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Review

Pandemic, War, and Global Energy Transitions

Behnam Zakeri [1,*], Katsia Paulavets [2], Leonardo Barreto-Gomez [3], Luis Gomez Echeverri [1], Shonali Pachauri [1], Benigna Boza-Kiss [1], Caroline Zimm [1], Joeri Rogelj [1,4], Felix Creutzig [5], Diana Ürge-Vorsatz [6], David G. Victor [7], Morgan D. Bazilian [8], Steffen Fritz [1], Dolf Gielen [9], David L. McCollum [1,10], Leena Srivastava [1], Julian D. Hunt [1] and Shaheen Pouya [11]

1 International Institute for Applied Systems Analysis (IIASA), 2361 Laxenburg, Austria
2 International Science Council (ISC), 75116 Paris, France
3 Austrian Energy Agency (AEA), 1150 Vienna, Austria
4 Centre for Environmental Policy, Imperial College London, London SW7 2AZ, UK
5 Sustainability Economics, Technische Universität Berlin, 10829 Berlin, Germany
6 Center for Climate Change and Sustainable Energy Policy, Central European University, 1100 Vienna, Austria
7 School of Global Policy and Strategy, University of California San Diego, San Diego, CA 92093, USA
8 Payne Institute, Colorado School of Mines, Golden, CO 80401, USA
9 IRENA Innovation and Technology Centre, 53113 Bonn, Germany
10 Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA
11 Industrial and Systems Engineering, Auburn University, Auburn, AL 36849, USA
* Correspondence: zakeri@iiasa.ac.at; Tel.: +43-2236-807-532

Abstract: The COVID-19 pandemic and Russia's war on Ukraine have impacted the global economy, including the energy sector. The pandemic caused drastic fluctuations in energy demand, oil price shocks, disruptions in energy supply chains, and hampered energy investments, while the war left the world with energy price hikes and energy security challenges. The long-term impacts of these crises on low-carbon energy transitions and mitigation of climate change are still uncertain but are slowly emerging. This paper analyzes the impacts throughout the energy system, including upstream fuel supply, renewable energy investments, demand for energy services, and implications for energy equity, by reviewing recent studies and consulting experts in the field. We find that both crises initially appeared as opportunities for low-carbon energy transitions: the pandemic by showing the extent of lifestyle and behavioral change in a short period and the role of science-based policy advice, and the war by highlighting the need for greater energy diversification and reliance on local, renewable energy sources. However, the early evidence suggests that policymaking worldwide is focused on short-term, seemingly quicker solutions, such as supporting the incumbent energy industry in the post-pandemic era to save the economy and looking for new fossil fuel supply routes for enhancing energy security following the war. As such, the fossil fuel industry may emerge even stronger after these energy crises creating new lock-ins. This implies that the public sentiment against dependency on fossil fuels may end as a lost opportunity to translate into actions toward climate-friendly energy transitions, without ambitious plans for phasing out such fuels altogether. We propose policy recommendations to overcome these challenges toward achieving resilient and sustainable energy systems, mostly driven by energy services

Keywords: global warming; energy policy; energy trade; renewable energy system models; international energy markets; decentralized energy storage

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1. Introduction

The COVID-19 pandemic affected many countries and economic sectors worldwide. Different measures were put in place to contain the outbreak of the virus, including complete or partial lockdowns, travel bans, and confinement measures, such as social (physical) distancing and remote working. These measures caused disruptions in the mobility of people, goods, and materials, which resulted in a reduced output of industrial and economic activities. Consequently, the economy shrunk in different countries, raising significant debate over health and economic recovery pathways and their climate impacts [1].

The energy sector was challenged by the pandemic too. The short-term developments marked a drastic fall in energy demand due to reductions in mobility and economic activities. The demand for transportation fell by 50% in countries under lockdown, compared to the same period in a normal year [2]. The reduced demand for transportation fuels directly translated into an unprecedented drop in global crude oil prices, raising concerns over the risks and resilience of energy systems being dependent on such volatile international energy markets [3]. Moreover, disruptions in industrial activities and the introduction of online and digitalized solutions for doing businesses reduced electricity demand in different countries [4]. These supply-side impacts were compounded by lifestyle changes that emerged following the pandemic and containment measures, such as remote working and homeschooling, which caused new patterns of occupancy and energy consumption in buildings at different times of the day [5]. The outcome of these changes multiplied by the lower capacity of consumers for paying energy bills left energy utilities in a difficult situation: reduced sales and decreased collection of revenues.

The COVID-19-induced disruptions were not limited to supply and demand for energy commodities. The supply chain of energy technologies, such as batteries and solar PV panels, was affected too, especially via inter-continental trade routes from China to other countries. The uncertainty in the supply chain, lack of mobility of the workforce, project shutdowns due to lockdowns, and declined revenues from energy sales reduced the capacity of firms and governments for investment in energy projects [6]. Moreover, unlike metals and agricultural goods, the energy sector will face the return shocks being broadcasted the most [7]. This raised concerns about green energy investments and efforts for reducing the climate impact of the energy sector [8]. COVID-19 exacerbated the progress toward meeting SDG7 (clean, modern, and affordable energy for all) since the economic slowdown in many developing countries reduced their capacity for development projects. Job losses and longer stays at home left many families in challenging conditions in terms of access to modern energy services and digitalized solutions for remote working and homeschooling [9].

Once lockdown measures were lifted at the beginning of 2021, and the industry resumed its day-to-day activity in many regions of the world, demand for energy carriers produced a surge in energy prices. Natural gas prices increased worldwide following an increased demand in Asia, followed by Europe, resulting in electricity and natural gas price hikes in 2021 [10]. The situation became so critical that some EU Member States introduced support mechanisms such as tax exemptions to protect low-income consumers already hit by the economic consequences of the pandemic [11], and the European Commission introduced a "toolkit" [12] to tackle the crisis. The energy price shocks raised debates as to what extent European energy and climate policy has been successful in increasing the security of energy supply, by increasing the role of natural gas as a "bridge fuel" in the renewable energy transition [13,14].

While many economies were still struggling to recover from the impact of the pandemic, and in some cases dealing with the post-pandemic energy price hikes, the invasion of Ukraine by the Russian Federation (hereafter "Russia") and the following war deepened the energy crisis furthermore. The physical blockade and sanctions imposed on Russia have disrupted the energy trade and increased energy prices. According to the World Bank, energy prices are expected to increase by more than 50% in 2022 [15], which together with other impacts of the conflict may push the global economy to a stagflation not observed in decades [16]. As the EU has significant energy imports from Russia (around 40% of natural gas, 25% of oil, and 50% of coal imported to the EU came from Russia in 2019), the geopolitical conflict has worsened the energy price crisis in the region, resulting in serious debates between the Member States on effective energy policies that could increase energy security, while maintaining a relatively ambitious climate target for the Union.

The vulnerability of global energy trade and volatility in fossil fuel prices in international markets have raised concerns related to the resilience of the energy system to shocks such as the pandemic and geopolitical conflicts. Hence, it is important to understand the impact of such disruptions on the transition to low-carbon energy systems and to formulate policy recommendations to tackle such impacts.

In this respect, different studies have reviewed the impact of COVID-19 on specific subsectors or certain stakeholders of the energy sector. Jiang et al. [5] investigate the impact of the pandemic on energy demand and report different developments observed during the pandemic and recovery, offering solutions for increasing energy efficiency and promoting energy savings. In Ref. [17], the impact of COVID-19 is analyzed on energy use in buildings, discussing the impetus for progress toward green housing. In another study [18], the impact of COVID-19 lockdowns on mobility trends is analyzed in selected cities, noting reductions in GHGs from the transportation sector. Hoang et al. [8] analyze the impact of the pandemic on renewable energy strategies, by reviewing different measures and summarizing short-term policy priorities and mid- to long-term action plans. The authors emphasize the smaller risk of offshoring for renewable energy investments and energy efficiency improvements compared to traditional fiscal stimulus methods as solutions for reducing the dependency on fossil fuels. Moreover, there is research indicating COVID-19 has revealed the sensitivity of oil prices to global crises, which in some cases has shifted investments from fossil fuels to other commodity markets [19]. Kuzemko et al. [3] investigate the politics and governance of energy in a COVID-19-affected world, highlighting the difficulty of regaining momentum for sustainable energy transitions in a constrained economy. Last but not the least, the financial implications of economic recovery packages are discussed in a number of studies, e.g., with regard to implications on climate change mitigation efforts in [20] and societal responses to climate urgency in green recovery packages in [21].

These studies have improved our understanding of different aspects related to the impact of the pandemic on the energy sector. However, there is a need for improving this body of knowledge in three aspects, by (i) analyzing the impact of the pandemic and the war based on recent studies backed with evidence from different countries, (ii) dealing with the energy sector as a system rather than focusing on a specific sub-system or agent, and (iii) proposing solutions for improving resilience and sustainability of energy systems considering both the pandemic and post-pandemic events including the Russian–Ukrainian conflict. This study aims to contribute to the above by reviewing the available body of literature and classifying them based on the impact of the pandemic and the war on the energy sector. Currently, there are few review studies that tackle the two recent global energy crises thoroughly, so this study aims to draw a link between these events regarding their impact on global energy transitions and discuss some measures to mitigate negative impacts.

We cover the supply of energy commodities and technologies; demand for energy services in buildings, industry, and transportation; energy investments and recovery packages; energy inequality, governance, and policy; and environmental impact of the energy sector including climate change. Based on our review of the impacts of the pandemic and building on a few consultation meetings including stakeholders from different communities, we distill policy recommendations, grouped into three topics, including solutions for improving livability and resilience of urban spaces; an accelerated transition to decentralized and digitalized energy systems; and the role of a sharing and circular economy.

The remainder of this paper is structured as follows. Section 2 reviews the impact of the pandemic and the war on different parts of the energy system. Section 3 discusses the rationale for sustainable energy transitions in the wake of the pandemic, while Section 4 discusses the main findings in comparison to the state-of-the-art in research, followed by conclusions and policy recommendations in Section 5.

2. Impact of the Pandemic and the War on the Energy Sector

The pandemic and the counteractive lockdown measures have led to significant changes in the energy system, due to the combination of economic and social disturbances compared to normality. In parallel, changes in the energy service demands, including reductions in travel and tourism, changes in the workplace, and altered use of goods and services have impacted people and the global economy, including the energy sector [22]. This has created many uncertainties in global commodity markets, of which one of the most vulnerable was energy markets. In some countries such as the USA, Germany, and Italy, the stock market suffered more than the Global Financial Crisis (GFC) in September 2008 [23], with the financial volatility index (VIX) (known as the fear gauge) being higher than the GFC during the pandemic [24]. Considering the relation between the stock and energy (particularly oil) markets, most of the pandemic or war-related volatilities in the energy market can potentially affect stocks as well. Energy markets have seen another shock due to the war in Ukraine. The normal energy supply and trading have been affected, and the geopolitical risks of energy dependency have stimulated plans for the diversification of energy supply and energy demand reductions in some countries [25].

The two recent disruptive events—though both shocking and global in nature—differ greatly in the way they impact the global and local energy systems. First, the pandemic is primarily an energy demand change that has induced a global, systemic, and rapid change, which has been short-lived. Secondly, the war directly impacts energy production, energy supply, and trade, while demand is affected through actions and decisions by individuals and nations to anticipate supply disruptions, sanction Russia, and reduce import dependency. As was seen, oil prices plummeted during the pandemic, in some cases to near zero or even below [26,27], while they skyrocketed to over 100 USD/barrel due to the war [28].

2.1. Supply of Energy

Unexpected disruptions affected the supply of energy, both in terms of commodities and technologies during the pandemic period and, especially, in the first 6 months, through the decrease and restructuring in energy demand. These developments were due to reduced demand for mobility and energy, as well as disruptions in the supply chains of energy technologies and related materials [29].

The war in Ukraine directly affected the upstream energy supply in many countries. The imposed sanctions on Russia have impeded the supply of energy, not only to importing regions such as Europe but also to the rest of the world, as importing regions seek to substitute the loss of supply from Russia by importing from other regions [30]. This has increased energy prices worldwide in the short term, with consequences for many countries with varying levels of development. Here, we discuss these by focusing on the fossil fuel and renewable energy supply as follows.

2.1.1. Upstream Fossil Fuel Industry

Decreased industrial activities and reduced energy demand, together with fuel price volatility at the beginning of the pandemic, impacted the international energy markets. Oil prices went down to their lowest level in 20 years [27], which reduced the investment capacity of some oil and gas companies, resulting in job cuts and damaging the economies of some oil-export-dependent countries [31]. For example, the oil field services companies in the USA alone have shed more than 99,000 jobs in the first months of the pandemic [32]. In the UK, the oil and gas industry observed 30,000 potential job losses [33]. Decreased electricity demand and lower-than-usual prices for natural gas caused a large reduction in the use of coal for electricity production and related GHG emissions [34].

However, this dynamic has been highly volatile—the Russian invasion of Ukraine and the concurrent pressure on fossil fuel supply chains led to hikes in fossil fuel prices and appear to have induced new investments into gas and oil drilling and infrastructure. Some fossil-fuel-exporting countries, e.g., in Africa and the Middle East, gauge opportunities to increase their supply of fossil fuels, especially natural gas and liquified natural gas (LNG), to Europe. This may accelerate the fossil-fuel-exploration plans in such regions, e.g., natural gas extraction from the Mediterranean Sea and possible pipeline infrastructure to Europe [35]. The Russian fossil fuel industry, on the other hand, will suffer in the long term not only because of the loss of exports but also because of the lack of access to Western capital markets and high investment risks in oil and gas exploration and technology transfer [36]. It is expected that the Russian stock market loses between USD 137 and 353 billion, equivalent to 7–20% of its annual GDP, due to war costs and lower energy exports. Importing countries will experience between a 2–3% loss in their stock markets [37].

The COVID-19 and war-related shocks in the energy sector are mainly received by consumers in oil-importing countries [38,39]. This includes an increase in oil prices in the post-pandemic recovery period in 2021 and the consequences of the war in Ukraine in 2022. An increase in oil prices will impact different sectors and industries, including the power sector in developing regions, e.g., in West Africa, where diesel generators are still a major source of electricity. The affected countries may, thus, encounter difficulties in meeting their low-carbon energy policy targets and implementing the fiscal stimuli necessary to support the transition to a more sustainable energy system.

2.1.2. Renewable Energy Transitions

Renewable energy scored a record in global electricity generation of 25% in 2019 before the pandemic, with remarkable growth in the Global South, in countries such as China, India, and Vietnam [40]. The pandemic had some short-term impacts on the renewable energy sector, mainly due to decreased manufacturing or disruptions to the supply chains of low-carbon technologies, e.g., solar photovoltaic (PV) or batteries, especially from major manufacturing countries such as China to the rest of the world. On the other hand, 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 [4]. However, these disruptions were temporary, as there was not a long-lasting change in the environmental quality or a more sustained effort for investment in green technology [41]. The reduced investment capacity of energy companies and delayed construction projects due to the confinement measures, combined with disrupted international trade and reduced availability of workforce, resulted in a 10–15% drop in new investments in clean energy projects in Europe, compared to pre-pandemic figures [42]. Considering this financial difficulty and the vulnerability observed in the resilience of centrally planned energy systems, there was a growth in the investment in onsite energy technologies post COVID-19, e.g., making solar-based applications in buildings and the development of mini-grid systems a priority in some developing countries [43].

The renewable energy sector showed relatively significant resilience to the crisis on a global scale. According to [44], "overall investment in new renewable power capacity (excluding large hydro-electric dams of more than 50 MW) was $281 billion in 2020 (cf. investments in fossil fuel power capacity reached $111 billion)". Despite recent developments in renewable energy investments, the relationship between financial markets and green bonds could be volatile in the future. Hence, risk management measures should be put in place for such investments [45].

The invasion of Ukraine by Russia was another impetus for some nations to accelerate their clean energy transitions based on renewable energy. Germany as one of the countries with a high dependency on fossil fuel imports has accelerated its transition to renewable energy to cope with the possible cut of energy imports from Russia [46]. However, the evidence as of July 2022 suggests that investors' assessments of renewable energy projects have not changed significantly after the conflict between Russia and Ukraine [47]. Renewable energy comprised 28% of the electricity generation globally in 2021, with wind and solar reaching a record high of 10% of the total electricity mix [48]. However, the 4%

surge in energy demand after the pandemic was met mainly by fossil fuels. The share of renewables in total energy consumption shows a slight growth from 8.7% in 2009 to 12.6% in 2020, leaving fossil fuels as the main source of energy needs globally (78.5% in 2020) [49]. The early evidence indicates that the global energy crises have not accelerated the transition to renewable energy, as anticipated, at least in the short term.

2.1.3. Global Energy Crises and Sustainability Goals

The 8.4% drop in manufacturing production in 2020 due to the pandemic [50], which was equally severe as during the Financial Crisis of 2007 [51], was exacerbated by the war and the related economic slowdown [16]. This long-term economic recession imposes significant risks on the availability of public expenditure on climate-related and green energy investments. The decline in the international cooperation and access to multinational development funds needed to support low-income countries in their effort to have access to capital, innovation, technology, and skills will hinder sustainable energy transitions. Based on reports published on the tracking of Sustainable Development Goal (SDG) 7 [52], "significant progress had been made on various aspects of SDG 7 prior to the start of the COVID-19 crisis". This included a significant reduction in the number of people without access to electricity, an increase in the penetration of renewable energy, and improved energy efficiency.

The progress in the developing world, e.g., in sub-Saharan Africa, is, however, not on track with the ambitions of SDG 7, which have been further delayed by the consequences of the pandemic and the war. Recent analyses suggest that a continued slow economic recovery from the pandemic will have a significant impact on making modern energy access unaffordable for a significant share of the population, particularly in regions with the largest access gaps [53]. The tracking of international financial flows to developing regions for improving the share of renewable and clean energy shows that only 12% of such economic support reached the least-developed countries in 2020 [52], a worsened situation due to the pandemic [54]. The Russian–Ukrainian conflict has exacerbated the situation in different world regions. The conflict has increased global energy prices, reducing the capacity of governments in developing regions for investment in development plans, including the transition to cleaner energy. The sanctions against Russia will distort the relationship between some African countries partnering with Russia in low-carbon energy technology transfer—as of 2020, seven African countries had nuclear power agreements with Russia [35].

Table 1 summarizes the main trends and impact of COVID-19 on the supply of energy commodities and technologies observed so far.

Table 1. Impacts of COVID-19 on the upstream supply of energy commodities and technologies.

Impact	Scale	Location	Timeframe	Driver	Ref.
Drop in energy investments	20% cf. 2019 (China 12%, USA 25%, and EU 17%)	Global	2020	Lower industrial activity and economic capacity; lockdown measures	[55]
Reduced investment in oil and gas industry	32.4% cf. 2019	Global	2020	Reduced industrial activity and economic slowdown; reduced revenues due to lower prices	[55]
Decline in investment in the power sector	10.4% cf. 2019	Global	2020	Lower industrial activity; lockdown measures	[55]
Reduced oil prices		Global	Feb–March 2020	Reduced demand for transportation and limited storage possibilities in producing countries	[2]

Table 1. *Cont.*

Impact	Scale	Location	Timeframe	Driver	Ref.
Reduced electricity prices		Some European countries (e.g., Germany, UK)	Lockdown periods	Reduced demand for electricity due to declined industrial activity and closure of businesses	[4]
Increased volatility in oil prices	11–39%	Europe, Africa, North America, South America, and Oceania	Weekly (21 days) to 3 months in 2020	Relationship between the speed affected cases and death with oil price volatility	[26]
Reduced sales of cars	50–80%	India, USA, China	Lockdown periods	Reduced industrial activity and closure of businesses	[56]
Drop in carbon prices	20–30%	EU (ETS)	March 2021	Following the announcement of the WHO on the pandemic	[57]
Decrease in electricity consumption loss	1.62% decrease by each percent decrease in time changing "effective reproductive number (R_t)"	Germany and five USA states	2022	Social features and energy implications changed by COVID-19	[58]
Reduction in CO_2 emissions and power sector cost	Up to 65% in CO_2 emissions and 20% in power cost	Netherlands	2035	A simulation with four future scenarios considering the impacts of lockdown on power cost, emission reduction, and electricity supply	[59]

2.2. Lifestyle, Behavior, and Demand for Energy Services

Demand for energy services was affected by the pandemic in many ways, mainly as a consequence of the related confinement measures. People's activities were restricted to the local level through work and study from home measures, travel restrictions, closure of public spaces, and access limitations to facilities and services. Though there were countries with lower levels of restrictions, they experienced a collateral impact. Depending on the stringency of the measures, energy demand was shown to have reduced 9% (limited lockdown), or ca. 17% (due to partial restrictions), or even up to 24% (full-scale lockdown) [31].

Though the setback in emissions in 2020 has proven to be largely temporary, there have been long-term changes in lifestyles, businesses, and institutions [60–62]. The direct impacts included reduced economic activity and demand for services, such as mobility, transport, space usage, and related material and energy demand reductions, leading to improvements in air quality and greenhouse gas (GHG) emissions [63,64]. The estimated climate impacts based on country-level, sector-specific CO_2 emissions' bottom-up data indicated an abrupt 8.8–9% decrease (−1551 Mt CO_2) between 2019 and 2020 [65,66]. Table 2 demonstrates real-life studies of trends related to energy demand change as a result of behavioral and lifestyle changes. Furthermore, new practices and reformed social norms have increased due to the pandemic causing potentially deeper energy demand changes [5]. The pandemic caused economic distress at the individual and macro levels and losses of income and jobs, which impacted saving decisions. The experiences of 2020 offered an opportunity for policymakers to build on people's willingness to maintain pro-environmental behavior changes, by identifying and enhancing these behaviors and by counteracting backlash [67]. For example, cycling grew by around 100% in Los Angeles and Houston [68] and increased in Paris (39%), Barcelona (30%), Cologne (11%), Vienna (12%), and Oslo (26%) [69], purely from a change in people's practices. This was reinforced by provisional redistribution of street space in many cities, with pop-up bike lanes appearing during the lockdowns in over 30 countries in Europe, such as 30 km in Paris, 21 km in Barcelona, or 9 km in Budapest, among many others. In addition, calming streets and zones have been added and costs for sharing systems reduced or enlarged, in parallel to focusing on walking and public transport. Many of these changes remained afterward, in 2022. In Paris, the pandemic response to extending the cycling infrastructure reinforced the previously already planned "Plan Vélo", making Paris bike-friendly by 2024 [70]. In other cities car-related measures were added, e.g., car bans in Seattle, speed limits in Milan and Philadelphia, etc. These have seen—though there has been a slowdown—still higher levels of biking than before the pandemic, worldwide.

Table 2. Selected trends and drivers of COVID-19 impacts on demand for energy services.

Impact	Scale	Location	Timeframe	Drivers	Ref.
Reduced energy demand	3–10% cf. 2019	Different world regions	2020	Drop of industrial activity and personal mobility	[5]
Reduced demand for transportation fuels	Crude oil: 6.5 mb/d; jet fuel and kerosene: 2.1 mb/d (26%); gasoline: 2.9 mb/d (11%); and diesel: 2 mb/d (7%) reduction cf. 2019	World	2020	Reduced demand for transportation, aviation, and fuel in the industry	[56]
Reduced electricity demand	15–23% during the first and 11% in the second lockdown	Poland	Lockdown periods	Closure of businesses and commercial buildings	[71]
Increased volatility in electricity demand	Weekly variations	Poland	Selected weeks in the year	Household activity changes, and the resulting electricity consumption pattern change in commercial and residential buildings	[71]
Need for air and water filtration systems, enhanced indoor air quality monitoring	N/A	World	Long-term	Change in norms and requirements for higher indoor quality standards in public and commercial buildings	[17]
Increased energy consumption and consequent CO_2 emission of office buildings	Energy demand between 10.18% and 69.48% and CO_2 between 5.8% and 120.61%	Rome and Paris	2022	HVAC usage and guidance in those buildings	[72]
Increased home activity duration which leads to increased energy consumption	80% increase in home activity duration and 29% energy consumption	Canada	2022	Pandemic and lockdown regulations	[73]
Reduced energy consumption in the indoor environment	Maximum 63.5% reduction	China	2019 and 2020	Lockdown measures	[74]
Idle energy demand in non-residential buildings	Approximately 46.9% of the typical energy consumption in academic buildings	Barcelona	2022	Space heaters, air filtration, ventilation, and COVID-19 regulations in partial usage	[75]

2.3. Pandemic and Climate Change: Lessons Learned

Besides the direct impacts on air quality [76] and greenhouse gas reduction [63], the pandemic can also be seen as an example of successful mobilization of the global community to mitigate and adapt to a shared but locally differentiated global crisis [77,78]. Response to the pandemic threat has shown that the world can act swiftly and in unity to tackle an urgent global challenge and is willing to adopt financial and social costs in order to contain the spread of the virus, with responsibility for others [79]. Though they are different in nature, response mechanisms, timespans, and support from the public and authorities, there are a number of lessons that should be acquired from how to mobilize actors for the climate crisis.

First, acting quickly saves lives and costs. Leadership is typically slow and careful, especially in unexpected situations, and policymakers prefer to wait to see what others do [77]. Similar to pandemic responses, earlier action will reduce mitigation costs significantly [80,81], however, successful actions are not popular in hindsight, because they appear as overreactions as the impacts have been avoided. To overcome opposition to timely and increased action, the delegation of the decision to institutions that are involved in long-term decision-making is reasonable [78].

Overall costs are high, but inaction has a significant price. Unprecedented economic recovery packages were seen in response to the pandemic. The green recovery responses to the COVID-19 crisis can contribute to and accelerate the pace of the climate transition, but the majority of stimulus funds are not transformative enough [82]. 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 [83] or significantly reduce the cost of keeping warming to 1.5 degrees Celsius above pre-industrial times [66].

Second, collective behavior is the basis of dealing with major crises. It must involve persuading the public to make significant changes to their lifestyles and behaviors, as it was necessary to fight COVID-19 (wearing face masks, exercising social distancing, becoming vaccinated, etc.). Obviously, the climate problem requires even graver public engagement, building individual action and community practices that can contribute to the transformational effect.

Thirdly, a global problem requires global action. Climate change, as a global problem, is best addressed by a global consensus to trigger collective solutions to urgent problems. The pandemic has taught us how to prevent, manage, and overcome a globally sensitive issue. The management of global perspectives has been shown to require international agreements and individual responsibilities, with a renewed value given to multilateral institutions in the phases of evaluation, target setting, standard setting, and coordination.

Finally, ensuring trust in science to inform decisions. It is not easy to connect policymaking and everyday decisions to science. The rise of populism was experienced during the pandemic and the war, including the spread of persuasive yet ill-informed rhetoric to dismiss reporters, expert opinions, and scientific advice. There was a period during the pandemic when the value to follow the science in informing public policy was well-recognized, but this dissipated as the threat was decreasing. Yet, scientific advice is never value-free. In any democratic society, politicians must necessarily take ownership of the public policy. It is their job to navigate difficult value judgments at the science-policy interface, but, when doing so, it is also important to make informed rather than popular decisions [77].

The pandemic exhibited both a challenge and an opportunity to think about the necessary instruments needed to lead the world toward an environmentally friendly and resilient energy system [84]. An economic recovery consistent with the targets of SDG 7 on energy can only be achieved by building on the opportunities that emerged during the pandemic, including the positive, unprecedented lifestyle and behavioral changes that can also be practiced in a post-pandemic world [85].

2.4. Adverse Impacts and Implications: Health, Social, and Economic Inequalities

The necessary abrupt changes in lifestyles in 2020 have challenged populations everywhere and hit vulnerable groups extensively. Given the digital transformation in the pandemic, low-income populations with lower access to social and energy services at the start have faced imbalanced exposure [86] and are now at a higher risk of poverty as a result of losing their jobs and income due to the economic slowdown [1]. The lack of access to affordable, clean, and modern energy services intensifies existing inequities by the ways vulnerable populations were impacted by the pandemic and the measures taken to contain the virus.

Working and studying at home meant higher home utility bills for many [87]. For those who experienced income losses, well-being at home and thermal comfort could be compromised if the required energy for heating/cooling was unaffordable [88]. Lockdown situations challenged many parents to struggle between family care and job commitments, especially, posing women with a disproportionate burden. These stress factors compromised the productivity of some adults and the education of young people in many regions [89], leaving millions of students with a lack of important education impacting their future lives. A higher reliance on digital solutions and a boom in the development of technologies and services underscored the value of affordable and reliable electricity and access to energy technologies and how these relate to the knowledge needed to use digital services [90]. For families relying on traditional cooking devices and methods, there is a concern that indoor pollution exposure inside homes will increase vulnerability to respiratory diseases such as COVID-19 [91]. The socioeconomic gap widened further due to the economic crisis triggered by the pandemic and the Russian–Ukrainian conflict. Developing countries relying on energy imports have suffered from the energy price hikes due to the conflict. The increase in energy prices combined with inflation and the economic slowdown will shrink the purchasing power of the poor in different regions. Figure 1 summarizes the key impacts of the pandemic on the energy sector.

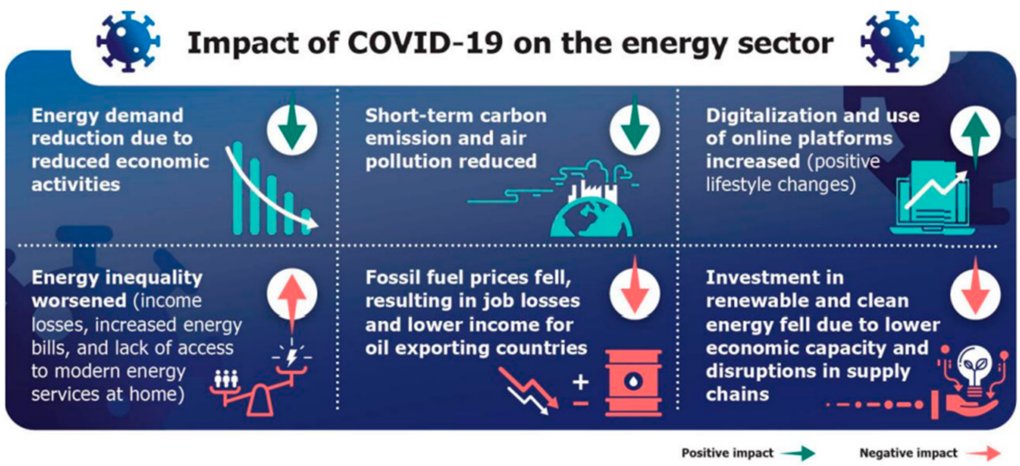

Figure 1. Key impacts of the pandemic on the energy sector [9].

3. Drivers of Sustainable Energy Transitions

SDG 7 on energy proposes three targets for energy access, renewable energy deployment, and energy efficiency. While progress has been made, the world is not on track to achieving all the indicators related to SDG 7 by 2030 [52]. In the aftermath of the pandemic and the war, short-term decisions in the energy sector were made mostly influenced by emergency response measures [92], but the long-term resilience of the system is gaining attention [93]. In this regard, the long-term impacts of the recent energy crises still need to unfold and are unclear. This raises questions as to how the post-COVID-19 recovery impacted by the consequences of the war will influence reaching the SDGs.

3.1. Clean Energy Investments Instead of Fossil Fuels

Globally, fossil fuels receive subsidies of USD 370 billion per year, while renewable energies receive only USD 100 billion [94]. The future impacts of continued support for fossil fuels include extreme events [95]. Early evidence suggested that post-COVID-19 recovery packages need to focus on a green recovery, including an accelerated large-scale deployment of renewables and energy efficiency. However, many national recovery packages continued traditional paths. The Energy Policy Tracker analyzed the recovery packages of G20+ countries and found that fossil fuels were favored over clean energy: 52% of all public money committed to the energy sector went to fossil fuels (USD 222 billion) [82].

The fossil fuel industry sustained the Russia–Ukraine conflict with additional benefits. The rise in the price of natural gas to more than double has stimulated investment in finding new resources and the development of natural gas fields in many regions, e.g., in Mediterranean offshore sites and in the Middle East [96–98]. With Russia using natural gas as leverage to promote its geopolitical interests, especially in Europe, the majority of energy-importing countries are considering diversifying their energy supplies [99,100]. This has led to plans for investment in the infrastructure for importing LNG, even considering floating LNG transfer terminals in Europe [101–103]. This led to a more than 19% rise in exports of LNG by the USA, making the USA the biggest LNG exporter in the world in the first half of 2022.

On the other hand, the geo-political risks of reliance on fossil fuels have led some countries and regions to consider massive investments in clean energy and accelerate their low-carbon energy transitions [104–106].

Investment reallocations away from fossil fuels could reduce the risk of stranded assets [107]. Development financing institutions are debating future financing of gas-fired power, often already accounting for the risk of stranded assets. The European Investment Bank, for example, plans to phase out support for unabated fossil fuel infrastructure [108].

3.2. Cities in the Energy Transition

Over 95% of the recorded COVID-19 cases are located in urban areas, with the most devastating impacts on the urban poor [108]. Cities are responsible for 60–80% of global energy and more than 70% of carbon emissions. By 2050, around 70% of the world population is projected to live in urban areas. Achieving the SDG targets in cities will be critical. Many (mega-)cities are larger than entire nations, hence, their utilities and investment decisions are crucial for the energy transformation. Renewable energy targets are already an important component of municipal policies. Here, cities in Asia and Africa are falling behind, while they experience growing energy demand [109].

The COVID-19-related travel restrictions significantly changed people's mobility [31]. In the short term, public transport nearly vanished. The UK's travel restrictions translated to a 95% reduction in subway journeys in London [110]. This was mainly due to the adjustments to individuals' daily travel activities (i.e., the home office, homeschooling, and online shopping). Recognizing the positive impacts of these changes, many cities have started to rethink urban planning. They have started to use public spaces differently, which has led to many synergies [111]. Examples include Milan's open streets plan; San Francisco's "slow streets"; Bogota's temporary bike lanes; and the conversion of over 100 streets for pedestrians in Buenos Aires. While some of these initiatives have been reversed since the pandemic (e.g., temporary bike paths in Berlin and Vienna have been reverted), the success of other initiatives is encouraging, considering that urban car trips are mostly shorter than 5 km and that 96% of the time cars are parked, using up valuable space [112].

The building construction sectors combined represent one-third of global final energy consumption and nearly 40% of total direct and indirect CO_2 emissions [113]. A low-carbon built environment is, thus, critical for addressing urban development challenges [114]. A sustainable city requires a combination of new technologies, institutions, innovative urban design, enabling policies, and novel planning and managing processes [115]. The world has infrastructure needs of USD 90 trillion investment for 2015–2030, mainly in developing countries [116]. This new infrastructure needs to be low-carbon and climate-resilient to stay within the Paris Agreement temperature guardrail.

3.3. Digitalization and the Digital Divide

During the height of the pandemic and because of more medium-term changes, many of those who could, have worked from home or switched to online shopping. This move to digital technologies is expected to continue. We, thus, want to explore the opportunities of digitalization for the energy transition [117]. Digital technologies are forming new economies and are creating new options for connectivity and collaboration, substituting physical service provisioning and forms of communication, thus reducing mobility. Digitalization has the potential to make less energy-, materials-, and emissions-intensive solutions [118]. Digitalization also provides opportunities by advancing decentralization and enhancing the ability to collect and analyze relevant data for demand management, renewables, and storage integration. This facilitates energy planning, investment, and operational decisions [119].

Other examples enabled by digital technologies include the remote control of assets (enabling demand responses), behind-the-meter generation, home energy management, vehicle-to-grid technologies, and unlocking flexibility from different sources, such as battery management systems, heat pumps, and appliances [120]. The mobility sector also sees many opportunities through digitalization, autonomous driving, connectivity through the Internet of Things (IoT), and electrification and shared mobility (so-called ACES), which can accelerate the uptake of new mobility options [121]. All this can improve mobility services and reduce private vehicle ownership, traffic, and parking needs [122]. Although digitalization can come with economic benefits such as greater productivity, job creation, and support services, it should be mentioned that digitalization can also lead to job losses, higher environmental impacts (i.e., higher consumption levels), and physical tasks [123].

Similarly, to the challenges related to energy inequality and poverty, great discrepancies exist with regard to the usage of digital technologies and the ways different population groups benefit from digitalization.

3.4. Decentralized Renewable Energy and Energy Efficiency

In the past few years, access to electricity has increased, now reaching more than 90% of the world's population. Lack of access is still a significant problem in many countries, where large shares of the population do not have access to reliable and affordable electricity and appliance. This has been further aggravated by COVID-19. The pandemic has shown the power of decentralized, renewable-based energy services, which can offer cost-effective and quickly deployable modular solutions. In Kenya, for example, solar PV panels provide health centers with reliable and renewable electricity to safely store vaccines [124]. The pandemic has been changing the design and operation of energy-efficient buildings, incorporating stringent health criteria, i.e., building codes on energy efficiency and COVID-19 mitigation criteria [125]. Today, less than one-third of countries have mandatory energy-related codes for new construction [126]. In the remaining countries, energy efficiency building codes exist but are not being enforced [127].

Green recovery packages could push new policy instruments focusing on energy performances. This would be people-centered and multi-beneficial and would lead to energy-demand changes and job creation, in line with just energy transition mechanisms [128]. Renewable energy and energy efficiency have an important role to play in hedging against fossil price volatility in the current global tight fossil gas market.

Following the Russian invasion of Ukraine, many countries are putting policies and several guidelines in place to motivate consumers to reduce their energy consumption, in general, and fossil fuels, in particular. The IEA's 10-Point Plan to cut oil use or the REPowerEU investment plans to stimulate clean energy investment by 2027 (such as EUR 56 billion for energy efficiency and heat pumps) are some examples [129,130].

3.5. Power of Collective Individual Behavior

COVID-19 has highlighted the critical role of individuals in bringing about positive social change. Hundreds of millions of individuals, following the knowledge of how to protect themselves and others, were self-isolated in response to the virus, often at a great social and financial cost. Almost immediately, people changed their daily routines and consumption patterns [131]. Public information campaigns to citizens on the effects of their behaviors could maybe also encourage more sustainable energy and transport practices for governments seeking to create long-term demand shifts in energy and mobility choices [132]. The response from societies to the energy crises after the invasion of Ukraine by Russia is a good example in this regard. The policymakers in several countries, especially in Europe, created an atmosphere to motivate people to reconsider their energy consumption, especially the usage of oil and natural gas, as a reaction to the threats caused by this or similar conflicts [104,133,134].

Similarly, the energy transition is leading to and is spurred by various forms of social innovation (i.e., ideas, products, services, or models) that meet social needs and create new collaborations [135]. Examples relevant for the energy transition include energy cooperatives, energy "prosumers" consuming and producing energy, citizen science applications, living labs, and new participative forms of decision-making, such as citizen assemblies and local energy fora [136,137]. Figure 2 illustrates the role of people in enabling sustainable energy transitions.

Figure 2. The role of people in bridging different elements of sustainable energy transitions [9].

4. Discussion

The recent energy crises, i.e., the pandemic and the war, have impacted global energy transitions significantly. Here, we discuss this impact from different dimensions by comparing the findings of this paper with the emerging body of knowledge in the field.

4.1. Temporal Dynamics of Energy Transitions

The longevity of the impact of an energy crisis such as those observed during and after the pandemic, including the current conflict in Ukraine, has been subject to debate. While the short-term impact of the pandemic on the energy sector was a rapid decline in energy demand and prices, the long-term impact was, and still is, uncertain. Some more optimistic views predicted the drop in energy demand to be long-lasting, as the extent of lifestyle changes was considered too large to be brought back to the pre-pandemic normal [138]. Other studies showed that the decline in energy demand is mainly due to top-down restrictions enforced by governments, so demand for energy will grow back to pre-pandemic levels once the urgency is over [139]. Based on the analysis of the short- and long-term impacts of the pandemic on energy demand (see Section 2.3), it is evident that some changes caused by the pandemic will stay for a long period, e.g., increased remote working and relying on digital solutions rather than intracity trips. However, some changes in behavior may cause higher energy demand, e.g., by demanding more air conditioning and larger spaces in office buildings and more individualized public transport choices such as private cars as opposed to using public transport. As noted by Kikstra et al. [66], a more persistent change in energy demand is likely to occur under a "green push" scenario, i.e., a set of rules and policies put in place by governments to enable green energy transitions.

The temporal dynamics of energy transitions, i.e., the timing and the pace of different measures and steps in reaching energy and climate targets, are of paramount importance [140]. Based on the latest IPCC report (AR6), the 2020s is a crucial decade for humans to tackle climate change [95]. In addition, further delay in climate action, due to the pandemic, the war, and their economic impacts, may not only increase the cost but also the risk of the attainability of the Paris Agreement goals [141].

4.2. Geopolitics of Energy Transitions and Energy Security

The response to the energy crisis caused by the war between Russia and Ukraine proved that energy security plays a key role in energy transitions. While many European nations were already hit by post-pandemic price hikes, starting from the second half of 2021, they made difficult choices for reducing their dependency on Russian fossil fuels, including oil sanctions and abandoning the Nord Stream 2 natural gas pipeline between Russia and Germany [142]. Different countries have put policies in place to diversify their sources of energy supply, looking into new gas pipelines and LNG routes [97]. These new dynamics in the geopolitics of energy supply can create new trade relationships (e.g., LNG trade) and new dependencies on suppliers of energy infrastructure (e.g., LNG terminals) or critical materials (e.g., battery cells). Short-term energy demand reductions in heating (e.g., lower room temperatures), agriculture (e.g., less fertilizer use, less meat), and transport (e.g., home office, car-free Sundays, speed limits, pop-up cycling infrastructure) could substitute for 20-60% of EU imports of fossil fuels from Russia [25]. However, the long-term solution is seen to be relying on local, decentralized energy solutions, as found in other studies too [8].

Different studies have shown that these events have positively changed the opinion of the public toward clean energy alternatives [30]. As discussed in Section 3, collective behavior and renewable energy are the two measures that can help nations in overcoming the vulnerability of a fossil-fuel-based energy supply. The response to the recent energy crises also showed that the government plays a key role in shaping energy transitions, as stipulated in [20], most notably, when public support and acceptance are sought after a critical situation threatens the energy security of a nation [3].

4.3. Limitations and Direction for the Future Research

This study reviews the impact of two recent energy crises (i.e., the pandemic and the war), based on the review of other studies and stakeholder input. The studies reviewed here may have used different methods and have published their results using different data at various stages of the development of the crisis. As such, their findings may not be directly comparable. Some studies reviewed here were published at earlier stages of each crisis, which may have been based on early responses to the crisis, thus lacking a holistic and global nature. We have put efforts to provide a context-free analysis of energy transitions. However, the lack of data and publications from less-developed regions may have affected the quality of the findings, with respect to the specificities of such regions.

Future research may focus on the long-term impacts of the energy crises on clean energy transitions across various regions caused by the crisis itself and the measures taken by governments. The access to large datasets collected during the crises, e.g., the transport pattern during the pandemic or the state of energy efficiency responses to the energy price hikes, will improve analyses of individual behaviors, lifestyles, and social practices. Furthermore, identifying policy options to incentivize positive behavioral changes and discourage unsustainable practices is key. Given the complexity of sustainable energy transitions, research practice needs to shift toward a more collaborative knowledge production—transdisciplinary research that integrates the diversity of scientific and societal views of energy problems.

5. Conclusions and Policy Recommendations

This paper reviewed the most important energy trends following the COVID-19 pandemic and the Russia–Ukraine war in 2022, from the short-term to more long-lasting events. While these two events, i.e., the pandemic and the war, are different by nature, some of their impacts on the energy sector were similar. For example, both events revealed the vulnerability of global energy supply chains to trade shocks, either due to physical disruptions (trade disturbances due to the pandemic or sanctions following the war) or supply-demand relationships (near-zero oil prices during the initial lockdowns and soaring prices due to uncertainties caused by the war). The occurrence of several energy price shocks in less than two years has intensified the debate in the energy community on alternative pathways to increase the resilience of energy systems. This may coincide with the efforts for the decarbonization of the energy sector, and, more broadly, with ambitions toward a sustainable energy transition. However, the early evidence suggests that these two energy crises may not necessarily pave the way for low-carbon energy transitions, without relevant policy enforcement. Governments are more focused on energy security in the short-term, relying on low-hanging but risky alternatives, such as looking for new routes of fossil fuel supply, nuclear extensions, or coal revival. Hence, the public sentiment against the vulnerability of fossil fuel supply routes may not be fully translated into ambitious actions to move away from fossil fuels altogether.

In the following, this paper offers some solutions and policy recommendations to improve the resilience of energy systems against global energy trade shocks, such as pandemic and geopolitical conflicts, and to simultaneously enable a sustainable transition to low-carbon energy systems.

5.1. Rethinking Consumption

Energy demand and the concept of consumption need to be transformed toward responsible, sustainable, and sufficient ways of meeting human needs [143]. 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 the increasing importance of the circular and sharing economy [144,145]. Industry can substantially improve its energy and resource efficiency by optimizing processes and introducing sharing-economy approaches for energy purposes [146]. Moreover, global value chains have been substantially affected by the COVID-19 crisis and should be reshaped to make them more resilient. Companies should map social and environmental risks in their international supply chains and take measures to prevent or mitigate them [147]. Active participation of customers in electricity markets, for example, requires regulatory frameworks that allow them to self-generate, self-consume, store, and sell their electricity, without relying on central grids and facing unnecessary barriers [148].

5.2. Reinventing Urban Space, Infrastructure, and Mobility

Urban areas and mobility are two key segments in achieving a sustainable energy transition. The suggested actions toward this policy include applying a holistic and systemic approach to urban planning, designing cities as urban, digitalized villages featuring compact neighborhoods with access to essential services within a short distance, reducing car-dependency in cities, promoting shared mobility services for different target groups, including underserved low-income populations, and promoting e-mobility and energy efficiency in the transport sector. To promote a built environment that is low-carbon, flexible, and resilient to multiple hazards, there is a need to invest in the construction of new buildings that are less resource- and carbon-intensive, renovate the existing building stock, and enforce the energy-performance standards and energy-efficient building codes, increase the use of bio-based, traditional low-carbon materials and designs as well as prioritize "nature-based solutions" such as parks, green roofs, green walls, and blue infrastructure. Figure 3 depicts an urban space design that can enable a sustainable energy transition.

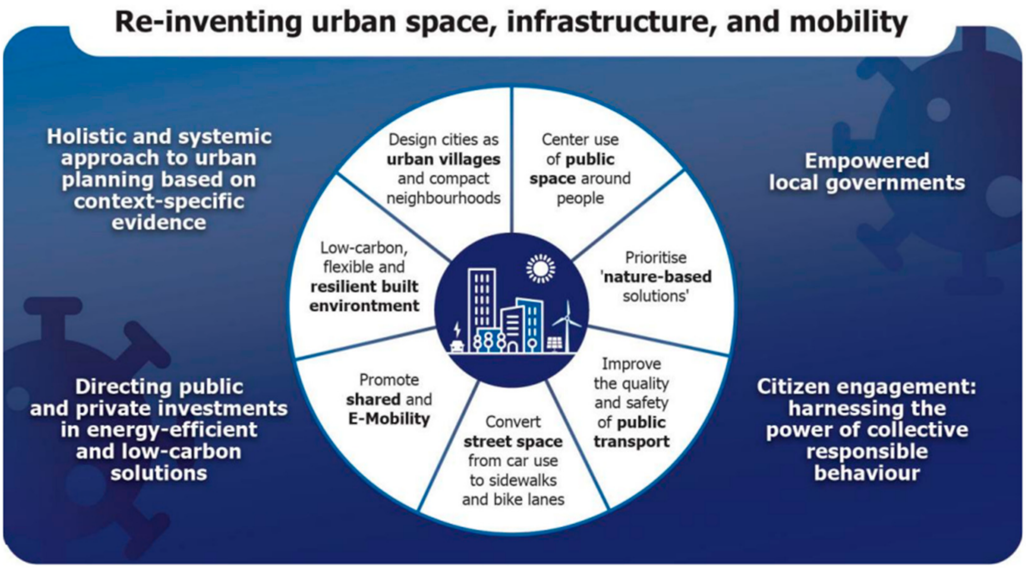

Figure 3. Role of urban space, infrastructure, and mobility in sustainable energy transitions [9].

5.3. Promoting Decentralized and Resilient Energy Systems

In the wake of the COVID-19 pandemic, post-pandemic price hikes, and the war between Russia and Ukraine, the role of decentralized, renewable-energy-based energy systems has become more important than before. Several recommendations can be formulated in this respect to reduce the vulnerability of energy supply chains to disruptions in international energy trade, including reducing or eliminating fossil fuel subsidies, diversifying investments in low-carbon assets, increasing transparency through corporate climate disclosures, removing barriers to renewable energy and green technologies deployment, prioritizing decentralized energy solutions, developing local value chains for renewable energy, promoting community-based governance and business models, expanding and strengthening energy safety nets for vulnerable low-income populations, and developing special recovery packages for small and medium enterprises.

Furthermore, a number of recommendations can be made to enhance energy efficiency, including prioritizing energy efficiency improvements when they are more cost-effective than supply-side solutions, linking energy efficiency to energy access to reduce the cost of appliances for low-income groups, incentivizing prosumers to participate in energy markets, promoting digitalized solutions for harvesting demand-side flexibility, and accelerating innovation in energy efficiency. Energy efficiency is also urgently required to reduce the consumption of fossil fuels and mitigate the effects of the current high fossil fuel prices caused by the current global energy crisis on consumers and economies.

International cooperation to develop energy efficiency and renewable energy in developing countries is necessary to reduce the impacts of the current global energy crisis. In particular, cooperation between the EU and partner countries/regions such as Africa can be mutually beneficial and stimulate trade relations. Cooperation that starts with fossil fuel

LNG will have to provide perspectives for a shift toward renewable energies, including green hydrogen, in the medium and long term, to be broadened to include environmental and climate policy [149].

5.4. Ensuring a Just Energy Transition

The pandemic has shown that 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 and to make such services affordable for all [131]. There is a risk of excluding the vulnerable from access to essential energy services without implementing strong policies such as energy safety nets, programs to guide off-grid companies to protect and support customers, and the provision of financial assistance for energy access companies [150]. Accounting for energy in social safety nets is required now, to guarantee essential energy services for the poor and vulnerable [151]. These could be linked to energy-efficiency programs, through soft loans or subsidies for energy-efficient appliances or repairs for low-income groups. This would reduce the impact of energy pricing and demand in the longer term, increase welfare, and alleviate energy poverty [152]. The effects of COVID-19 have exacerbated the existing inequalities faced by women and girls and have threatened the progress that has been made on gender equality and women's rights [153].

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References

1. World Bank Group. *Global Economic Prospects 2020: Pandemic, Recession: The Global Economy in Crisis*; World Bank Group: Washington, DC, USA, 2020.
2. International Energy Agency (IEA). COVID-19—Topics. Available online: https://www.iea.org/topics/covid-19 (accessed on 12 October 2021).
3. Kuzemko, C.; Bradshaw, M.; Bridge, G.; Goldthau, A.; Jewell, J.; Overland, I.; Scholten, D.; Van de Graaf, T.; Westphal, K. COVID-19 and the politics of sustainable energy transitions. *Energy Res. Soc. Sci.* **2020**, *68*, 101685. [CrossRef]
4. Halbrügge, S.; Schott, P.; Weibelzahl, M.; Buhl, H.U.; Fridgen, G.; Schöpf, M. How did the German and other European electricity systems react to the COVID-19 pandemic? *Appl. Energy* **2021**, *285*, 116370. [CrossRef]
5. Jiang, P.; Van Fan, Y.; Klemeš, J.J. Impacts of COVID-19 on energy demand and consumption: Challenges, lessons and emerging opportunities. *Appl. Energy* **2021**, *285*, 116441. [CrossRef] [PubMed]

6. Andrijevic, M.; Schleussner, C.F.; Gidden, M.J.; McCollum, D.L.; Rogelj, J. COVID-19 recovery funds dwarf clean energy investment needs. *Science* **2020**, *370*, 298–300. [CrossRef] [PubMed]
7. Farid, S.; Naeem, M.A.; Paltrinieri, A.; Nepal, R. Impact of COVID-19 on the quantile connectedness between energy, metals and agriculture commodities. *Energy Econ.* **2022**, *109*, 105962. [CrossRef]
8. Hoang, A.T.; Nižetić, S.; Olcer, A.I.; Ong, H.C.; Chen, W.H.; Chong, C.T.; Thomas, S.; Bandh, S.A.; Nguyen, X.P. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: Opportunities, challenges, and policy implications. *Energy Policy* **2021**, *154*, 112322. [CrossRef]
9. Zakeri, B.; Paulavets, K.; Barreto-Gomez, L.; Gomez Echeverri, L.; Pachauri, S.; Rogelj, J.; Creutzig, F.; Urge-Vorsatz, D.; Victor, D.; Boza-Kiss, B.; et al. *Transformations within Reach: Pathways to a Sustainable and Resilient World—Rethinking Energy Solutions*; International Institute for Applied Systems Analysis (IIASA): Laxenburg, Austria, 2021.
10. Zakeri, B.; Staffell, I.; Dodds, P.; Grubb, M.; Ekins, P.; Jääskeläinen, J.; Cross, S.; Helin, K.; Castagneto-Gissey, G. Energy Transitions in Europe—Role of Natural Gas in Electricity Prices. *SSRN Electron. J.* **2022**. [CrossRef]
11. Euronews. Why Europe's Energy Prices Are Soaring and Could Get Much Worse. Available online: https://www.euronews.com/2021/10/28/why-europe-s-energy-prices-are-soaring-and-could-get-much-worse (accessed on 21 November 2021).
12. European Commission. Tackling Rising Energy Prices: A Toolbox for Action and Support. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A660%3AFIN&qid=1634215984101 (accessed on 4 November 2021).
13. CNA. Europe's Recent Electricity Price Surge Inevitable If It Wants Green Energy. Available online: https://www.channelnewsasia.com/commentary/europe-eu-electricity-price-green-energy-transition (accessed on 19 December 2021).
14. Samseth, E.; Stockhausen, F.; Veillard, X.; Weiss, A. Five Trends Reshaping European Power Markets. Available online: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/five-trends-reshaping-european-power-markets (accessed on 19 December 2021).
15. The World Bank. *Commodity Markets Outlook: The Impact of the War in Ukraine on Commodity Markets*; The World Bank: Washington, DC, USA, 2022.
16. The World Bank Global Economic Prospects. Available online: https://www.worldbank.org/en/publication/global-economic-prospects (accessed on 10 June 2022).
17. Kaklauskas, A.; Lepkova, N.; Raslanas, S.; Vetloviene, I.; Milevicius, V.; Sepliakov, J. COVID-19 and Green Housing: A Review of Relevant Literature. *Energies* **2021**, *14*, 2072. [CrossRef]
18. Abu-Rayash, A.; Dincer, I. Analysis of mobility trends during the COVID-19 coronavirus pandemic: Exploring the impacts on global aviation and travel in selected cities. *Energy Res. Soc. Sci.* **2020**, *68*, 101693. [CrossRef] [PubMed]
19. Tanin, T.I.; Sarker, A.; Brooks, R.; Do, H.X. Does oil impact gold during COVID-19 and three other recent crises? *Energy Econ.* **2022**, *108*, 105938. [CrossRef]
20. Hepburn, C.; O'Callaghan, B.; Stern, N.; Stiglitz, J.; Zenghelis, D. Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? *Oxford Rev. Econ. Policy* **2020**, *36*, S359–S381. [CrossRef]
21. Rochedo, P.R.R.; Fragkos, P.; Garaffa, R.; Couto, L.C.; Baptista, L.B.; Cunha, B.S.L.; Schaeffer, R.; Szklo, A. Is Green Recovery Enough? Analysing the Impacts of Post-COVID-19 Economic Packages. *Energies* **2021**, *14*, 5567. [CrossRef]
22. Nature. Coronavirus: The First Three Months As It Happened. Available online: https://www.nature.com/articles/d41586-020-00154-w (accessed on 21 January 2021).
23. Shehzad, K.; Xiaoxing, L.; Kazouz, H. COVID-19′s disasters are perilous than Global Financial Crisis: A rumor or fact? *Financ. Res. Lett.* **2020**, *36*, 101669. [CrossRef] [PubMed]
24. Batten, J.A.; Kinateder, H.; Szilagyi, P.G.; Wagner, N.F. Hedging stocks with oil. *Energy Econ.* **2021**, *93*, 104422. [CrossRef]
25. Creutzig, F. Fuel crisis: Slash demand in three sectors to protect economies and climate. *Nature* **2022**, *606*, 460–462. [CrossRef]
26. Christopoulos, A.G.; Kalantonis, P.; Katsampoxakis, I.; Vergos, K. COVID-19 and the Energy Price Volatility. *Energies* **2021**, *14*, 6496. [CrossRef]
27. How Oil Prices Went Subzero: Explaining the COVID-19 Oil Crash. Available online: https://www.visualcapitalist.com/subzero-oil-price-crash-covid-19/ (accessed on 1 June 2022).
28. The Economic Times. Oil Prices Will Remain above $100/Barrel as Long as Ukraine War Rages on. Available online: https://economictimes.indiatimes.com/industry/energy/oil-gas/oil-prices-will-remain-above-100/barrel-as-long-as-ukraine-war-rages-on/articleshow/91065993.cms (accessed on 11 July 2022).
29. The Economist. Crude Oil Has Fallen to Less than Nothing. Available online: https://www.economist.com/graphic-detail/2020/04/19/american-crude-oil-has-fallen-to-less-than-nothing (accessed on 22 November 2020).
30. Steffen, B.; Patt, A. A historical turning point? Early evidence on how the Russia-Ukraine war changes public support for clean energy policies. *Energy Res. Soc. Sci.* **2022**, *91*, 102758. [CrossRef]
31. International Energy Agency (IEA). *Global Energy Review 2020: The Impacts of the COVID-19 Crisis on Global Energy Demand and CO2 Emissions*; International Energy Agency (IEA): Paris, France, 2020.
32. COVID-19 Impact: Job Cuts in US Oilfield Services Sector Accelerate. Available online: https://www.offshore-technology.com/news/covid-19-job-cuts-us-oilfield-services-sector/ (accessed on 23 November 2021).
33. BBC News. Coronavirus: "Thousands" of North Sea Oil and Gas Jobs under Threat. Available online: https://www.bbc.com/news/uk-scotland-scotland-business-52446555 (accessed on 23 November 2021).

34. Bertram, C.; Luderer, G.; Creutzig, F.; Bauer, N.; Ueckerdt, F.; Malik, A.; Edenhofer, O. COVID-19-induced low power demand and market forces starkly reduce CO_2 emissions. *Nat. Clim. Chang.* **2021**, *11*, 193–196. [CrossRef]
35. Auth, K.; Moss, T. How Russia's Invasion of Ukraine Will Impact Africa's Energy Transition. Available online: https://www.cfr.org/blog/how-russias-invasion-ukraine-will-impact-africas-energy-transition (accessed on 9 August 2022).
36. Ismailov, N.; Kilinc-Ata, N.; Volkova, I.; Berezhnih, M. Sanctions and the Russian Federation's Economy: A Systematic Literature Review and Comprehensive Analysis of Energy Sector. *SSRN Electron. J.* **2022**. [CrossRef]
37. Huang, L.; Lu, F. The Cost of Russian Sanctions on the Global Equity Markets. *SSRN Electron. J.* **2022**. [CrossRef]
38. Xi, Y.; Zeng, Q.; Lu, X.; Huynh, T.L.D. Oil and renewable energy stock markets: Unique role of extreme shocks. *Energy Econ.* **2022**, *109*, 105995. [CrossRef]
39. Akyildirim, E.; Cepni, O.; Molnár, P.; Uddin, G.S. Connectedness of energy markets around the world during the COVID-19 pandemic. *Energy Econ.* **2022**, *109*, 105900. [CrossRef]
40. International Energy Agency (IEA). *Renewables 2020—Analysis and Forecast to 2025*; International Energy Agency (IEA): Paris, France, 2020.
41. Madaleno, M.; Dogan, E.; Taskin, D. A step forward on sustainability: The nexus of environmental responsibility, green technology, clean energy and green finance. *Energy Econ.* **2022**, *109*, 105945. [CrossRef]
42. COVID-19 Impact on the Power Sector—Eurelectric—Powering People. Available online: https://www.eurelectric.org/news/covid-19/ (accessed on 1 June 2022).
43. Ali, T.; Aghaloo, K.; Chiu, Y.R.; Ahmad, M. Lessons learned from the COVID-19 pandemic in planning the future energy systems of developing countries using an integrated MCDM approach in the off-grid areas of Bangladesh. *Renew. Energy* **2022**, *189*, 25–38. [CrossRef]
44. BloombergNEF. Clean Energy Investment Trends. Available online: https://about.bnef.com/energy-transition-investment/ (accessed on 12 June 2022).
45. Elsayed, A.H.; Naifar, N.; Nasreen, S.; Tiwari, A.K. Dependence structure and dynamic connectedness between green bonds and financial markets: Fresh insights from time-frequency analysis before and during COVID-19 pandemic. *Energy Econ.* **2022**, *107*, 105842. [CrossRef]
46. Reuters. Ukraine Conflict Could Speed Up Germany's Green Energy Transition, Study Says. Available online: https://www.reuters.com/business/sustainable-business/ukraine-conflict-could-speed-up-germanys-green-energy-transition-study-says-2022-07-17/ (accessed on 9 August 2022).
47. Nerlinger, M.; Utz, S. The impact of the Russia-Ukraine conflict on the green energy transition—A capital market perspective. *SSRN Electron. J.* **2022**. [CrossRef]
48. REN21. *Renewables 2022 Global Status Report*; REN21 Secretariat: Paris, France, 2022.
49. International Energy Agency (IEA). Coal Power's Sharp Rebound Is Taking It to a New Record in 2021, Threatening Net Zero Goals. Available online: https://www.iea.org/news/coal-power-s-sharp-rebound-is-taking-it-to-a-new-record-in-2021-threatening-net-zero-goals (accessed on 9 August 2022).
50. Fulzele, R.; Fulzele, V.; Dharwal, M. Mapping the Impact of COVID-19 Crisis on the Progress of Sustainable Development Goals (SDGs)—A focus on Global Environment and Energy Efficiencies. *Mater. Today Proc.* **2021**, *60*, 873–879. [CrossRef] [PubMed]
51. Chatziantoniou, I.; Gabauer, D.; de Gracia, F.P. Tail risk connectedness in the refined petroleum market: A first look at the impact of the COVID-19 pandemic. *Energy Econ.* **2022**, *111*, 106051. [CrossRef]
52. Tracking SDG 7 | Progress Towards Sustainable Energy. Available online: https://trackingsdg7.esmap.org/ (accessed on 23 November 2021).
53. Pachauri, S.; Poblete-Cazenave, M.; Aktas, A.; Gidden, M.J. Access to clean cooking services in energy and emission scenarios after COVID-19. *Nat. Energy* **2021**, *6*, 1067–1076. [CrossRef]
54. WHO. *COVID-19 Intensifies the Urgency to Expand Sustainable Energy Solutions Worldwide*; WHO: Geneva, Switzerland, 2020.
55. International Energy Agency (IEA). World Energy Investment 2020. Available online: https://www.iea.org/reports/world-energy-investment-2020 (accessed on 14 October 2021).
56. International Energy Agency (IEA). Oil—Global Energy Review 2020. Available online: https://www.iea.org/reports/global-energy-review-2020/oil#abstract (accessed on 14 October 2021).
57. Steffen, B.; Egli, F.; Pahle, M.; Schmidt, T.S. Navigating the Clean Energy Transition in the COVID-19 Crisis. *Joule* **2020**, *4*, 1137–1141. [CrossRef] [PubMed]
58. Li, Z.; Ye, H.; Liao, N.; Wang, R.; Qiu, Y.; Wang, Y. Impact of COVID-19 on electricity energy consumption: A quantitative analysis on electricity. *Int. J. Electr. Power Energy Syst.* **2022**, *140*, 108084. [CrossRef]
59. Luo, S.; Hu, W.; Liu, W.; Cao, D.; Du, Y.; Zhang, Z.; Chen, Z. Impact analysis of COVID-19 pandemic on the future green power sector: A case study in the Netherlands. *Renew. Energy* **2022**, *191*, 261–277. [CrossRef]
60. U.S. Electric System Operating Data. Available online: https://www.eia.gov/realtime_grid/#/status?end=20201123T07 (accessed on 23 June 2022).
61. ENTSO-E Transparency Platform. Available online: https://transparency.entsoe.eu/ (accessed on 13 March 2021).
62. Le Quéré, C.; Peters, G.P.; Friedlingstein, P.; Andrew, R.M.; Canadell, J.G.; Davis, S.J.; Jackson, R.B.; Jones, M.W. Fossil CO_2 emissions in the post-COVID-19 era. *Nat. Clim. Chang.* **2021**, *11*, 197–199. [CrossRef]

63. Le Quéré, C.; Jackson, R.B.; Jones, M.W.; Smith, A.J.; Abernethy, S.; Andrew, R.M.; De-Gol, A.J.; Willis, D.R.; Shan, Y.; Canadell, J.G.; et al. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nat. Clim. Chang.* **2020**, *10*, 647–653. [CrossRef]
64. Liu, Z.; Ciais, P.; Deng, Z.; Lei, R.; Davis, S.J.; Feng, S.; Zheng, B.; Cui, D.; Dou, X.; Zhu, B.; et al. Near-real-time monitoring of global CO_2 emissions reveals the effects of the COVID-19 pandemic. *Nat. Commun.* **2020**, *11*, 5172. [CrossRef]
65. Parker, L.; Elder, S. (National Geographic). 3 Ways COVID-19 Is Making Us Rethink Energy and Emissions. Available online: https://www.nationalgeographic.com/magazine/article/three-ways-covid-19-is-making-us-rethink-energy-and-emissions-feature (accessed on 21 June 2022).
66. Kikstra, J.S.; Vinca, A.; Lovat, F.; Boza-Kiss, B.; van Ruijven, B.; Wilson, C.; Rogelj, J.; Zakeri, B.; Fricko, O.; Riahi, K. Climate mitigation scenarios with persistent COVID-19-related energy demand changes. *Nat. Energy* **2021**, *6*, 1114–1123. [CrossRef]
67. Corker, E.A.; Mitev, K.; Nilsson Lewis, A.; Tamis, M.; Bouman, T.; Holmlid, S.; Lambe, F.; Michie, S.; Osborne, M.; Jan Renes, R.; et al. The impact of COVID-19 related regulations and restrictions on mobility and potential for sustained climate mitigation across the Netherlands, Sweden and the UK: A data-based commentary. *UCL Open Environ.* **2022**, 4. [CrossRef]
68. Bliss, L. How the Coronavirus Affected Biking in U.S Cities. Available online: https://www.bloomberg.com/news/articles/2020-09-23/how-the-coronavirus-affected-biking-in-u-s-cities (accessed on 11 July 2022).
69. Buehler, R.; Pucher, J. COVID-19 Impacts on Cycling, 2019–2020. *Transp. Rev.* **2021**, *41*, 393–400. [CrossRef]
70. Nikitas, A.; Tsigdinos, S.; Karolemeas, C.; Kourmpa, E.; Bakogiannis, E. Cycling in the Era of COVID-19: Lessons Learnt and Best Practice Policy Recommendations for a More Bike-Centric Future. *Sustainability* **2021**, *13*, 4620. [CrossRef]
71. Malec, M.; Kinelski, G.; Czarnecka, M. The Impact of COVID-19 on Electricity Demand Profiles: A Case Study of Selected Business Clients in Poland. *Energies* **2021**, *14*, 5332. [CrossRef]
72. Cortiços, N.D.; Duarte, C.C. Energy efficiency in large office buildings post-COVID-19 in Europe's top five economies. *Energy Sustain. Dev.* **2022**, *68*, 410–424. [CrossRef]
73. Khalil, M.A.; Fatmi, M.R. How residential energy consumption has changed due to COVID-19 pandemic? *An agent-based model. Sustain. Cities Soc.* **2022**, *81*, 103832. [CrossRef]
74. Su, Y.; Cheng, H.; Wang, Z.; Wang, L. Impacts of the COVID-19 lockdown on building energy consumption and indoor environment: A case study in Dalian, China. *Energy Build.* **2022**, *263*, 112055. [CrossRef]
75. Gaspar, K.; Gangolells, M.; Casals, M.; Pujadas, P.; Forcada, N.; Macarulla, M.; Tejedor, B. Assessing the impact of the COVID-19 lockdown on the energy consumption of university buildings. *Energy Build.* **2022**, *257*, 111783. [CrossRef]
76. Mandal, J.; Samanta, S.; Chanda, A.; Halder, S. Effects of COVID-19 pandemic on the air quality of three megacities in India. *Atmos. Res.* **2021**, *259*, 105659. [CrossRef]
77. Klenert, D.; Funke, F.; Mattauch, L.; O'Callaghan, B. Five Lessons from COVID-19 for Advancing Climate Change Mitigation. *Env. Resour. Econ* **2020**, *76*, 751–778. [CrossRef]
78. Field, B.G. COVID-19 lessons for climate change. *J. Mega Infrastruct. Sustain. Dev.* **2021**, *1*, 303–309. [CrossRef]
79. Nicola, M.; Alsafi, Z.; Sohrabi, C.; Kerwan, A.; Al-Jabir, A.; Iosifidis, C.; Agha, M.; Agha, R. The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *Int. J. Surg.* **2020**, *78*, 185–193. [CrossRef] [PubMed]
80. Dietz, S.; Venmans, F. Cumulative carbon emissions and economic policy: In search of general principles. *J. Environ. Econ. Manag.* **2019**, *96*, 108–129. [CrossRef]
81. Goulder, L.H. Timing Is Everything: How Economists Can Better Address the Urgency of Stronger Climate Policy. *Rev. Environ. Econ. Policy* **2020**, *14*, 143–156. [CrossRef]
82. Energy Policy Tracker. Track Public Money for Energy in Recovery Packages. Available online: https://www.energypolicytracker.org/ (accessed on 21 December 2021).
83. Forster, P.M.; Forster, H.I.; Evans, M.J.; Gidden, M.J.; Jones, C.D.; Keller, C.A.; Lamboll, R.D.; Le Quéré, C.; Rogelj, J.; Rosen, D.; et al. Current and future global climate impacts resulting from COVID-19. *Nat. Clim. Chang.* **2020**, *10*, 913–919. [CrossRef]
84. Sovacool, B.K.; Del Rio, D.F.; Griffiths, S. Contextualizing the COVID-19 pandemic for a carbon-constrained world: Insights for sustainability transitions, energy justice, and research methodology. *Energy Res. Soc. Sci.* **2020**, *68*, 101701. [CrossRef]
85. Bragge, P.; Becker, U.; Breu, T.; Carlsen, H.; Griggs, D.; Lavis, J.N.; Zimm, C.; Stevance, A.S. How policymakers and other leaders can build a more sustainable post-COVID-19 'normal'. *Discov. Sustain.* **2022**, *3*, 7. [CrossRef] [PubMed]
86. Boza-Kiss, B.; Pachauri, S.; Zimm, C. Deprivations and Inequities in Cities Viewed Through a Pandemic Lens. *Front. Sustain. Cities* **2021**, *3*, 15. [CrossRef]
87. A Perfect Storm? COVID-19 Cuts Incomes and Hikes Home Energy Bills. Available online: https://www.aceee.org/blog-post/2020/05/perfect-storm-covid-19-cuts-incomes-and-hikes-home-energy-bills (accessed on 23 December 2021).
88. COVID 19—End Fuel Poverty Coalition. Available online: http://www.endfuelpoverty.org.uk/tag/covid-19/ (accessed on 21 December 2021).
89. Amir, M.; Khan, S.Z. Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa. *Energy Built Environ.* **2022**, *3*, 348–362. [CrossRef]
90. United Nations. COVID-19 Makes Universal Digital Access and Cooperation Essential. Available online: https://news.un.org/en/story/2020/05/1063272 (accessed on 21 December 2021).
91. Wu, X.; Nethery, R.; Sabath, B.; Braun, D.; Dominici, F. Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study. *MedRxiv* **2020**. [CrossRef]

92. International Energy Agency (IEA). Russia's War on Ukraine. Available online: https://www.iea.org/topics/russia-s-war-on-ukraine (accessed on 16 July 2022).
93. Leslie, G.W.; Stern, D.I.; Shanker, A.; Hogan, M.T. Designing electricity markets for high penetrations of zero or low marginal cost intermittent energy sources. *Electr. J.* **2020**, *33*, 106847. [CrossRef]
94. Bridle, R.; Sharma, S.; Mostafa, M.; Geddes, A. *Fossil Fuel to Clean Energy Subsidy Swaps: How to Pay for an Energy Revolution*; International Institute for Sustainable Development: Winnipeg, MB, Canada, 2019.
95. IPCC AR6 Climate Change 2022: Mitigation of Climate Change. Available online: https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/ (accessed on 15 June 2022).
96. Makholm, J.D. The 2021–2022 European Natural Gas Disaster: Was Reagan Right and Thatcher Wrong? *Clim. Energy* **2022**, *38*, 1–9. [CrossRef]
97. Selei, A.; Kotek, P.; Takácsné Tóth, B. Russia's Gas Weapon and Europe's Best Response. *SSRN Electron. J.* **2022**. [CrossRef]
98. Zeitler, E. Opportunities for Energy and Climate Sectors in the Infrastructure Investment and Jobs Act. *Clim. Energy* **2022**, *38*, 10–15. [CrossRef]
99. McWilliams, B.; Sgaravatti, G.; Tagliapietra, S.; Zachmann, G. Can Europe Survive Without Russian Gas? Available online: https://www.bruegel.org/blog-post/can-europe-survive-without-russian-gas (accessed on 18 June 2022).
100. Tollefson, J. What the war in Ukraine means for energy, climate and food. *Nature* **2022**, *604*, 232–233. [CrossRef]
101. Eckert, V. (Reuters). Germany Ramps Up Capacity for LNG Imports to Replace Russian Gas. Available online: https://www.reuters.com/business/energy/germany-ramps-up-capacity-lng-imports-replace-russian-gas-2022-05-05/#:~{}:text=FRANKFURT%2C%20May%205%20(Reuters),as%20the%20first%20handling%20hub (accessed on 12 July 2022).
102. Delfs, A.; Dezem, V. Germany Rents Floating LNG Hubs to Cut Reliance on Russian Gas. Bloomberg. Available online: https://www.bloomberg.com/news/articles/2022-05-05/germany-charters-floating-lng-terminals-to-help-cut-russian-gas (accessed on 12 July 2022).
103. Drager, L.; Gründler, K.; Potrafke, N. Political Shocks and Inflation Expectations: Evidence from the 2022 Russian Invasion of Ukraine. *SSRN Electron. J.* **2022**. [CrossRef]
104. Foregin Policy Research Institute. Climate Action Meets Energy Security: The Russian Invasion of Ukraine Adds a New Dimension to Energy Transition. Available online: https://www.fpri.org/article/2022/06/climate-action-meets-energy-security-the-russian-invasion-of-ukraine-adds-a-new-dimension-to-energy-transition/ (accessed on 12 July 2022).
105. Birol, F. What Does The current Global Energy Crisis Mean for Energy Investment? *IEA*. Available online: https://www.iea.org/commentaries/what-does-the-current-global-energy-crisis-mean-for-energy-investment (accessed on 12 July 2022).
106. Nouveau, P. *EU Strategic Sovereignty and Industrial Policy after Versailles*; EGMONT: Brussels, Belgium, 2022.
107. Carbon Tracker CTI Annual Review 19. Available online: https://www.annualreview2019.carbontracker.org/ (accessed on 6 March 2021).
108. United Nation. UN-Habitat COVID-19 Response Plan. Available online: https://unhabitat.org/un-habitat-covid-19-response-plan (accessed on 21 December 2020).
109. IRENA. *Rise of Renewables in Cities: Energy Solutions for the Urban Future*; IRENA: Abu Dhabi, United Arab Emirates, 2020.
110. International Energy Agency (IEA). Changes in Transport Behaviour during the COVID-19 Crisis. Available online: https://www.iea.org/articles/changes-in-transport-behaviour-during-the-covid-19-crisis (accessed on 21 January 2021).
111. Creutzig, F.; Lohrey, S.; Vázquez Franza, M. COVID-19, shifting urban mobility patterns, and sustainability implications. *Environ. Res. Infrastruct. Sustain.* 2022; *under review*.
112. Neiuwenhuijsen, M. Urban and transport planning pathways to carbon neutral, liveable and healthy cities; A review of the current evidence. *Environ. Int.* **2020**, *140*, 105661. [CrossRef]
113. Internaitonal Energy Agency (IEA). *Buildings: A Source of Enormous Untapped Efficiency Potential*; IEA: Paris, France, 2020.
114. Cabeza, L.F.; and Urge-Vorsatz, D. The role of buildings in the energy transition in the context of the climate change challenge. *Glob. Transit.* **2020**, *2*, 257–260. [CrossRef]
115. Newton, P.W.; Rogers, B.C. Transforming Built Environments: Towards Carbon Neutral and Blue-Green Cities. *Sustainability* **2020**, *12*, 4745. [CrossRef]
116. Meltzer, J.P.; Constantine, C. How Do We Finance Low-Carbon Infrastructure? The Brookings Institution: Washington, DC, USA, 2018.
117. Motlagh, N.H.; Mohammadrezaei, M.; Hunt, J.; Zakeri, B. Internet of things (IoT) and the energy sector. *Energies* **2020**, *13*, 494. [CrossRef]
118. Krutzler, T.; Wiesenberger, H.; Heller, C.; Gössl, M.; Stranner, G.; Storch, A.; Heinfellner, H.; Winter, R.; Kellner, M.; Schindler, I. *Szenario Erneuerbare Energie 2030 und 2050*; Umweltbundesamt GmbH: Vienna, Austria, 2016.
119. Kaack, L.H.; Donti, P.L.; Strubell, E.; Kamiya, G.; Creutzig, F.; Rolnick, D. Aligning artificial intelligence with climate change mitigation. *Nat. Clim. Chang.* **2022**, *12*, 518–527. [CrossRef]
120. IRENA. *Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables*; IRENA: Abu Dhabi, United Arab Emirates, 2019.
121. McKinsey. The Future of Mobility Is at Our Doorstep. Available online: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-mobility-is-at-our-doorstep (accessed on 21 December 2021).

122. Sanvicente, E.; Kielmanowicz, D.; Rodenbach, J. Key Technology and Social Innovation Drivers for Car-Sharing. Available online: http://stars-h2020.eu/wp-content/uploads/2019/06/STARS-D2.2.pdf (accessed on 12 December 2021).
123. European Commission. Industry Digitalization from an Energy Perspective. Available online: https://ee-ip.org/en/article/industry-digitalisation-from-an-energy-perspective-1729 (accessed on 12 July 2022).
124. Chen, C.; Mwachandi, R.; Sanyal, S. In Kenya's Rural Health Clinics, Business Performance and Renewables Go Hand-in-Hand. Available online: https://www.wri.org/insights/kenyas-rural-health-clinics-business-performance-and-renewables-go-hand-hand (accessed on 12 July 2022).
125. Environmental Protection Agency (EPA). EPA Supports Healthy Indoor Environments in Schools During COVID-19 Pandemic. Available online: https://www.epa.gov/coronavirus/healthy-indoor-environments-schools-during-covid-19-pandemic-and-beyond (accessed on 21 December 2021).
126. International Energy Agency (IEA). Sustainable Recovery: A World Energy Outlook Special Report in Collaboration with the International Monetary Fund. Available online: https://www.iea.org/reports/sustainable-recovery (accessed on 21 December 2021).
127. United Nation Environment Program (UNEP). Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector. Available online: https://www.unep.org/resources/report/2021-global-status-report-buildings-and-construction (accessed on 21 December 2021).
128. Henry, M.S.; Bazilian, M.D.; Markuson, C. Just transitions: Histories and futures in a post-COVID world. *Energy Res. Soc. Sci.* **2020**, *68*, 101668. [CrossRef] [PubMed]
129. Mathiesen, B.V.; Ilieva, L.S.; Skov, I.R.; Maya-Drysdale, D.W.; Korberg, A.D. *REPowerEU and Fitfor55 Science-Based Policy Recommendations for Achieving the Energy Efficiency First Principle*; Aalborg University: Copenhagen, Denmark, 2022.
130. International Energy Agency (IEA). A 10-Point Plan to Cut Oil Use. Available online: https://www.iea.org/reports/a-10-point-plan-to-cut-oil-use (accessed on 12 July 2022).
131. Budd, L.; Ison, S. Responsible Transport: A post-COVID agenda for transport policy and practice. *Transp. Res. Interdiscip. Perspect.* **2020**, *6*, 100151. [CrossRef]
132. The World Bank. Citizen Engagement. Available online: https://www.worldbank.org/en/topic/citizen-engagement (accessed on 20 December 2021).
133. Findlay, A. Fighting climate change. *Nat. Clim. Chang.* **2022**, *12*, 619. [CrossRef]
134. Castanho Silva, B.; Wäckerle, J.; Wratil, C. *Determinants of Public Opinion Support for a Full Embargo on Russian Energy in Germany*; ECONtribute Discussion Papers Series; University of Bonn: Bonn, Germany; University of Cologne: Cologne, Germany, 2022.
135. European Commission. *Guide to Social Innovation. European Innovation Partnership on Active and Healthy Ageing*; European Commission: Brussels, Belgium, 2013.
136. Global Forum on Sustainable Energy (GFSE). Engaging Citizens via Social Innovations for the Energy Transition. Available online: https://www.gfse.at/news/gfse-policy-brief-11-engaging-citizens-via-social-innovations-for-the-energy-transition (accessed on 21 December 2021).
137. Wittmayer, J.M.; de Geus, T.; Pel, B.; Avelino, F.; Hielscher, S.; Hoppe, T.; Mühlemeier, S.; Stasik, A.; Oxenaar, S.; Rogge, K.S.; et al. Beyond instrumentalism: Broadening the understanding of social innovation in socio-technical energy systems. *Energy Res. Soc. Sci.* **2020**, *70*, 101689. [CrossRef]
138. Alvik, S.; Irvine, M. Impact of COVID on Energy Transition. Available online: https://www.dnv.com/energy-transition/impact-of-covid19-on-the-energy-transition.html (accessed on 4 August 2022).
139. Bazzana, D.; Cohen, J.J.; Golinucci, N.; Hafner, M.; Noussan, M.; Reichl, J.; Rocco, M.V.; Sciullo, A.; Vergalli, S. A multi-disciplinary approach to estimate the medium-term impact of COVID-19 on transport and energy: A case study for Italy. *Energy* **2022**, *238*, 122015. [CrossRef]
140. Sovacool, B.K. How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* **2016**, *13*, 202–215. [CrossRef]
141. Riahi, K.; Bertram, C.; Huppmann, D.; Rogelj, J.; Bosetti, V.; Cabardos, A.M.; Deppermann, A.; Drouet, L.; Frank, S.; Fricko, O.; et al. Cost and attainability of meeting stringent climate targets without overshoot. *Nat. Clim. Chang.* **2021**, *11*, 1063–1069. [CrossRef]
142. Mišík, M. The EU needs to improve its external energy security. *Energy Policy* **2022**, *165*, 112930. [CrossRef]
143. Creutzig, F.; Niamir, L.; Bai, X.; Callaghan, M.; Cullen, J.; Díaz-José, J.; Figueroa, M.; Grubler, A.; Lamb, W.F.; Leip, A.; et al. Demand-side solutions to climate change mitigation consistent with high levels of well-being. *Nat. Clim. Chang.* **2021**, *12*, 36–46. [CrossRef]
144. Bocken, N.; Short, S. *Transforming Business Models: Towards a Sufficiency-Based Circular Economy*; Handbook of the Circular Economy; Edward Elgar Publishing: Cheltenham, UK, 2019.
145. Millward-Hopkins, J.; Steinberger, J.K.; Rao, N.; Oswald, Y. Providing decent living with minimum energy: A global scenario. *Glob. Environ. Chang.* **2020**, *65*, 102168. [CrossRef]
146. Rissman, J.; Bataille, C.; Masanet, E.; Aden, N.; Morrow, W.R., III; Zhou, N.; Elliott, N.; Dell, R.; Heeren, N.; Huckestein, B.; et al. Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. *Appl. Energy* **2020**, *266*, 114848. [CrossRef]
147. Roy, L. *5 Ways Traceability Technologies Can Lead to a Safer, More Sustainable World*; World Economic Forum: Cologny, Switzerland, 2019.

148. Energy Community Regulatory Board (ECRB). *Prosumers in the Energy Community: Legal and Regulatory Framework for Support and Treatment of Small-Scale Generators*; ECRB: Vienna, Austria, 2020.
149. Barreto, L. *Natural Gas and Renewable Hydrogen in Africa and Cooperation Opportunities with the EU*; Global Forum on Sustainable Energy: Vienna, Austria, 2022.
150. Editor's Pick: Powering Health Across Africa through COVID-19 and a Changing Climate | Sustainable Energy for All. Available online: https://www.seforall.org/news/powering-health-across-africa-through-covid-19 (accessed on 23 November 2020).
151. OECD. *Supporting Livelihoods during the COVID-19 Crisis: Closing the Gaps in Safety Nets. OECD Policy Responses to Coronavirus (COVID-19)*; OECD: Paris, France, 2020.
152. SEforAll. *Energy Safety Nets: Using Social Assistance Mechanisms to Close Affordability Gaps for the Poor*; SEforAll: Vienna, Austria, 2020.
153. Women Leaders Call for Action in Response to COVID-19: Opening Opportunities for Gender Equality in the Transition to Sustainable Energy. Available online: https://www.energia.org/women-leaders-call-for-action-in-response-to-covid-19-opening-opportunities-for-gender-equality-in-the-transition-to-sustainable-energy/ (accessed on 21 June 2022).