy Cooking Services, UK. Accessed 25 November 2020. [https://mecs.org.uk/wp-content/uploads/2020/07/CHEEG-Covid-recovery-strategies-Final.pdf]

BloombergNEF (2020). Clean Energy Investment Trends, 1H 2020. BloombergNEF, 13 July 2020. Accessed 25 November 2020. [https://data.bloomberglp.com/professional/sites/24/BNEF-Clean-Energy-Investment-Trends-1H-2020.pdf]

Bocken, N. & Short, S. (2019). Transforming Business Models: Towards a Sufficiency-based Circular Economy. Handbook of the Circular Economy.

Bouman, T., Steg, L., & Dietz, T. (2020). Insights from early COVID-19 responses about promoting sustainable action. *Nat Sustain* (2020). Accessed 25 November 2020. [https://www.nature.com/articles/s41893-020-00626-x]

Bridle, R., Sharma, S., Mostafa, M., & Geddes, A. (2019). Fossil Fuel to Clean Energy Subsidy Swaps: How to pay for an energy revolution. International Institute for Sustainable Development. [https://www.iisd.org/gsi/news-events/reforming-subsidies-could-help-pay-clean-energy-revolution-report]

Cabeza, L.F., & Ürge-Vorsatz, D. (2020). The role of buildings in the energy transition in the context of the climate change challenge, *Global Transitions*, Volume 2, Pages 257-260, ISSN 2589-7918. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S2589791820300268]

Canales, M. & Berman-Vaporis, I. (2020). The First 100 Days. How the coronavirus outbreak grew from a few cases in China to a global pandemic in less than three months. National Geographic Magazine, Coronavirus coverage, 13 October.

Carbon Tracker (2017). Stranded Assets, 23 August. Accessed 25 November 2020. [https://carbontracker.org/terms/stranded-assets]

Castagneto Gissey, G., Subkhankulova, D., Dodds, P.E., & Barrett, M. (2019). Value of energy storage aggregation to the electricity system. *Energy Policy* 2019;128:685–96. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S0301421519300655?via%3Dihub]

Chen, C., Mwachandi, R., & Sanyal, S. (2019). In Kenya's Rural Health Clinics, Business Performance and Renewables Go Hand-in-Hand.Humans of Clean Energy. World Resources Institute, March 13. Accessed 25 November 2020. [https://www.wri.org/blog/2019/03/kenyas-rural-health-clinics-business-performance-and-renewables-go-hand-hand]

Chilvers, J., Pallett, H., & Hargreaves, T. (2018). Ecologies of participation in socio-technical change: The case of energy system transitions. *Energy Research & Social Science* Volume 42, August 2018, Pages 199-210. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S2214629618303025]

Cleary, K. & Palmer, K. (2019). Energy-as-a-Service: A Business Model for Expanding Deployment of Low-Carbon Technologies. Resources for the Future. Issue Brief (19-09). Accessed 25 November 2020. [https://www.rff.org/publications/issue-briefs/energy-service-business-model-expanding-deployment-low-carbon-technologies/ (2019).]

Cooling as a Service Initiative (2020). Cooling as a Service: how it works. Basel Agency for Sustainable Energy (BASE) and Kigali Cooling Efficiency Program (K-CEP). Accessed 25 November 2020. [https://www.caas-initiative.org/how-it-works]

Dalton, G. & Pope, T. (2020). The government's post-Covid 19 stimulus package. Institute for Government, UK, 15 July. Accessed 25 November 2020. [https://www.instituteforgovernment.org.uk/explainers/governments-post-covid-19-stimulus-package]

Drehobl, A. (2020). A perfect storm? COVID-19 cuts incomes and hikes home energy bills. ACEEE, 15 May. Accessed 25 November 2020. [https://www.aceee.org/blog-post/2020/05/perfect-storm-covid-19-cuts-incomes-and-hikes-home-energy-bills]

European Commission (2013). Guide to Social Innovation. European Innovation Partnership on Active and Healthy Ageing. European Commission, 28 February. Accessed 25 November 2020. [https://ec.europa.eu/eip/ageing/library/guide-social-innovation_en]

European Commission (2019). Industry digitalization from an energy perspective. European Commission. Accessed 25 November 2020. [https://ee-ip.org/fileadmin/user_upload/DOCUMENTS/Content/JRC119416_industry_digitalisation_factsheet.pdf]

European Commission (2019). The new ecodesign measures explained. European Commission. Accessed 25 November 2020. [https://ec.europa.eu/commission/presscorner/detail/en/QANDA_19_5889]

European Commission (2020). Circular Economy Action Plan: for a cleaner and more competitive Europa. European Commission. Accessed 25 November 2020. [https://ec.europa.eu/jrc/communities/en/community/city-science-initiative/document/circular-economy-action-plan-cleaner-and-more-competitive]

ECRB (2020). Prosumers in the Energy Community. Energy Community Regulatory Board, March.

ECREEE (2020). The Impact of Covid-19 on The ECOWAS Energy Sector. ECOWAS Center for Renewable Energy and Energy Efficiency. Brief, July. Accessed 25 November 2020. [http://www.ecreee.org/sites/default/files/documents/countries/ecowas_energy_sector_ecreee_brief_2020.pdf]

EIA (2020). U.S. Electric System Operating Data. US Energy Information Administration. Accessed 25 November 2020. [https://www.eia.gov/realtime_grid]

Ellen, I., Graves, E., O'Regan, K., & Schuetz, J. (2020). Strategies for increasing affordable housing amid the COVID-19 economic crisis. Brookings, 8 June. Accessed 25 November 2020. [https://www.brookings.edu/research/strategies-for-increasing-affordable-housing-amid-the-covid-19-economic-crisis/]

Emtairah, T. (2020). COVID stimulus packages must carry energy efficiency incentives to help industries and economies rebound. Industrial Energy Accelerator. Accessed 25 November 2020. [https://www.industrialenergyaccelerator.org/general/covid-stimulus-packages-must-carry-energy-efficiency-incentives-to-help-industries-and-economies-rebound/]

End Fuel Poverty Coalition (n.d.). End Fuel Poverty Before the Winter, 24 September 2020. Accessed 25 November 2020. [http://www.endfuelpoverty.org.uk/tag/covid-19/]

Energy Policy Tracker (2020). Track public money for energy in recovery packages, 18 November 2020. Accessed 25 November 2020. [https://www.energypolicytracker.org/]

ENTSO-E Transparency Platform (2020). Accessed 25 November 2020. [https://transparency.entsoe.eu/]

EU (2018). Co-Chairs' Summary of the High-Level Forum Africa-Europe 2018: "Taking Cooperation to the Digital Age". European Union News, 18 December. Accessed 25 November 2020. [https://www.eu2018.at/de/latest-news/news/12-18-Co-Chairs--Summary-of-the-High-Level-Forum-Africa-Europe-2018---Taking-cooperation-to-the-digital-age-.html]

Eurelectric (2020). COVID-19 impact on the power sector. Eurelectric, 15 June 2020. Accessed 25 November 2020. [https://www.eurelectric.org/news/covid-19/]
Eurelectric (2020). COVID-19 impact on the power sector. Eurelectric, 15 June 2020. Accessed 25 November 2020. [https://www.eurelectric.org/news/covid-19/]
European Commission (2020). Powering a climate-neutral economy: An EU Strategy for Energy System Integration. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions. Brussels, 8.7.2020, COM(2020) 299 final.

European Economic and Social Committee (2020). Towards an EU strategy on sustainable consumption. Opinion. Section for Agriculture, Rural Development and the Environment. European Economic and Social Committee.

European Investment Bank (2019). EIB energy lending policy. Supporting the energy transformation. Final Version Adopted by the EIB's Board of Directors on 14 November 2019. European Investment Bank. Accessed 25 November 2020. [https://www.eib.org/attachments/strategies/eib_energy_lending_policy_en.pdf]

GFSE (2020). Engaging Citizens via Social Innovations for the Energy Transition. GFSE Policy Brief. Global Forum on Sustainable Energy, Vienna, Austria. November. Accessed 25 November 2020. [https://www.gfse.at/fileadmin/files/Services___Policy_Briefs/GFSE_Policy_Brief__11_Engaging_Citizens_via_Social_Innovations_for_the_Energy_Transition.pdf.]

Gissey, G.C., Zakeri, B., Dodds, P.E., & Subkhankulova D (2020). Evaluating consumer investments in distributed energy technologies. *Energy Policy* (in press). Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/abs/pii/S0301421520307199?via%3Dihub]

Glachant, J.M. (2020). New Business Models in the Electricity Sector. Robert Schuman Centre for Advanced Studies. Research Paper No. RSCAS 2019/44, 1 June. Accessed 25 November 2020. [https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3425893]

Global Alliance for Buildings and Construction (2019). International Energy Agency, and the United Nations Environment Programme (2019). 2019 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector.

Global Forum on Sustainable Energy (2020). Digital Solutions and Knowledge Transfer for Energy, Water and Agriculture. Vienna, Austria. GFSE Policy Brief. August. Accessed 25 November 2020. [https://www.gfse.at/fileadmin/files/Services___Policy_Briefs/GFSE_Policy_Brief__10_Digital_Solutions_and_Knowledge_Transfer_for_Energy__Water_and_Agriculture.pdf]

Gordon, J.T. (2020). The implications of the coronavirus crisis on the global energy sector and environment. The Atlanticist, March 24. Accessed 25 November 2020. [https://www.atlanticcouncil.org/blogs/new-atlanticist/the-implications-of-the-coronavirus-crisis-on-the-global-energy-sector-and-the-environment/]

Goutte, S. & Vassilopoulos, P. (2019). The value of flexibility in power markets. *Energy Policy* 2019;125:347–57. Accessed 25 November 2020. [https://doi.org/10.1016/j.enpol.2018.10.024]

GWNET (2020). Women Leaders Call for Action in Response to Covid-19: Opening Opportunities for Gender Equality in the Transition to Sustainable Energy. Global Women Network for the Energy Transition, 24 June. Accessed 25 November 2020. [https://www.globalwomennet.org/women-leaders-call-for-action-in-response-to-covid-19/]

Haf, S., & Robison, R. (2020). How Local Authorities can encourage citizen participation in energy transitions. UK Energy Research Centre, London, April. Accessed 25 November 2020. [https://energy-cities.eu/wp-content/uploads/2020/05/HafRobison_LAs-and-citizen-participation_published.pdf]

Hanna, R., Xu, Y., & Victor, D. (2020). After COVID-19, green investment must deliver jobs to get political traction. *Nature*. 582. 178-180. Accessed 25 November 2020. [https://www.nature.com/articles/d41586-020-01682-1]

Henry, M.S., Bazilian, M.D., & Markuson, C. (2020). Just transitions: Histories and futures in a post-COVID world, *Energy Research & Social Science*, Volume 68, 101668, ISSN 2214-6296. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S2214629620302437?via%3Dihub]

Hossein Motlagh, N., Mohammadrezaei, M., Hunt, J., & Zakeri, B. (2020). Internet of Things (IoT) and the Energy Sector. *Energies* 13, 494.

IBON International (2020). Beyond Efficiency: Transforming Trade to Achieve Sustainable Consumption and Production. Policy Brief. August.

IEA, Global (2020). Global Energy Review 2020: The impacts of the COVID-19 crisis on global energy demand and CO2 emissions. International Energy Agency, April.

IEA (2020). Clean energy innovation in the Covid-19 crisis, International Energy Agency, Paris, France. Accessed 25 November 2020. [https://www.iea.org/articles/clean-energy-innovation-in-the-covid-19-crisis]

IEA, Buildings (2020). Buildings: A source of enormous untapped efficiency potential. International Energy Agency. Accessed 25 November 2020. [https://www.iea.org/topics/buildings]

IEA, Digitalization (2017). Digitalization and Energy. Technology Report. November 2017. International Energy Agency, Paris, France. Accessed 25 November 2020. [https://www.iea.org/reports/digitalisation-and-energy]

IEA, IRENA, UNSD, WB, WHO (2019). Tracking SDG 7: The Energy Progress Report 2019, Washington DC. Accessed 25 November 2020. [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/2019-Tracking-SDG7-Report.pdf]

IEA, Recovery (2020). Paving the way to recovery with utility-funded energy efficiency. International Energy Agency, Paris, 21 August. Accessed 25 November 2020. [https://www.iea.org/articles/paving-the-way-to-recovery-with-utility-funded-energy-efficiency]

IEA, Renewables (2019). Market analysis and forecast from 2019 to 2024. Fuel report — October 2019. International Energy Agency. Accessed 25 November 2020. [https://www.iea.org/reports/renewables-2019]

IEA, World Energy (2020). World Energy Outlook 2020, International Energy Agency, Paris, France. Accessed 25 November 2020. [https://www.iea.org/reports/world-energy-outlook-2020]

IEA, Demand Response (2019). Demand Response. International Energy Agency, Paris, France. Accessed 25 November 2020. [https://www.iea.org/reports/demand-response]

Indian National Load Dispatch Center (2020). Daily Reports. Accessed 25 November 2020. [https://posoco.in/reports/daily-reports/]

International Energy Agency and International Monetary Fund (2020). Sustainable Recovery. A World Energy Outlook Special Report in collaboration with the International Monetary Fund. World Energy Outlook 2020. Paris, France.

IoT for All (2018). 3 Ways AI is Making Buildings Smarter. 19 March. Accessed 25 November 2020. [https://www.iotforall.com/ai-for-smart-buildings/]

IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp. Accessed 25 November 2020. [https://www.ipcc.ch/assessment-report/ar5/]

IPCC (2018). Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (Eds.)]. Accessed 25 November 2020. [https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf]

IRENA (2019). Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables. International Renewable Energy Agency, Abu Dhabi. Accessed 25 November 2020. [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_report.pdf]

IRENA, Capital (2020). Mobilising institutional capital for renewable energy, International Renewable Energy Agency, Abu Dhabi, November. Accessed 25 November 2020. [https://www.irena.org/publications/2020/Nov/Mobilising-institutional-capital-for-renewable-energy]

IRENA, Global (2020). Global renewable energy outlook: Energy Transformations 2050. International Renewable Energy Agency, April. Accessed 25 November 2020. [https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020]

IRENA, Recovery (2020). The post-COVID recovery: An agenda for resilience, development and equality. International Renewable Energy Agency, Abu Dhabi, June. Accessed 25 November 2020. [https://www.irena.org/publications/2020/Jun/Post-COVID-Recovery]

IRENA, Renewables (2020). Rise of renewables in cities: Energy solutions for the urban future. International Renewable Energy Agency, Abu Dhabi, October. Accessed 25 November 2020. [https://www.irena.org/publications/2020/Oct/Rise-of-renewables-in-cities]

Kammen, D. (2020). How electric vehicles can help advance social justice. Opinion. San Francisco Chronicle, June 21/22. Accessed 25 November 2020. [https://www.sfchronicle.com/opinion/article/How-electric-vehicles-can-help-advance-social-15351293.php]

Kane, J.W. & Shivaram, R. (2020). How clean energy jobs can power an equitable COVID-19 recovery. Brookings, 10 September. Accessed 25 November 2020. [https://www.brookings.edu/blog/the-avenue/2020/09/10/how-clean-energy-jobs-can-power-an-equitable-covid-19-recovery/]

Keane, K. (2020). Coronavirus: "Thousands" of North Sea oil and gas jobs under threat. BBC News, 27 April. Accessed 25 November 2020. [https://www.bbc.com/news/uk-scotland-scotland-business-52446555]

Klenert, D., Funke, F., Mattauch, L., et al. (2020). Five Lessons from COVID-19 for Advancing Climate Change Mitigation. *Environ Resource Econ* 76, 751–778. Accessed 25 November 2020. [https://doi.org/10.1007/s10640-020-00453-w.]

Lavrijssen, S. & Carrillo Parra, A (2017). Radical Prosumer Innovations in the Electricity Sector and the Impact on Prosumer Regulation. *Sustainability* 9(7), 1207. Accessed 25 November 2020. [https://www.mdpi.com/2071-1050/9/7/1207]

Le Quéré, C., Jackson, R.B., Jones, M.W., et al. (2020). Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nat. Clim. Chang*. 10, 647–653. Accessed 25 November 2020. [https://doi.org/10.1038/s41558-020-0797-x]

Li, B., Ma, Z., Hidalgo-Gonzalez. P., et al. (2020). Modeling the Impact of Evs in the Chinese Power System: Pathways for Implementing Emissions Reduction Commitments in the Power and Transportation Sectors", *Energy Policy*, in press.

Liu, Z., Ciais., P., Deng. Z., et al. (2020). Near-real-time monitoring of global CO_2 emissions reveals the effects of the COVID-19 pandemic. *Nat Commun* 11**,** 5172 (2020). Accessed 25 November 2020. [https://www.nature.com/articles/s41467-020-18922-7]

Lund, P.D., Lindgren, J., Mikkola, J., & Salpakari, J. (2015). Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renew Sustain Energy Rev* 2015;45:785–807. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/abs/pii/S1364032115000672?via%3Dihub]

McKinsey & Company (2019). The future of mobility is at our doorstep. 19 December. Accessed 25 November 2020. [https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-mobility-is-at-our-doorstep]

McPhail, D. (2015). What is demand response. The Uplight Blog, June 18. Accessed 25 November 2020. [https://uplight.com/blog/what-is-demand-response/]

McPherson, M., Johnson, N., & Strubegger, M. (2018). The role of electricity storage and hydrogen technologies in enabling global low-carbon energy transitions. *Appl Energy* 2018;216:649–61. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/abs/pii/S0306261918302356?via%3Dihub]

Meltzer, J.P. & Constantine, C. (2018). How do we finance low-carbon infrastructure? Brookings, 19 July. Accessed 25 November 2020. [https://www.brookings.edu/blog/planetpolicy/2018/07/19/how-do-we-finance-low-carbon-infrastructure/]

Millward-Hopkins, J., Steinberger, J.K., Rao, N., & Oswald, Y. (2020). Providing decent living with minimum energy: A global scenario. *Global Environmental Change* 65:e102168. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S0959378020307512]

Mintz-Woo, K., Dennig, F., Liu, H., & Schinko, T. (2020). Carbon pricing and COVID-19. *Climate Policy* (forthcoming). Accessed 25 November 2020. [https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3709367]

Neiuwenhuijsen, M. (2020). Urban and transport planning pathways to carbon neutral, liveable and healthy cities; A review of the current evidence. *Environment International*, Volume 140, July, 105661. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S0160412020302038?via%3Dihub]

Newton, P.W., & Rogers, B.C. (2020). Transforming Built Environments: Towards Carbon Neutral and Blue-Green Cities, *Sustainability* 12(11), 4745. Accessed 25 November 2020. [https://www.mdpi.com/2071-1050/12/11/4745]

OECD (2020). Supporting livelihoods during the COVID-19 crisis: Closing the gaps in safety nets. OECD Policy Responses to Coronavirus (COVID-19). Organisation for Economic Cooperation and Development, Paris, France. Updated 20 May. Accessed 25 November 2020. [https://www.oecd.org/coronavirus/policy-responses/supporting-livelihoods-during-the-covid-19-crisis-closing-the-gaps-in-safety-nets-17cbb92d]

Offshore Technology (2020). Covid-19 impact: Job cuts in US oilfield services sector accelerate. 11 August 2020. Accessed 25 November 2020. [https://www.offshore-technology.com/news/covid-19-job-cuts-us-oilfield-services-sector/]

Ökoinstitut and Technical University Berlin (2014). Study on the practical application of the new framework methodology for measuring the environmental impact of ICT - cost/benefit analysis (SMART 2012/0064) – 2014. A study prepared for the European Commission DG Communications Networks, Content & Technology. Accessed 25 November 2020. [https://ec.europa.eu/digital-single-market/en/news/study-practical-application-new-framework-methodology-measuring-environmental-impact-ict]

Overland, I., & Sovacool, B.K. (2020): The misallocation of climate research funding. *Energy Research & Social Science*, Volume 62, 2020, 101349, ISSN 2214-6296. Accessed 25 November 2020. [http://www.sciencedirect.com/science/article/pii/S2214629619309119]

Parker, L., & Elder, S. (2020). 3 ways COVID-19 is making us rethink energy and emissions. National Geographic Magazine, October 13. Accessed 25 November 2020. [https://www.nationalgeographic.com/magazine/2020/11/three-ways-covid-19-is-making-us-rethink-energy-and-emissions-feature/?cmpid=org=ngp::mc=social::src=twitter::cmp=editorial::add=tw20201112ngm-cvdissueenergyemissions::rid=&sf239890929=1]

Power, K. (2020). The COVID-19 pandemic has increased the care burden of women and families. *Sustain Sci Pract Policy* 2020;16:67–73. Accessed 25 November 2020. [https://doi.org/10.1080/15487733.2020.1776561]

Rahmstorf, S., & Levermann, A. (2017). Why global emissions must peak by 2020. *RealClimate*. 2 June. Accessed 25 November 2020. [http://www.realclimate.org/index.php/archives/2017/06/why-global-emissions-must-peak-by-2020/]

Rissman, J., Bataille, C., Masanet, E., et al. (2020). Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. *Applied Energy*, Volume 266, 2020, 114848, ISSN 0306-2619. Accessed 25 November 2020. [http://www.sciencedirect.com/science/article/pii/S0306261920303603]

Roy, L. (2019). 5 ways traceability technologies can lead to a safer, more sustainable world. World Economic Forum, 13 September. Accessed 25 November 2020. [https://www.weforum.org/agenda/2019/09/5-ways-traceability-technology-can-lead-to-a-safer-more-sustainable-world/]

Sanvicente, E., Kielmanowicz, D., Rodenbach, J., et al. (2018). Key technology and social innovation drivers for car-sharing. H2020 STARS Project. Accessed 25 November 2020. [http://stars-h2020.eu/wp-content/uploads/2019/06/STARS-D2.2.pdf]

Schmidt, O., Hawkes, A., Gambhir, A., & Staffell, I. (2017). The future cost of electrical energy storage based on experience rates. *Nat Energy* 2017;2:1–8. Accessed 25 November 2020. [https://www.nature.com/articles/nenergy2017110]

SEforALL, Climate Policy Initiative (2020). Energizing Finance: Understanding the landscape 2020. Sustainable Energy for All and Climate Policy Initiative. Accessed 25 November 2020. [https://www.seforall.org/system/files/2020-11/EF-2020-UL-SEforALL_0.pdf]

SEforALL, Off-Grid (2020). Identifying options for supporting the Off-Grid sector during COVID-19 crisis. Data presentation from High-Level Dialogue. Sustainable Energy for All, 16 April. Accessed 25 November 2020. [https://www.seforall.org/system/files?file=2020-04/SEforALL-survey-findings-20200417.pdf]

SEforall, Safety (2020). Energy Safety Nets: Using Social Assistance Mechanisms to Close Affordability Gaps for the Poor. Sustainable Energy for All. Accessed 25 November 2020. [https://www.seforall.org/publications/esn]

SEIA (2020). Solar Industry Research Data: Solar Industry Growing at a Record Pace. Solar Energy Industries Association. Accessed 25 November 2020. [https://www.seia.org/solar-industry-research-data]

SolarPowerEurope (2018). Digitalization in the Energy Sector – Questionnaire. Accessed 25 November 2020. [https://www.solarpowereurope.org/wp-content/uploads/2019/10/SolarPower-Europe_Digitalisation_Consultation-Digitalisation-Energy.pdf]

Sovacool, B.K., Del Rio, D.F., & Griffiths, S. (2020). Contextualizing the Covid-19 pandemic for a carbon-constrained world: Insights for sustainability transitions, energy justice, and research methodology. *Energy Research & Social Science*, Volume 68, 101701, ISSN 2214-6296. Accessed 25 November 2020. [https://doi.org/10.1016/j.erss.2020.101701]

Staffell, I., & Rustomji, M. (2016). Maximising the value of electricity storage. *J Energy Storage* 2016; 8:212–25. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S2352152X1630113X?via%3Dihub]

Szinai, J., Deshmukh, R., Kammen, D., & Jones, A. (2020). Evaluating cross-sectoral impacts of climate change and adaptations on the energy-water nexus: A framework and California case study. *Environmental Research Letters*, in press.

The Economist (2020). American crude oil has fallen to less than nothing. Daily Chart., 20 April. Accessed 25 November 2020. [https://www.economist.com/graphic-detail/2020/04/19/american-crude-oil-has-fallen-to-less-than-nothing]

The Energy Progress Report, Tracking SDG 7 (2020). Accessed 25 November 2020. [https://trackingsdg7.esmap.org/]

The World Bank, Global Outlook (2020). The Global Economic Outlook During the COVID-19 Pandemic: A Changed World. Feature story, June 8. The World Bank, Washington, D.C. Accessed 25 November 2020. [https://www.worldbank.org/en/news/feature/2020/06/08/the-global-economic-outlook-during-the-covid-19-pandemic-a-changed-world]

The World Bank, Global Prospects (2020). Global Economic Prospects 2020. Pandemic, Recession: The Global Economy in Crisis. Accessed 24 November 2020. [https://www.worldbank.org/en/publication/global-economic-prospects#overview]

The World in 2050 (2020). Innovations for Sustainability. Pathways to an efficient and post-pandemic future. Report prepared by The World in 2050 initiative. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. Accessed 25 November 2020. [https://iiasa.ac.at/web/home/research/twi/TWI2050.html]

Twidale, S. (2020). Green energy ratchets up power during coronavirus pandemic. Reuters, 22 July. Accessed 25 November 2020. [https://www.reuters.com/article/us-health-coronavirus-renewables-insight-idUSKCN24N111]

UBA (2019). Digitalisation can make consumption more sustainable. Press release, 11 June. Umweltbundesamt, Berlin, Germany. Accessed 25 November 2020. [https://www.umweltbundesamt.de/en/press/pressinformation/digitalisation-can-make-consumption-more]

UN Habitat (2020). UN-Habitat COVID-19 Response Plan, April 2020. Accessed 25 November 2020. [https://unhabitat.org/un-habitat-covid-19-response-plan]

UN News – Tech agency (2020). COVID-19 makes universal digital access and cooperation essential: UN News, 5 May 2020. Accessed 25 November 2020. [https://news.un.org/en/story/2020/05/1063272]

UNIDO (2020). Market Adoption of Energy-Efficient Products. Discussion Paper. Vienna Energy Forum 2021. VEF Virtual Series. Accessed 25 November 2020. [https://www.viennaenergyforum.org/sites/default/files/Products%20Layout.pdf]

U.S. Environmental Protection Agency (2020). EPA Supports Healthy Indoor Environments in Schools During COVID-19 Pandemic. Accessed 25 November 2020.

[https://www.epa.gov/iaq-schools/epa-supports-healthy-indoor-environments-schools-during-covid-19-pandemic]

Van Leeuwen, R., & Tubb, A. (2020). Editor's pick: Powering health across Africa through COVID-19 and a changing climate. Sustainable Energy for All, 19 May. Accessed 25 November 2020. [https://www.seforall.org/news/powering-health-across-africa-through-covid-19]

Walther, T. (2020). ESPC: The Remedy Schools Need During The COVID-19 Pandemic. Facility Executive, August 6. Accessed 25 November 2020. [https://facilityexecutive.com/2020/08/espc-remedy-schools-need-during-covid-19-pandemic/]

Wang, R., Saunders, H., Moreno-Cruz. J., & Caldeira, K. (2019). Induced Energy-Saving Efficiency Improvements Amplify Effectiveness of Climate Change Mitigation. *Joule*, Volume 3, Issue 9, 18 September, Pages 2103-2119. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S254243511930368X]

WHO (2020). COVID-19 intensifies the urgency to expand sustainable energy solutions worldwide. World Health Organization, May 28. Accessed 25 November 2020. [https://www.who.int/news/item/28-05-2020-covid-19-intensifies-the-urgency-to-expand-sustainable-energy-solutions-worldwide]

Wiedmann, T., Lenzen, M., Keyßer, L.T., & Steinberger, J.K. (2020). Scientists' warning on affluence. *Nat Commun* 11, 3107. Accessed 25 November 2020. [https://www.nature.com/articles/s41467-020-16941-y]

WindEurope (2020). COVID-19 Wind Information Hub. Accessed 25 November 2020. [https://windeurope.org/newsroom/covid19/]

Wittmayer, J.M., de Geus, T., Pel, B., et al. (2020). Beyond instrumentalism: Broadening the understanding of social innovation in socio-technical energy systems. *Energy Research & Social Science*, Volume 70, 101689, ISSN 2214-6296. Accessed 25 November 2020. [http://www.sciencedirect.com/science/article/pii/S2214629620302644]

World Bank (2020). Citizen Engagement. Brief, 13 October. Accessed 25 November 2020. [https://www.worldbank.org/en/about/what-we-do/brief/citizen-engagement]

Budd, L. & Ison, S. (2020). Responsible Transport: A post-COVID agenda for transport policy and practice. *Transportation Research Interdisciplinary Perspectives*, Volume 6, 2020, 100151, ISSN 2590-1982. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/pii/S2590198220300622?via%3Dihub]

Wu, X., Nethery, R., Sabath, B., Braun, D., & Dominici, F.(2020). Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study, 27 April. *MedRxiv Prepr Serv Heal Sci* 2020:2020.04.05.20054502. Accessed 25 November 2020. [https://www.medrxiv.org/content/10.1101/2020.04.05.20054502v2]

Wu, X., Nethery, R.C., Sabath, B.M,. et al. (2020). Exposure to air pollution and COVID-19 mortality in the United States. *medRxiv* 2020.04.05.20054502. Accessed 25 November 2020.

[https://www.medrxiv.org/content/10.1101/2020.04.05.20054502v2]

Zakeri, B. & Syri, S. (2015). Electrical energy storage systems: A comparative life cycle cost analysis. *Renew Sustain Energy Rev* 2015;42. Accessed 25 November 2020. [https://www.sciencedirect.com/science/article/abs/pii/S1364032114008284?via%3Dihub]

Participants of the consultation meetings

(in alphabetical order)

Mahmoud Abdrabou, Professor, University of Science and Technology, Zewail City, and Chairman and Executive President Zewail City of Science, Technology and Innovation, Egypt

M. H. Albadi, Associate Professor, Electric and Computer Engineering, Sultan Qaboos University, Oman

Douglas J. Arent, Deputy Associate Lab Director, National Renewable Energy Laboratory (NREL), USA

Pierre Audinet, Senior Economist and Lead Energy Specialist, Coordinator of Renewable Energy Community of Practice, World Bank

Faten Attig Bahar, Member of the Executive Board of the Young Earth Systems Scientists (YESS) and Doctoral Student at the University of Carthage Polytechnic School, Tunisia

Subhes Bhattacharyya, Professor of Energy Economics and Policy, Institute of Energy and Sustainable Development, De Montfort University, Leicester, United Kingdom

Angela Ines Cadena Monroy, Associate Professor, Electric and Electronic Engineering, Los Andes University, Colombia

Kuei-Hsien Chen, Professor, Academia Sinica, Taiwan

Pedro Conceicao, Director, Human Development Report, UNDP

Faustine Delasalle, Director, Energy Transitions Commission, United Kingdom

Reid Detchon, Senior Adviser and former Vice President, UN Foundation

Tareq Emtairah, Director, Department of Energy, UNIDO

Brett Feldman, Research Director and Leader of Distributed Energy Resource Research, Guidehouse Insights, USA

Frank W. Geels, Professor of Systems Innovation and Sustainability at the Sustainable Consumption Institute, University of Manchester and Chairman, International Sustainability Transitions Research Network, United Kingdom

Rana Ghoneim, Chief, Energy systems and Infrastructure Division, UNIDO

Teresa Harmann, Climate Lead, World Economic Forum

Abimanyu Haznan, Senior Researcher, The Indonesian Institute of Science (LIPI), Indonesia

Gary Jackson, Executive Director, The Caribbean Center for Renewable Energy and Energy Efficiency (CCREEE)

Pan Jiahua, Professor and Director of the Institute for Urban and Environmental Studies at Chinese Academy of Social Sciences (CASS), China

Daniel M. Kammen, Distinguished Professor of Energy in the Energy and Resources Group, University of California, Berkeley, USA

Jiang Kejun, Senior Researcher, Energy Research Institute (ERI), China

Stefan Lechtenböhmer, Director, Future Energy and Industry Systems, Wuppertal Institute, Germany

Michael Liebreich, Chairman and CEO, Liebreich Associates, United Kingdom

Andreas Löschel, Chair of Energy and Resource Economics, University of Münster, Germany

Mili Majumdar, Managing Director, Green Business Certification Institute Pvt Ltd, India and Senior Vice President of USGBC

Vijay Modi, Professor, School of Engineering and Applied Science, Columbia University, USA

Koji Nagano, Deputy Director, Central Research Institute of Electric Power Industry (CRIEPI), Japan

Shivani Nayyar, Research Specialist, UNDP Human Development Report Office

Kudakwashe Ndhlukula, Executive Director, The Southern African Center for Renewable Energy and Energy Efficiency (SACREEE)

Damilola Ogunbiyi, CEO and Special Representative of the UN Secretary-General for Sustainable Energy for All and Co-Chair of UN-Energy

Sheila Oparaocha, International Coordinator and Program Manager, ENERGIA International Network of Gender and Sustainable Energy, and Co-Chair of SDG 7 Technical Advisory Body

Joyashree Roy, Professor, Asian Institute of Technology, Thailand,

Roberto Schaeffer, Professor, Energy Planning Program, Federal University of Rio de Janeiro, Brazil

Guido Schmidt-Traub, Leader of Policy work, SDSN, France

Youba Sokona, Vice Chair, IPCC

Gerhard Stryi-Hipp, Group Head, Smart Energy Cities, Fraunhofer ISE, Freiburg, Germany

Minoru Takada, Team Leader (Energy), UNDESA

German Velazquez, Director of Mitigation and Adaptation Division, The Green Climate Fund

ABOUT THE IIASA-ISC CONSULTATIVE SCIENCE PLATFORM:

Transformations within reach: Pathways to a sustainable and resilient world

Starting in May 2020, a partnership between the International Institute for Applied Systems Analysis (IIASA) and the International Science Council (ISC) has drawn on the combined strengths and expertise of the two organizations to define and design sustainability pathways that will enable building-back a more sustainable post COVID-19 world. The platform has engaged a unique set of transdisciplinary global thought leaders on four themes:

- Governance for sustainability
- Strengthening science systems
- Resilient food systems
- Sustainable energy

The series of publications, Transformations within reach: Pathways to a sustainable and resilient world, presents the results and recommendations of the platform on the design of sustainable pathways and policy choices during the COVID-19 recovery period.

The platform is informed and supported by an advisory board under the patronage of the former Secretary-General of the United Nations H.E. Ban Ki-moon.

covid19.iiasa.ac.at/isc

International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Institute for Applied Systems Analysis
IIASA is an independent, international research institute with National Member Organizations in Africa, the Americas, Asia, and Europe. Through its research programs and initiatives, the Institute conducts policy-oriented research into issues that are too large or complex to be solved by a single country or academic discipline. This includes pressing concerns that affect the future of all of humanity, such as climate change, energy security, population aging, and sustainable development. The results of IIASA research and the expertise of its researchers are made available to policymakers in countries around the world to help them produce effective, science-based policies that will enable them to face challenges such as these.

www.iiasa.ac.at
info@iiasa.ac.at
IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria

twitter.com/iiasavienna
facebook.com/iiasa
blog.iiasa.ac.at
linkedin.com/company/iiasa-vienna
youtube.com/iiasalive
flickr.com/iiasa

International Science Council

International Science Council
The vision of the ISC is to advance science as a global public good. Scientific knowledge, data and expertise must be universally accessible and their benefits universally shared. The practice of science must be inclusive and equitable, as should opportunities for scientific education and capacity development. ISC is a non-governmental organization with a unique global membership that brings together 40 international scientific Unions and Associations and over 140 national and regional scientific organizations including Academies and Research Councils.

www.council.science
secretariat@council.science
International Science Council,
5 rue Auguste Vacquerie, 75116 Paris, France

twitter.com/ISC
facebook.com/InternationalScience
linkedin.com/company/international-science-council
instagram.com/council.science