What happened and will happen in the energy sector under the impact of COVID-19? A review

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Abstract: The outbreak of coronavirus disease 2019 (COVID-19) has had a considerable impact on every sector. As a pillar industry of economic development, the energy sector is experiencing a difficult moment in the global epidemic. This paper reviews the influence of the epidemic on the global energy sector in terms of demand, price, employment, government policy, countermeasure, and academic research. Although the virus has greatly impacted the energy sector, action to address climate issues has not been suspended, but more urgent than ever. Experts pointed out that it is the time to promote clean energy transition vigorously. Thus, this paper discusses the development focus of clean energy transition, including bioenergy, mineral resources for clean energy technique, battery, and electrolyzer. The results indicate that supply chain stability, power storage, and policy-making during and after the outbreak are significant challenges for the clean energy transition. Meanwhile, it can bring more opportunities for employment, economic recovery, and the human living environment.

Keywords: COVID-19; energy sector; energy policy; clean energy transition; bioenergy; battery; electrolyzer

1. Introduction

1.1. Background

In the first quarter of 2020, the outbreak of coronavirus disease 2019 (COVID-19) not only killed many people but also had a significant impact on the global economy. According to the COVID-19 system developed by Johns Hopkins University (JHU), as of May 7, 2020, there were 3,836,215 infections worldwide and 269,267 deaths, and it has affected 187 countries or regions around the world. Many countries have issued restrictions to slow down the spread of the virus, including the closure of educational institutions, partial or full lockdowns, home office, and so on. In this context, transportation, catering, entertainment, medical care, manufacturing, real estate, and other aspects have been adversely affected. As a result, more than half of the global population is greatly affected by containment measures [1]. It is not hard to imagine that, as the pillar of the global economy, the energy sector has suffered a lot.

1.2. Motivations and contributions

The motivation for doing this research are:

1) To allow more people, especially managers and policymakers, to fully understand the impact of COVID-19 on the energy industry through this paper;

2) Let more people have a comprehensive understanding of the countermeasures and policies made by some countries to COVID-19;

3) Let managers clarify the future development direction, existing opportunities, and possible challenges for the energy sector.

The primary contributions of this paper are:

a) To the best of the authors' knowledge, this is the first comprehensive description of the impact of COVID-19 on the energy sector from various aspects;

b) The future development direction, opportunities, and challenges of the energy sector are summarized.

2. Methodology

This paper is developed based on academic databases and online resources. Thus, academic search and general search are used to collect relevant information. ScienceDirect and Google Scholar are used as academic search tools, and Google and Bing are utilized as general search tools. Since the theme of this paper is the impact of COVID-19 on the energy sector, "COVID" and "energy" are determined as keywords. Then extract valuable information and data through careful reading. Finally, 38 resources are selected, including academic papers, reports, and forums.

3. Review findings

Through the literature review, the impact of COVID-19 on the energy sector can be described from the following six aspects: energy demand, energy price, employment, energy policy, countermeasure, and academic research.

3.1. Renewables increased and other declined

According to statistics from the International Energy Agency (IEA) [1], global energy demand in the first quarter of 2020 has decreased by 3.8% (150 Mtoe) compared to 2019 due to the reduction of economic activities and traffic caused by the lockdown. Based on the analysis from IEA, global energy demand will drop by 6% in 2020. If the economy is restarted and the virus's spread is effectively contained, the energy demand drop will be controlled at 4%. However, restarting the economy is difficult because it may lead to the second large-scale outbreak of the virus and have a more negative impact on the energy sector. In the first quarter of 2020, the consumption of various energy sources has changed to varying degrees compared to the first quarter of 2019. Their rate of change, causes, and countries (or regions) that are more affected are shown in Table 1. IEA forecasted the rate of change in energy demand by 2020 compared to 2019 (see Fig.1). The decline in oil demand will be the largest, reaching 9%; the decline in natural gas and electricity will be the same, reaching 5%; the growth rate of renewable energy will be 1%. The reduction in energy consumption has not been seen in 70 years, more than the financial crisis in 2008.

Table 1. Energy demand changes and reasons in the first quarter of 2020 (Data source: [1]).

Energy type	Changes from the first quarter of 2019	Reason	More affected countries/regions	Remark
Oil	-5%	➢ Decline in the vehicle (decreased by 50%) and aviation (decreased by 60%) usage ➢ Decline in car sales	China, Europe	Gasoline is the oil product with the largest drop in demand.
Natural gas	-2%	➢ Demand for electricity is lower than before	China, the United States, Europe	The consumption of natural gas in power generation decreased by 7%, with the highest proportion of the decline
Coal	-8%	➢ Demand for electricity is lower than before ➢ The competitiveness is not as good as natural gas	China	China's coal consumption trend may change global coal development. The outlook for coal depends on electricity demand, and it has the highest level of uncertainty in the development of all fuels.
Electricity	-2.5%	➢ The reduction of industrial production and economic activity; ➢ The average temperature in the first quarter of 2020 is higher than that in 2019	Europe, India, United States	Electricity demand is mainly driven by residential demand. It has the greatest impact on the service sector and the smallest impact on industrial production.
Renewables	+1.5%	➢ Additional output from new wind and solar projects	United States, Europe	Although COVID-19 has resulted in delays in construction and supply chain, renewable energy generation has increased by 5%. The growth rate of renewable power generation capacity is likely to decline in 2020.

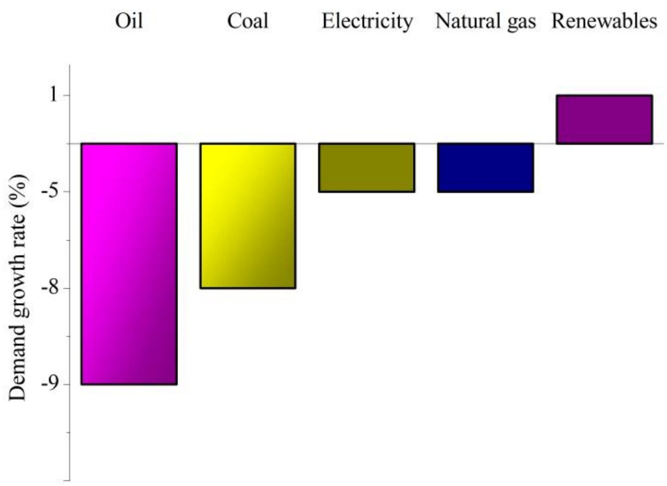


Fig.1. The growth rate of energy demand in 2020 predicted by IEA.

IEA predicted the energy demands of some major countries and regions around the world, as shown in Fig.2. Fig.2(a) reveals that as China was the first to be affected by COVID-19, the decrease in crude oil demand was the largest at the beginning of 2020; the outbreak in the United States and Europe led to a significant reduction in crude oil demand from April to June; India's crude oil demand was basically unaffected after May; the decline in global crude oil demand will ease in July. Fig.2(b) indicates that although the electricity demand of some countries or regions is reduced before 2020, the global electricity demand is increasing; the global electricity demand of 2020 shows a clear downward trend, of which Europe has the highest decline rate. Fig.2(c) implies that among Europe and the United States, only the natural gas for power generation in the United States will increase in 2020; France's demand of natural gas for power generation will decline the most, with a decline rate of 71%; the decline in natural gas demand is mainly dominated by natural gas for non-power generation. Fig.2(d) shows that the growth rate of wind power demand in 2020 is expected to be the same as in 2019, and the growth rate of the demand for other renewable energy sources has dropped significantly, with bioenergy having the highest decline rate.

IEA also conducted a regional analysis, as shown in Table 2. It reveals that the degree of restriction is different in different countries or regions around the world, and the restriction ways are not uniform. Oxford University has developed a Government Response Stringency Index to measure the government's response to COVID-19 (see Fig.3). This index considers nine factors, such as school closures and travel bans [2]. For example, the restrictions in Europe are gradual; the restriction in India is entirely lockdown from the beginning; due to the severity of the epidemic in China, the severity of each province is different. Among them, the restrictions in Hubei Province (the province where Wuhan is located) are the strictest. Moreover, the stricter the restrictions, the more the weekly energy demand declines.

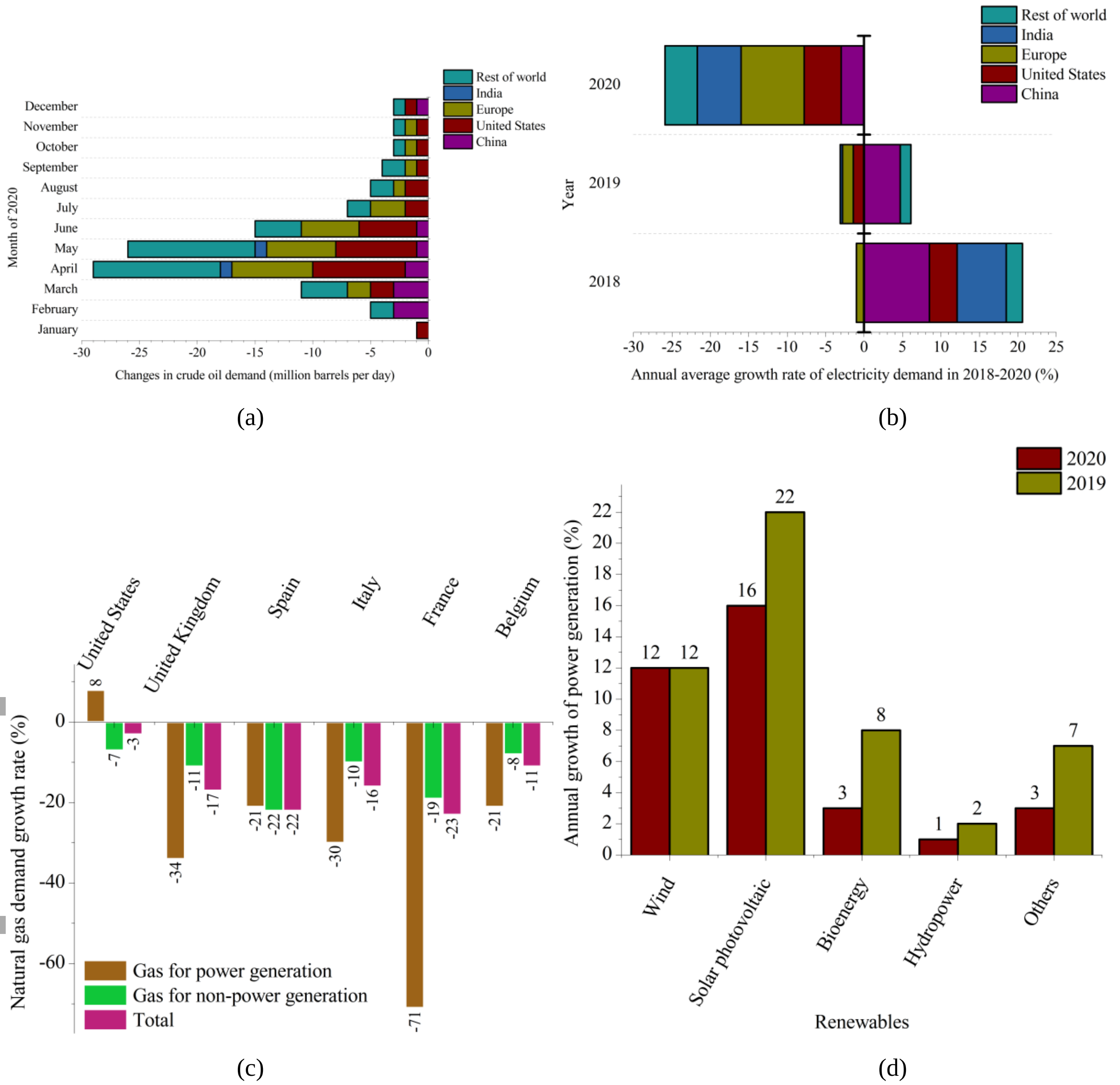
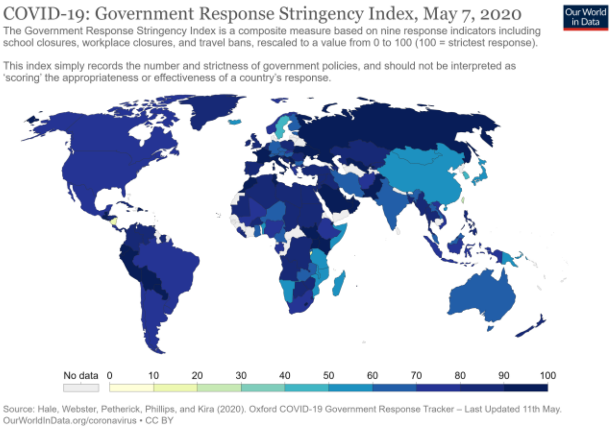


Fig.2. Changes in energy demand in some countries or regions (Data source: [1]). (a) Oil; (b) Electricity; (c) Natural gas; (d) Renewables.

Table 2. The energy demands of some countries with different levels of lockdown.

Country/region	Extent of restriction	Weekly energy demand decrease	Projected annual energy demand decrease
China	Different levels in different provinces	15%	4%
Korea and Japan	Less stringent	Below 10%	7%
Europe	Progressive	17%	10%
India	Full lockdown	30%	4%



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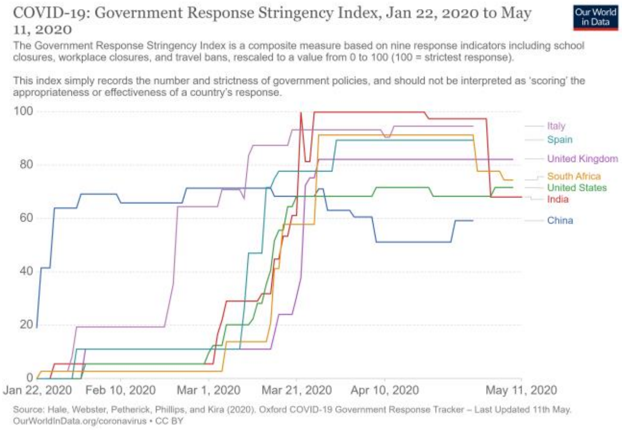


(b)

Fig.3. Government Response Stringency Index after the outbreak of COVID-19 in some countries (Source: [3]). (a) Global heatmap; (b) Trends in some countries.

3.2. Oil price declined most

Due to changes in energy supply and demand, energy prices will change accordingly. As shown in Fig.4, since the outbreak of the epidemic, crude oil prices have continued to decline, and for the first time in history, there has been a negative value, with the lowest price of -40.32 dollars per barrel. This is because the demand for crude oil is so low that the oil storage facilities are almost exhausted, and the market crashed. Due to the correlation between coal prices and crude oil prices, coal prices have continued to decline, but they rebounded in early April. This is because China is a large coal consumer and restarted some provinces' economy in early April, leading to rising coal demand. Overall, the decline in coal prices is lower than that of crude oil, and the impact of the epidemic on coal prices is short-lived. The price of natural gas was minimally affected by the epidemic and fluctuated in the first quarter of 2020, with a slight decrease in general. Due to the reduction in economic activity during the epidemic, electricity consumption has been reduced, and the price of electricity has been affected and reduced. In the first quarter of 2020, electricity prices generally showed a downward trend because of the increased intensity of the lockdown. Besides, taking the United States as an example, the average electricity price in February 2020 is lower than the same month in 2019. However, the average residential electricity price in February was higher than that in February 2019. This may be because of the increase in residential electricity consumption due to home segregation.

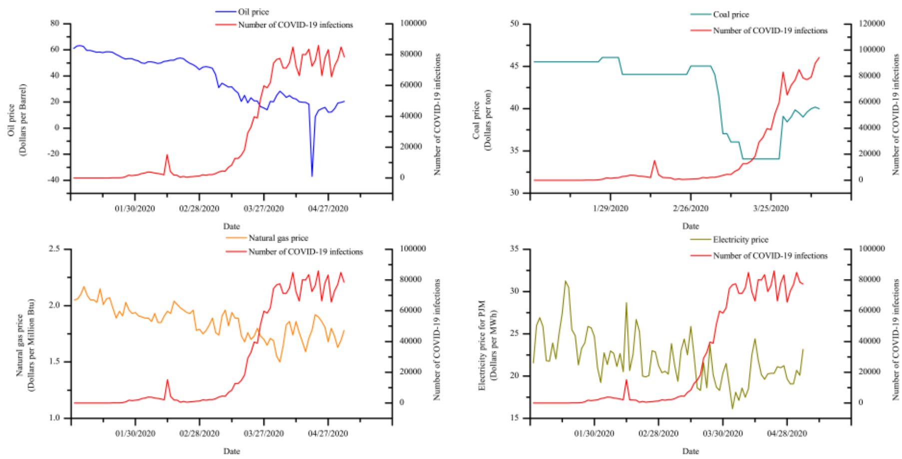
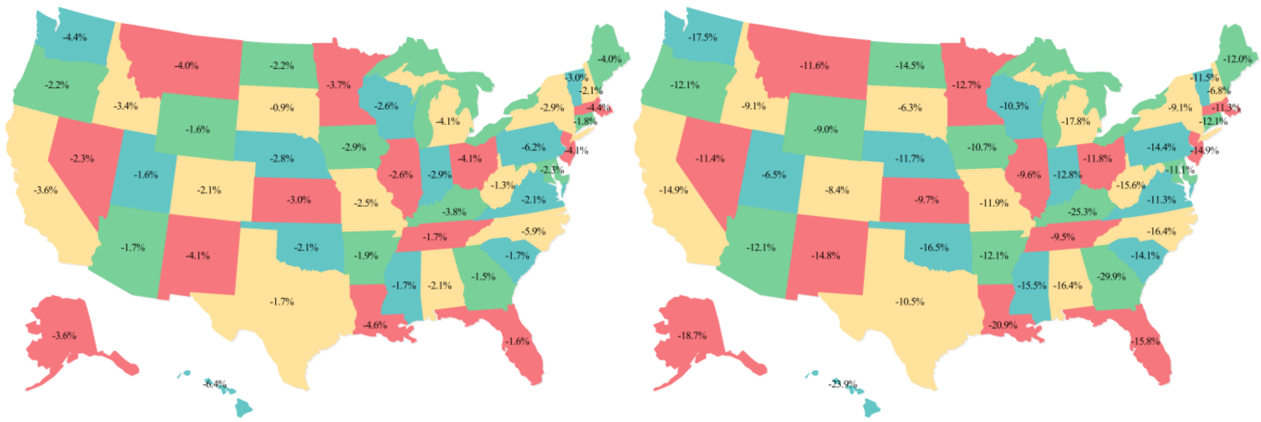


Fig.4. Energy prices during the outbreak.

3.3. Unemployment continues to grow

Due to restrictions, some energy companies shut down. However, this will directly lead to lower corporate profits, leading some energy companies to implement layoffs. A report from the BW Research Partnership shows that in April 2020, the clean energy industry in the United States lost 447,200 jobs, and the employment rate fell by 17% [4], which is much higher than 3.1% for March [5]. Among them, Hawaii has the highest unemployment rate in March 2020, which is 6.4% (see Fig.5(a)). Georgia state has the highest unemployment rate in April 2020, which is 29.9% (see Fig.5(b)). They indicate that the unemployment rate in the United States in April is much higher than in March. Fig.6 reveals that 65%-70% of total clean energy unemployment is in the energy efficiency sector, the highest of all sectors. However, these data are only initial estimates, not including underemployed and temporary leave workers. BW Research Partnership also estimated that the clean energy sector of the United States will lose 850,000 jobs by the second quarter of 2020 without policy measures [4].



(a) (b)

Fig.5. The unemployment rate in the United States. (a) March 2020; (b) April 2020.

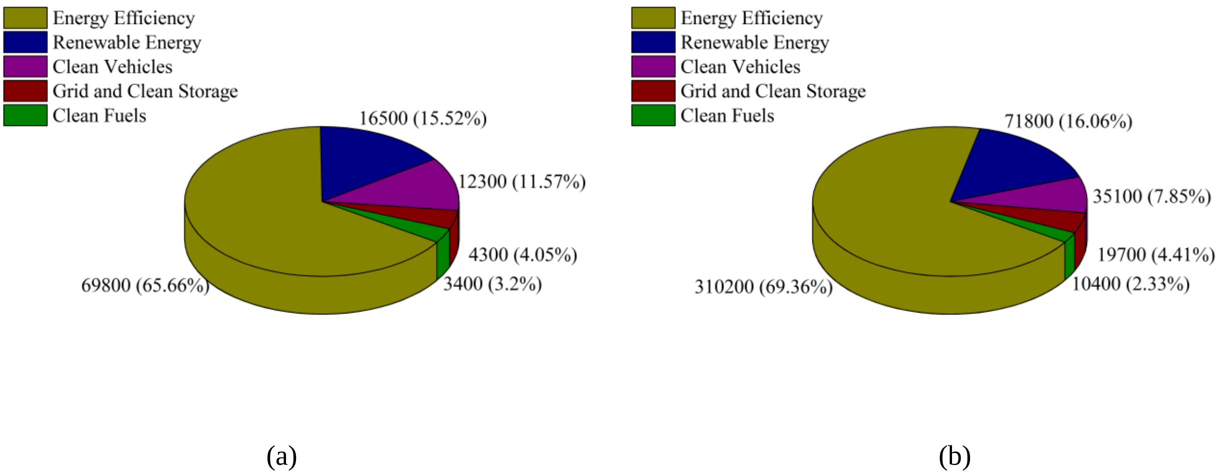


Fig.6. Unemployment structure of the clean energy sector in the United States. (a) March 2020; (b) April 2020.

The energy storage industry may not be seriously affected by the epidemic as clean energy due to the reduction of overall energy consumption and the increase of energy storage demand. According to a survey conducted by energy storage association, 63% of respondents think their expected income will drop due to delayed approval, difficulty in obtaining equipment and materials and cancellation of customer orders. 25% of respondents hope to reduce labor force, with the highest reduction rate of 20%. However, many respondents believe that despite the enormous economic losses they are facing, they still want to retain their employees for the follow-up business [6].

3.4. Government policies focus on energy security

The energy policy issued by the government is mainly to provide reliable energy supply to the people. In the context of COVID-19, countries have also issued corresponding policies to respond to the epidemic. At present, various countries have formulated short-term policies for the epidemic, and the main target is customers [7]. As shown in Table 3, China and Malaysia have adopted policies to reduce electricity prices to support consumers' use of electricity during the epidemic. Canada, the United States, Argentina, France, Germany, Italy, the United Kingdom, and Japan have introduced policies that allow users to postpone payment without interrupting service. Indonesia has even introduced a policy of free electricity for the poor.

Table 3. Policies of governments to electricity users in response to COVID-19.

Country	Reference	Government policy		
		Energy price reduction	Allow late payment without interrupting service	Free for the poor
China	[8]	√	√	
United States	[9]		√	
Canada	[10]		√	
Australia	[11]		√	
Argentina	[12]		√	
France	[13]		√	
Germany	[14]		√	
Italy	[15]		√	
United Kingdom	[16]		√	
India	[17]	√	√	
Japan	[18]		√	
Malaysia	[19]	√		
Indonesia	[20]			√

3.5. Countermeasure against COVID-19 was taken

After the outbreak, the reliable energy supply is the key because it can ensure the normal functioning of people's livelihoods. Therefore, some management and countermeasures are essential. According to the survey, most energy companies responded quickly in the early stages of the outbreak. Their responses are focused on employees, production, and society. Table 4 lists the responses to COVID-19 in the fields of nuclear energy, oil and gas, and renewable energy.

Table 4. Countermeasures of the epidemic in some energy fields.

Sector	Response	Content
Nuclear [21]	Employee	➢ Social distancing measures: remote working, shift system, cancel unnecessary business trips, ensure food safety, exclusive means of transportation
	Production	➢ Stop or reduce uranium mining ➢ Replace the main components of the reactor, reduce tasks, reschedule tasks, and reduce power output ➢ Reduce or stop construction ➢ Close the waste treatment plant
	Society	➢ Help with medical supplies and technology
Oil and gas [22]	Employee	➢ Strengthen communication between the company and employees ➢ Social distancing measures ➢ Pay attention to the challenges encountered by female employees
	Production	➢ Reduce tasks ➢ Reduce or stop construction
	Society	➢ Donate ➢ Manufacturing medical products
Renewables [23]	Employee	➢ Revise labor and education policies ➢ Social distancing measures
	Production	➢ Delay project delivery deadline
	Society	➢ Provide reliable energy for people's lives

3.6. Academic research focuses on energy policy

Since the outbreak of COVID-19, some scholars have also acted. Although there is not much related research, it still provides inspiration and direction for academic research. Qarnain et al. [7] reviewed the actions taken by G20 member countries in response to energy consumption during the epidemic. They summarized the policy contents and proposed 11 relevant policy recommendations (see Fig.7). The policy recommendations mainly include that the energy sector should ensure a stable supply of energy and grant subsidies to companies that have suffered losses due to the lockdown. Klemeš et al. [24] put forward the concept of the plastic waste footprint (PWF) for the use of massive plastic products during the period of COVID-19, to facilitate the subsequent waste treatment. They proposed that waste management challenges after the outbreak mainly include waste classification and treatment. Besides, they pointed out six research directions in the future (see Fig.8). Steffen et al. [25] put forward challenges and suggestions for the clean energy transition in the short, medium, and long term to help energy policy makers make more reasonable policy plans during and after COVID-19. Smith [26] pointed out the problems and challenges that may be encountered in the energy industry's public service. These problems can provide references for managers. Mastropietro et al. [27] analyzed the energy poverty problem in Italy and Spain in detail and gave solutions and policy suggestions to solve the problem. Graff and Carley [28] discussed the contradiction between low-income people and the continuous supply of energy. They gave specific data on energy insecurity in the United States and made corresponding policy recommendations. Forero-García et al. [29] discussed the energy-saving strategies of people at home during the outbreak and put forward relevant suggestions. From the above research, it can be concluded that recent scholars' research focuses on the formulation of relevant energy policies during and after COVID-19.

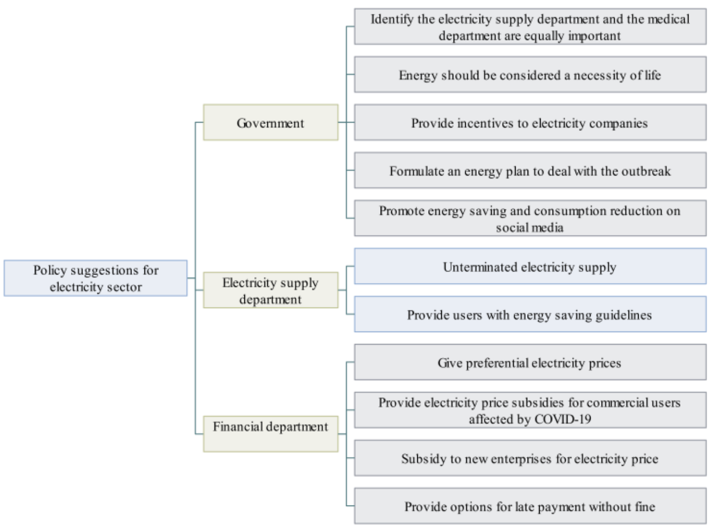


Fig.7. Policy suggestions for the electricity sector proposed by Qarnain et al. [7].

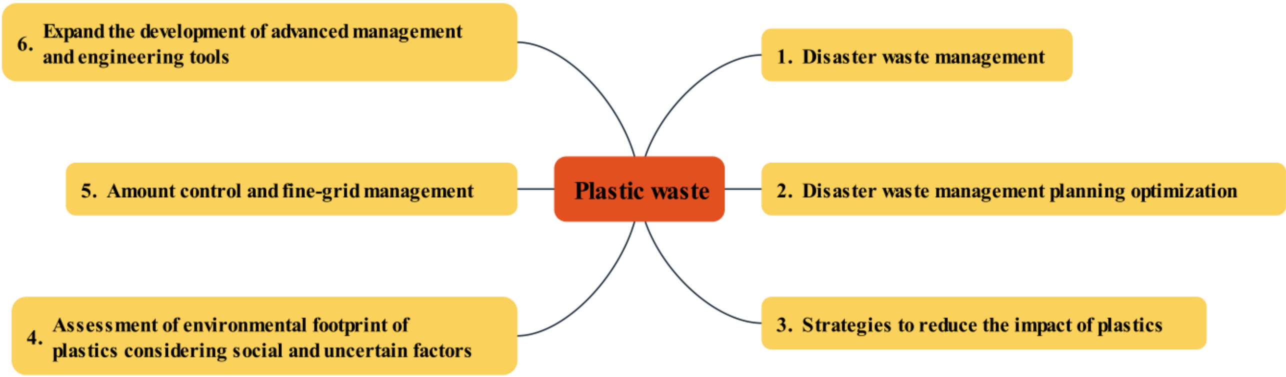
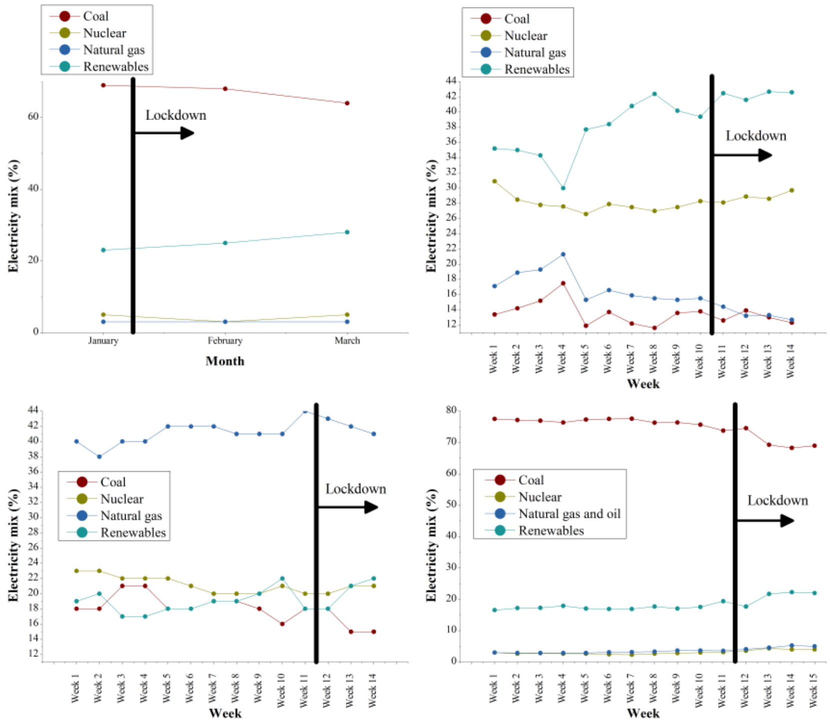


Fig.8. Six research directions of plastic waste management proposed by Klemeš et al. [24].

4. Clean energy transition

While responding to the epidemic, how to revive the energy system has become a top priority. Experts pointed out that it is difficult to carry out energy transition at this time. However, this is also an opportunity for the energy sector [30]. Fig.9 indicates that, after the epidemic outbreak, the proportion of renewable energy in power generation has increased globally. According to the EIA's outlook [31], renewable energy production will rank third by 2030, and it will be the fastest growing source of power generation by 2050. The focus of the energy transition is on clean energy, and its goal is to reduce carbon emissions. Under the influence of the epidemic, although carbon emissions in the first quarter of 2020 have been greatly reduced (reduced by 5% compared to the first quarter of 2019 [1]), experts pointed out that this is not optimistic [32]. Based on the experience of the 2008 financial crisis, carbon emissions in 2009 were reduced by 400 million tons, but carbon emissions in 2010 rebounded by 1.7 billion tons [33]. Only by achieving a clean energy transition can the structural reduction of carbon emissions be truly achieved. The development focus, challenges, opportunities, and relevant suggestions for clean energy transition are discussed in this section.



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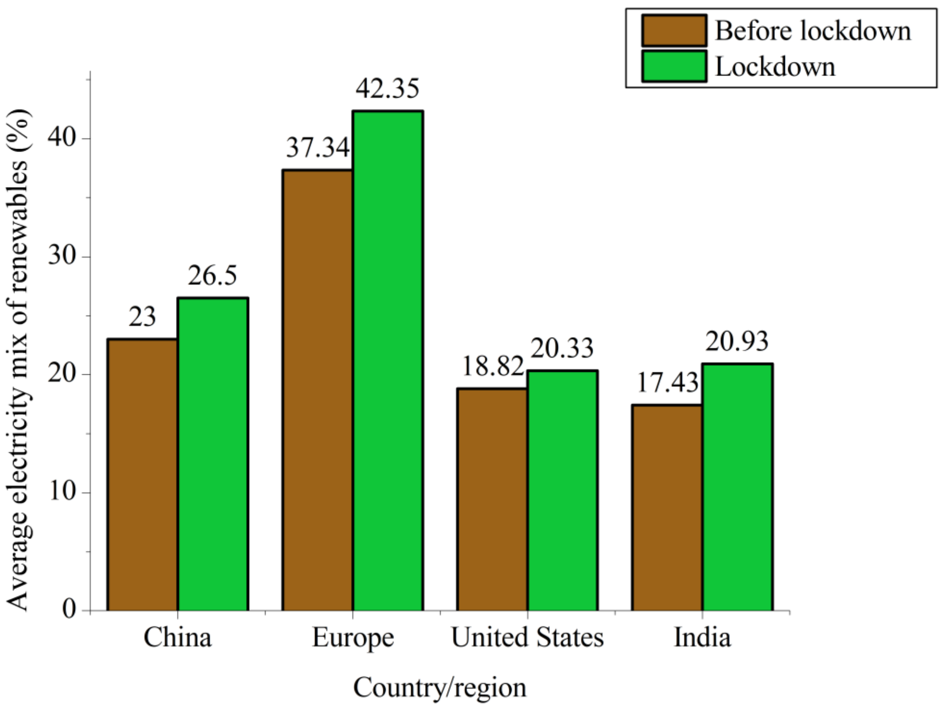


(b)

Fig.9. Electricity mix of major countries or regions in the first quarter of 2020. (a) Monthly or weekly data (Data source: [1]); (b) Average values.

4.1. Development focus

4.1.1. Bioenergy

Bioenergy is a renewable energy that is often overlooked and is commonly used for transportation fuels. Nearly 25% of global demand comes from Latin America. Argentina and Brazil are the two largest markets, and the proportion of renewable energy in transportation has reached 9%. Brazil is also the world's second-largest producer of biofuels, which is the result of policies to replace fossil fuels with biofuels following the 1973 oil crisis [34].

Biofuel is also a source of economy and employment in rural Brazil. According to rough statistics, bioenergy directly or indirectly provides Brazil with about 2.3 million jobs, which is higher than other agricultural products. Due to the impact of COVID-19, the reduction in total energy consumption has led to a decline in bioenergy prices and reduced demand in Latin America. Therefore, the government should issue corresponding policies to solve the crisis.

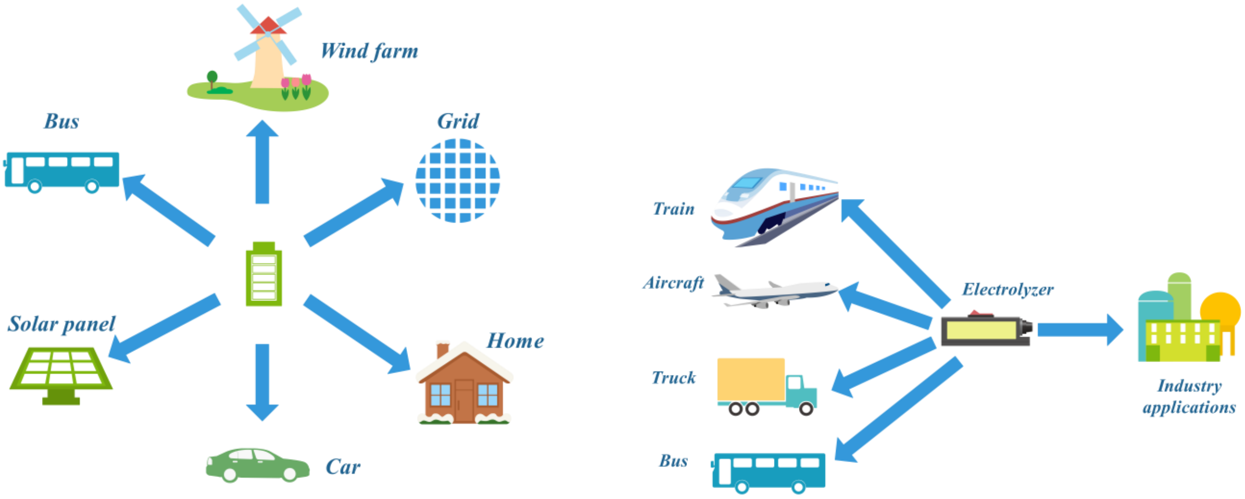
4.1.2. Mineral resources for clean energy techniques

Mineral resources are critical raw materials in many clean energy technologies that are widely used, such as electric vehicles, wind turbines, and solar panels. According to rough statistics, clean energy technology usually requires more mineral resources than traditional fossil fuel technology. For example, onshore wind power plants require eight times more mineral resources than gas power plants with the same capacity. With the rapid deployment of clean energy technologies, the demand for mineral resources has increased significantly, and prices have also increased. Thus, the stability of the supply chain of mineral resources is vital in the energy transition [35].

Due to the lockdown caused by COVID-19, the mining industry was halted on a large scale. For example, Peru, which accounts for 12% of the world's copper mines, has stopped mining operations due to the epidemic, and mines in South Africa have been required by the government to reduce production operations. As global demand has fallen, the prices of many mineral resources have also decreased. However, driven by the energy transition, the demand and prices of mineral resources will rise after resuming work. Thus, the mineral resource supply chain's stability has caused the relevant departments to be alert because long-term stable supply is not inevitable.

4.1.3. Battery and electrolyzer

In clean energy technology, batteries and hydrogen-producing electrolyzers play an essential role in economic stimulus [36]. They are all small and modular technologies, suitable for mass production. Since many countries have introduced relevant policies to encourage the use of electric vehicles, the price of lithium-ion batteries has also been reduced. At present, lithium-ion batteries have gained more opportunities in renewable energy systems. In addition to the transportation field, they are also widely used in integrated power systems (see Fig.10(a)). The electrolyzer is a low-carbon hydrogen production equipment. Due to its high cleanliness, it is often used in industries where emission reduction is difficult, such as aviation and chemical industries (see Fig.10(b)). Its advantage is that it can be easily deployed in various fields.



(a) (b)

Fig.10. Application scenarios of batteries and electrolyzers. (a) Battery; (b) Electrolyzer.

According to the goals set by various countries, the global annual output of electric vehicles will reach 1500 GWh by 2030. Despite the crisis of COVID-19, this goal has not changed, but it has given a greater driving force. China has 70% of the world's battery production capacity. Although COVID-19 has affected production centers in Hubei, Guangdong, and Hunan, as these provinces have gradually resumed work, manufacturing capacity has gradually recovered. Europe is the leading producer of electrolyzers. Although production is still in its early stages, production capacity is rapidly expanding. The number of factories producing electrolyzers has increased significantly in recent years, and the production capacity is expanding rapidly. According to statistics, the average capacity of the electrolyzer projects reached 0.64 MW from 2015 to 2019, while the average capacity from 2005 to 2009 was only 0.16 MW. In the next few years, large manufacturing plants in countries such as Norway, Canada, and Japan will be completed and put into production.

IEA analysis shows that to decarbonize the economy truly, clean energy technologies and products need to be combined. There is no doubt that electric vehicles will be the most prominent manifestation of the use of battery technology. The cost of batteries accounts for about 40% of the total cost, which will bring huge benefits. Moreover, the deployment of large-scale stationary batteries will make the development of solar power and wind power projects more rapid.

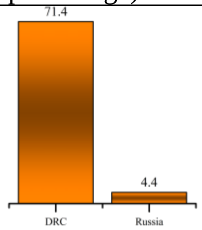
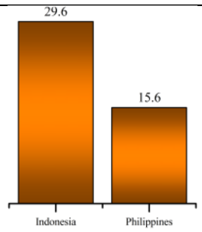
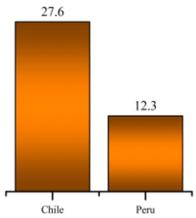
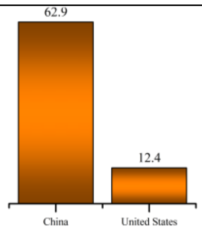
4.2. Challenges

The negative impact of lockdown is already evident. In the clean energy field, due to labor shortages, the delivery of materials, and the installation of new energy facilities have been delayed. Due to the closure of some government agencies, some inspection agencies are unable to approve the license, so even if the construction is completed, it cannot be put into production. As a result of these uncertainties, it will also cause cash flow problems in some supporting businesses and even lead to some investors' insufficient confidence, thus reducing or withdrawing investment. Therefore, the stability of the supply chain is the biggest challenge in the context of COVID-19. The problem of energy supply and demand balance caused by the pandemic is also apparent. During the lockdown, the problem of oversupply became more prominent. At this time, how to store energy is crucial and challenging, especially for the power industry.

For clean energy, there have been supply chain problems for a long time. Driven by COVID-19, these problems have become more serious. Section 4.1.2 has mentioned that some mineral resources are the necessities of clean energy technology. However, due to the uneven distribution of mineral resources on the earth, there are some geopolitical issues, as shown in Table 5. Although the demand for mineral resources is currently reduced due to the epidemic, the demand for mineral resources after COVID-19 may rebound significantly driven by the clean energy transition, and the problem of imbalanced supply may occur in the next few years.

The manufacturing of clean energy equipment has a problem with excessive dependence. For example, Europe and the United States and other countries rely too much on batteries and solar photovoltaic modules from China. Some major Chinese companies provide more than 50% of the supply of solar photovoltaic equipment; China and Europe provide about 60% of the global supply of wind energy equipment.

Table 5. Challenges of several primary mineral resources [35].

Mineral resources	Physical figure	Challenges	The proportion of production in the world (Unit: percentage)
Cobalt		➢ Its supply is greatly affected by the nickel and copper markets ➢ Geopolitical restrictions are large, and the dependence on a single country is high	
Nickel		➢ Geopolitical restrictions are large, and supply security cannot be guaranteed ➢ New investment does not match expected demand	
Copper		➢ Depletion of reserves	
Rare earths		➢ Geopolitical restrictions are large ➢ The environment pollution in the process is great	

Note: DRC represents the Democratic Republic of the Congo

For governments of all countries, they are now facing tremendous pressure. It is challenging for them to accurately assess its impact on the energy sector due to the uncertainty of COVID-19. From the perspective of clean energy companies and investors, the government's policy is the primary consideration of their decision-making. It has been reported that the behavior of governments is unpredictable. Steffen et al. [] put forward that the government can formulate policies in the short, medium, and long term. In short-term policy-making, it is difficult to determine the policy priority that can permanently affect energy transformation; in medium-term policy formulation, manage the impact of low interest rates, low oil prices and economic downturn is hard; in long-term policy-making, predicting possible future turbulence and coordinating policy flexibility and rigidity is challenging.

4.3. Opportunities

Although the clean energy transition is facing severe challenges, the opportunities coexist. The most significant opportunity is that clean energy can provide numerous jobs. According to the statistics of E2 company, clean energy has provided 3.4 million jobs to the United States in 2019, of which about 60% for energy efficiency, 15% for renewable energy power generation, 7% for new energy vehicles, 4.4% for the construction of clean energy facilities, and 1.2% for biofuels. Although COVID-19 has a major impact on employment in the new energy field, job demand will rebound after the epidemic. Because COVID-19 made the demand for energy storage more visible, there may be more jobs in the field of energy storage. Globally, renewable energy employed 11 million people in 2018 and may reach 44 million by 2050, while system flexibility and energy efficiency may increase employment opportunities by another 40 million. Thus, its income-generating effect is conceivable. It is estimated that renewable energy can create a GDP of 100 trillion US dollars by 2050 [38].

On the other hand, the transition of clean energy can make resources better allocated and utilized. For a long time, government subsidies for fossil fuels and coal-fired power have caused a series of problems. To a certain extent, this has wasted some resources. If these resources can be used for clean energy, it can make the energy system more flexible. Futhermore, environmental pollution caused by fossil fuels makes some people more susceptible to COVID-19. Clean energy can control the deterioration of the environment. In this respect, it brings about an improvement in people’s health.

5. Conclusions and recommendations

This paper reviews the impact of COVID-19 on the global energy sector from six aspects and looks forward to what will happen to the energy sector. The primary findings of the review are as follows:

(1) COVID-19 will reduce the energy demand in 2020 to varying degrees, of which the demand for oil has the highest decline rate;

(2) Due to the lockdown, the epidemic has reduced energy prices to varying degrees and has a huge negative impact on employment;

(3) Governments of various countries have introduced preferential policies for energy consumers, mainly from the aspect of lowering electricity prices and allowing delayed payment;

(4) Most energy companies have taken countermeasures to respond to the epidemic from employees, society, and production;

(5) Most scholars' research focuses on energy supply security and policy formulation.

Although the epidemic has negatively affected most aspects of the energy industry, the pace of transition to clean energy has not stopped. This paper describes the focus of clean energy transition from bioenergy, mineral resources, battery, and electrolyzer, and points out the existing challenges and opportunities. The discussions imply that the supply chain stability during and after the outbreak, electricity storage, and policy formulation are the biggest challenges for the clean energy transition. At the same time, it can bring more opportunities for employment, economic recovery, and the human living environment. Based on the review findings, the following recommendations for the energy sector during this particular period are given:

(a) Governments and companies should pay attention to the stability of the supply chain in the clean energy system for a long time, periodically assessing and forecasting demand and supply;

(b) Investors should maintain confidence in clean energy because the reliable investment is crucial to clean energy development. The government should promote the benefits of clean energy for the economy, employment, and the environment because public opinion is the cornerstone of development;

(c) The government should formulate short-term, medium-term, and long-term policy plans as early as possible, and design a flexible policy framework to withstand the crisis;

(d) When faced with a crisis, the government should treat the energy sector and the medical sector equally, and issue corresponding policies to benefit the people to ensure energy security;

(e) Due to the shortage of workforce during the epidemic, the construction party should be allowed to delay delivery;

(f) Energy companies should consider building energy storage facilities. In response to the epidemic, energy storage equipment can be used to adjust the balance between supply and demand, and can be used for peak shaving when the supply exceeds the demand;

(g) Combine energy efficiency, renewable energy, and batteries to truly decarbonize power systems.

Declaration of interest

None

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