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An impact study of COVID-19 on the electricity sector: A comprehensive literature review and Ibero-American survey

Joaquín Lazo^a, Gerson Aguirre^a, David Watts^{a,b,c,*}

^a Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, 7820436, Chile

^b Escuela Iberoamericana de Regulación Eléctrica EIRE-UC, Vicuña Mackenna 4860, Santiago, 7820436, Chile

^c UC Energy Research Center, Vicuña Mackenna 4860, Macul, Santiago, 7820436, Chile

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ABSTRACT

To stop the spread of COVID-19, governments have implemented confinement measures unprecedented in modern society. One of the main consequences has been the paralysis of commercial and industrial sectors worldwide, primary electricity consumers. This paper examines the impact of these measures on the electricity sector through a literature review accompanied by fieldwork on the impact of COVID-19 in Ibero-America and its energy regulatory response. First, we will review the causes of the reduction in electricity demand due to the confinement measures and their technical and financial consequences in the electricity sector. Second, we will examine the impact of COVID-19 on the wind and solar PV energy sectors, mainly affected by the paralysis of production and export of materials and components. Third, we will revise the regulatory measures implemented by the countries to avoid the interruption of electricity supply to households. This paper will end by reviewing economic recovery plans and their relationship to the energy transition.

Although there are no fundamental differences between developed and developing countries in their regulatory reaction to this crisis in the energy sector, there are significant differences in economic recovery planning. While developed countries aim for a green economic recovery and the creation of green jobs, developing countries are allocating least resources to social protection and general economic stimulus programs, postponing climate objectives. In Latin America, this adds to the high levels of debt faced by utilities and the possible resurgence of social crises that were stopped by the COVID-19 outbreak, making a green recovery even more difficult.

1. Introduction

By the end of 2019, a peculiar coronavirus emerged in Wuhan, China, and caused an outbreak of a rare viral pneumonia [1]. Later, this coronavirus was named SARS-CoV-2 by the International Committee of Taxonomy of Viruses (ICTV) [2]. The World Health Organization (WHO) declared COVID-19 a public health emergency of international concern on January 31, 2020 [3,4], and on March 11, 2020, the outbreak of COVID-19 was recognized as a pandemic [5]. By Mid-June 2021, the world was approaching 175 M confirmed cumulative cases, and the WHO had reported more than 3.7 M deaths [6].

The transmission of COVID-19 occurs between humans, mainly through respiratory droplets from coughing or sneezing [3]. Thus, to slow down the spread of COVID-19, governments worldwide have carried out a variety of policy interventions [7], from social distancing to

strict lockdowns and the paralyzation of non-essential economic activities [8,9]. These interventions, which have resulted in industries functioning under limited operating hours, people working from home, schools and universities moving to a virtual mode, and a collapse of the aviation industry [10], have had a massive impact on the world's economy, provoking, in many countries, massive destruction of employment [11] and an unprecedented rise in poverty levels [10]. The April 2021 World Economic Outlook [12] estimated a global economic contraction of -3.3% in 2020, making the COVID-19 global recession the deepest since the end of World War II [13]. The UN News reported that "working poverty is back to 2015 levels" and, compared to 2019, "an additional 108 million workers worldwide are now categorized as 'poor' or 'extremely poor'" [14].

At the time of writing this article, 1.6 B people in the world have received the first dose of the COVID-19 vaccine [15], and the use of masks is no longer mandatory in some countries such as Israel [16] and

* Corresponding author. Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, 7820436, Chile.
E-mail addresses: hjlazo@uc.cl (J. Lazo), dwwatts@ing.puc.cl (D. Watts).

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Abbreviations	
PV	Photovoltaic
DER	Distributed energy resource
IDB	Inter-American Development Bank
ARIAE	Ibero-American Association of Energy Regulatory Entities
USAID	United States Agency for International Development
NREL	National Renewable Energy Laboratory
ADB	Asian Development Bank
PJM	Pennsylvania-New Jersey-Maryland Interconnection
MISO	Midcontinent Independent System Operator
NYISO	New York Independent System Operator
DSO	Distribution system operators
AOD	Aerosol Optical Depth

France [17]. Even though the pandemic is still not under control in several parts of the world, its varied impacts on the global economy are already evident. In the **electricity sector**, the confinement measures have caused unseen impacts in history, mainly due to the pronounced and prolonged reduction in electricity demand caused by the paralysis of commerce and industry, large energy consumers [18]. The resilience that power systems had developed throughout history was aimed at preventing supply outages in the event of natural disasters; therefore, the demand reduction, changes in consumption patterns, and high debt levels that will accompany the sector over the coming decades are challenges for which not all the world’s electricity systems are equally prepared.

The main objective of this review is to provide a broad overview of the impact of confinement measures in the electricity sector. The analysis focused on the reduction of electricity demand, the delay in the development of wind and solar PV projects, the regulatory measures enacted by governments to secure the electricity supply, and the post-pandemic economic recovery in the context of the energy transition. This paper contributes to the COVID-19 literature in two aspects. First, most papers analyzing the impact of COVID-19 on the electricity sector focus on a single country or a small group of developed countries, drawing very particular conclusions. This comprehensive review, which examines a wide variety of countries with diverse characteristics, allows to reach more general conclusions. Second, scarce literature was found on the policies implemented by governments to ensure access to electricity in a context that makes the population dependent on electricity supply, both for teleworking and distance learning activities and for the proper functioning of hospitals with intensive use of electric ventilators. This paper contributes to filling this gap by including the regulatory response of the electricity sectors in Ibero-America. This fieldwork was developed with the support of several local regulatory agencies, which added extra value to this review by studying developing countries whose data, reports, and analyses are scarce or limited.

This paper is structured as follows. Section 2 presents the methodology used to select the literature and compile information on the Ibero-American experience. Section 3 presents the consequences of the confinement measures on electricity demand and consumption patterns. Section 4 presents the implications of COVID-19 on the solar PV and wind energy sectors. Section 5 examines the regulatory measures enacted by governments to secure electricity supply. Finally, Section 6 examines the post-pandemic economic recovery and the impact of COVID-19 on the energy transition.

2. Methodology: literature review complemented with regulatory responses

This study is developed mainly through a literature review, following

traditional methodologies. It is complemented by the regulatory response of some Ibero-American countries, although it has not yet been documented in research articles. In addition, some sections are complemented with the Ibero-American experience and particularities. The search methodologies are presented below.

2.1. Stage 1: Literature review

The current study and data were extracted on May 27, 2021, from the Scopus database. The following search criteria were used:

1. Topic (Title-Abs-Key): (“energy market” or “energy sector” or “energy policy”) and (“covid” or “pandemic” or “coronavirus”);
2. The language of the article is English; and
3. The article was published in 2020 or 2021.

The query returned 156 results. 81 papers were excluded based on abstract scanning because they did not focus on the impact of COVID-19, did not consider the energy sector, or focused on the impact of COVID-19 exclusively on the oil sector. Thus, 75 papers were selected as candidates for the review. The backward tracking included analysis of references from the selected papers. In total, 106 papers were selected for the study. This three-part paper selection process is represented in Fig. 1. The frequently used keywords in the selected papers are shown graphically in Fig. 2.

2.2. Stage 2: Regulatory measures in Ibero-America

The literature on the regulatory response of the electricity sector to the economic and health crisis is still scarce. To fill this gap, this review is complemented by an exploration of the regulatory measures implemented by the member countries of the Ibero-American Association of Energy Regulators (ARIAE) to ensure the supply of electricity to the population.

The **first stage** of this work consisted of a bibliographic review that included research articles, reports from international institutions, and regulatory newsletters. This review identified laws, resolutions, decrees, agreements, ordinances, and circulars. Then, in a **second stage**, regulators from ARIAE member countries were asked to validate the information gathered in the first stage through a pre-answered questionnaire indicating whether or not each measure was applied in their country and asking them to provide additional information that was not identified in the first stage. The **third stage** consisted of generating a report for each of the 22 countries studied, identifying beneficiaries, deadlines, coverage, application mechanisms, and other details. Finally, the regulators were asked to validate the reports again and make suggestions and comments on this final document.

The first stage questionnaire was validated by 13 countries, it was partially validated by one country, and was not validated by 9 countries:

- **Validated the questionnaire:** Andorra, Bolivia, Brazil, Colombia, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Peru, Portugal, Spain, Dominican Republic, and Uruguay;
- **Partially validated the questionnaire:** Chile; and
- **Did not validated the questionnaire:** Argentina, Costa Rica, Cuba, Mexico, Nicaragua, Panama, Puerto Rico, and Paraguay.

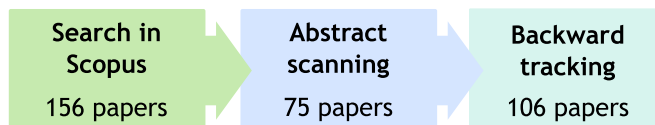


Fig. 1. Literature selection process.

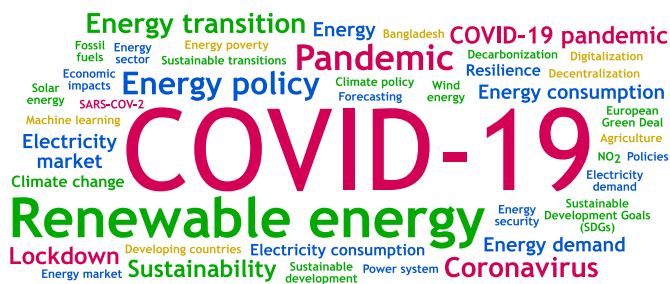


Fig. 2. Top keywords in the reviewed literature.

3. Reduction in electricity demand and change in consumption patterns

3.1. Electricity demand reduction reports

3.1.1. National and international reports on electricity demand reduction

There is widespread consensus that one of the most significant impacts of containment measures in the energy sector are a reduction in electricity demand and a change in consumption patterns, driven by a dramatic slowdown in industrial and commercial sectors and the increased amount of time that people spend in their homes [20]. This impact on the electricity sector is unprecedented worldwide, so many international agencies have rushed to publish international reports with their views of the situation. The International Energy Agency (IEA) focused on the COVID-19 crisis in its Global Energy Review 2020 [21]. The report states that in addition to the impact on health, “the current crisis has major implications for global economies, energy use, and CO₂ emissions”. Their collection of data from 30 countries, accounting for two-thirds of global energy demand, indicates that “countries in full lockdown experienced an average decline of 25% in energy demand per week and countries in partial lockdown an average decline of 18%”. Thus, “demand depression depends on duration and stringency of lockdowns.” The IDB [22] described the financial impact of regulatory measures in the electricity sector to address the crisis and a summary of the measures adopted in Latin America to secure the electricity supply. USAID and NREL [23] published a report on the impact of COVID-19 on the power sector in Southeast Asia, focusing on electricity demand, contracts and investment, air quality, energy sector workforce, and renewable energy sector. The report ends by identifying opportunities for increasing resilience in the power sector in these countries. The Asian Development Bank (ADB) [24] published a report on the impact of COVID-19 on the Asia-Pacific power sector, including electricity demand, gas sector, and oil sector. Regarding electricity demand, the report highlights a reduction in demand of around 25% in India between 2020 March and April compared to the same period in 2019. Under a similar comparison, the reduction in demand in Indonesia and the Philippines was 30% and 15%, respectively. The report also investigates the financial impacts on energy producers and utilities, the effects on the supply chain, and guidance for response and recovery of the energy sector in the context of COVID-19.

Country-specific reports also indicate significant reductions in electricity demand. In **Poland**, the average daily electricity consumption in May 2020 decreased by 6.9%, and the peak was 6.4% smaller than in 2019 in the same period [25]. In **Ukraine** and **Hungary**, the decrease in electricity consumption in the first half of 2020 compared to the same period in 2019 was 4.9% and 3.6%, respectively [26]. In **Portugal**, electricity consumption was reduced by 12% and 13.2% in April and May compared to 2019, respectively, and overall, the electricity consumption in the first half of 2020 faced a 5.1% reduction, reaching the lowest level since 2004 [27]. In **Turkey**, the most significant impact on energy consumption was experienced in April 2020, with a decrease of 15.5% compared to April 2019 [28]. In **Kuwait**, the imposition of curfews caused a fall in demand for electrical power of 17.6% compared

with the expected demand [29]. In **India**, from March to July 2020, electricity demand declined by 15.9% relative to 2019 [30]. In **Bangladesh**, the electricity demand started declining sharply from April 2020, and until June 2020, it was still lower than the 2019 levels [31]. In the **U.S.**, overall electricity demand declined by less than 10% from late March to June 2020, compared to energy consumption before the shutdowns [32]. In **Brazil**, the decrease in electricity loads was 15% compared with data before the beginning of the isolation decrees [18]. In **Colombia**, April and May 2020 were the months with the highest reduction in electricity consumption, accounting for a decrease of 12% and 8%, respectively, compared to 2019 [27]. The presented data are summarized in Table 1.

Ibero-American countries like Peru, Mexico, and Uruguay suffered reductions in electricity demand similar to developed countries. However, some Ibero-American countries increased their electricity consumption during confinement compared to the same period in the previous year, like Chile, which first underwent a period of social crisis that began in mid-October 2019. The health crisis began in early March 2020 with Chile’s first case of COVID-19 [33,34]. The social crisis had a more profound impact than COVID-19 on the economy but a much shorter duration. A comparison of the pre- and post-pandemic energy demand of some Ibero-American countries is shown in Fig. 3, with data extracted from the IDB Energy Hub [19].

3.1.2. Differences in demand reduction within the same country

Some reports indicate that the demand reduction was different in different localities of the same country. In **Brazil**, compared to the period before the confinement decree, the energy consumption fell by 20% in the country’s southern regions, while in the northern region, which has higher residential consumption, the energy consumption fell by 7% [18,35]. In **Canada**, the electricity demand fell by about 5% relative to expected levels in Alberta, New Brunswick, and British Columbia; and by about 10% in Ontario after introducing containment measures in each province [36]. The authors note two plausible

Table 1
Magnitude of the reduction in power demand in different countries.

Country	Magnitude of demand reduction	Study period	Comparative period	Reference
Poland	Average daily electricity consumption decreased by 6.9%	May 2020	May 2019	[25]
Ukraine	Decrease in electricity consumption was 4.9%	First half of 2020	First half of 2019	[26]
Hungary	Decrease in electricity consumption was 3.62%	First half of 2020	First half of 2019	[26]
Portugal	Electricity consumption was reduced by 12%	April 2020	April 2019	[27]
Turkey	The energy consumption decreased by 15%	April 2020	April 2019	[28]
Kuwait	The demand for electrical power fell 17.6%	During the curfew	Expected demand	[29]
India	Electricity demand declined by 15.9%	March to July 2020	March to July 2019	[30]
Bangladesh	The electricity demand in June 2020 was lower than the 2019 level	April to June 2020	April to June 2019	[31]
U.S.	Overall electricity demand declined by less than 10%	March to June 2020	Before the shutdown	[32]
Brazil	The decrease in electricity loads was 15%	During isolation decrees	Before isolation decrees	[18]
Colombia	The reduction in electricity consumption decreased 12%	April and May 2020	April and May 2019	[27]

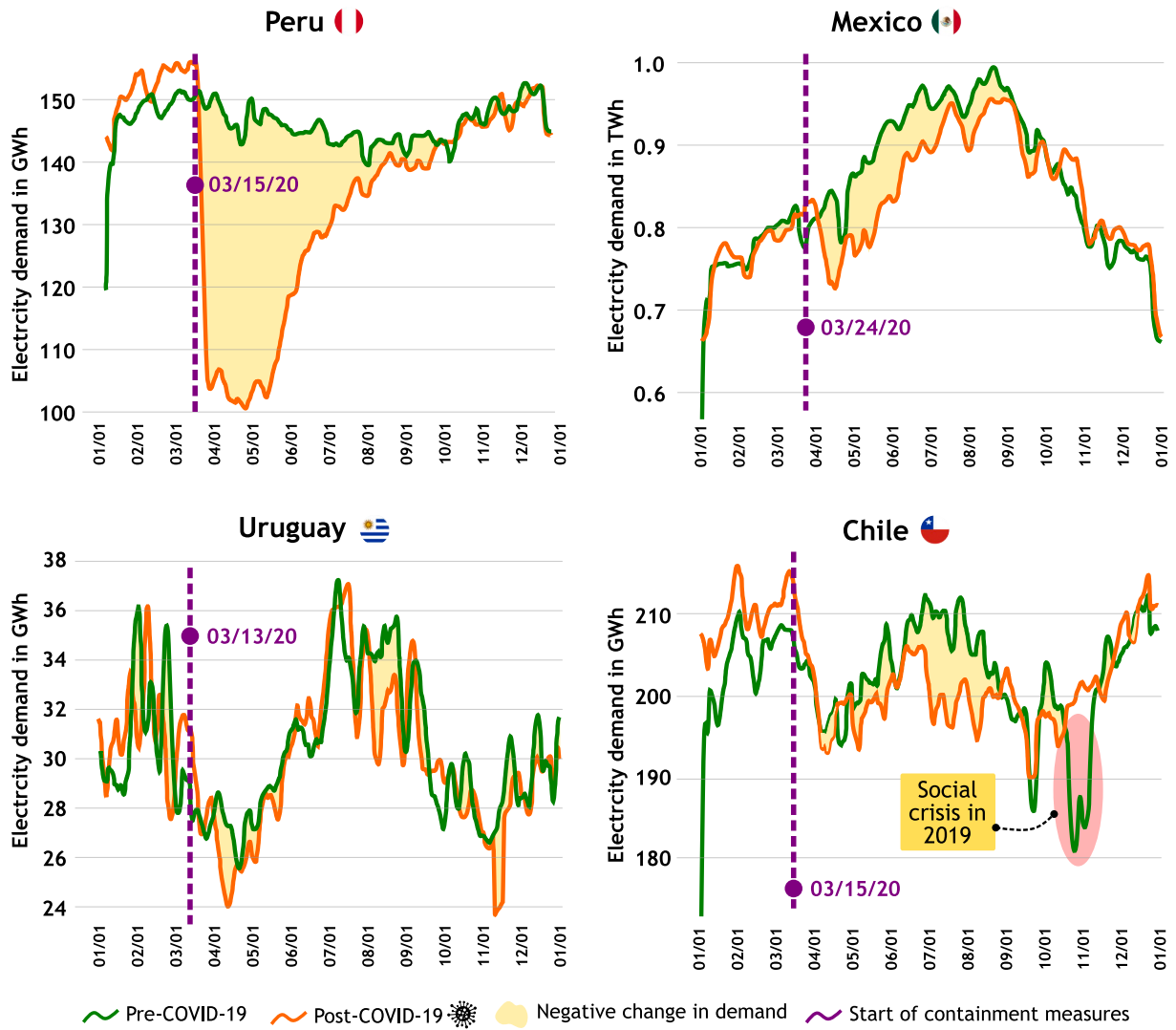


Fig. 3. Changes in electricity demand in the context of COVID-19 in Peru, Mexico, Uruguay, and Chile [19].

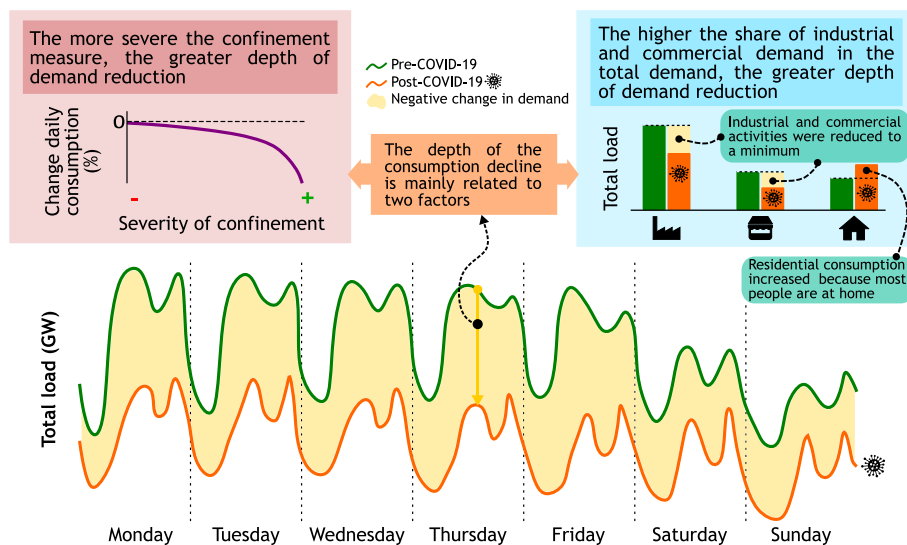


Fig. 4. Causes of the depth of power demand reduction.

hypotheses to explain these differences in Canada. First, Ontario was the province hardest hit by COVID-19 in terms of confirmed cases and deaths. Second, Ontario has a much higher commercial and industrial consumption rate than the other provinces studied, reducing their operation due to the enacted measures [36]. We examine the relationship between demand reduction and quarantine severity in Section 3.2. Changes in consumption patterns and the composition of electricity use are discussed in Section 3.3. In practice, the depth of demand reduction has been caused by both reasons, summarized graphically in Fig. 4.

3.2. Relationship between demand reduction and the severity of the pandemic at the local level

3.2.1. Relationship between demand reduction and the severity of the pandemic

The evidence suggests that the reduction in electricity demand is strongly related to both confirmed COVID-19 cases and the number of deaths [20]. Ruan et al. [37] introduced a data hub aggregating multiple data sources for analyzing the impact of COVID-19 on the U.S. electricity sector. Their results suggest that the change in total electricity consumption is correlated with the number of confirmed COVID-19 cases, the degree of social distancing, and the level of commercial activity observed in each area. Similarly, Norouzi et al. [38] developed a comparative regression and neural network model to analyze the impact of COVID-19 on electricity and oil demand in China. Their data show that electricity demand decreased by 0.65% when daily death cases increased by 1%.

Several studies have shown that the stricter the containment measures, the more significant the reduction in energy consumption. Bahmanyar et al. [39] compared the impact of different containment measures taken by European countries in response to COVID-19 on the electricity consumption profiles. Their data show that in countries with **severe restrictions** like Spain, Italy, Belgium, and the U.K., the weekday consumption was considerably reduced, and energy consumption profiles were similar to pre-pandemic weekend profiles for the same period in 2019. For countries with **less restrictive measures**, the decrease in power consumption was lower. In fact, for Sweden, where a lockdown was never imposed, the consumption even increased at particular points compared to the same period in 2019. This relationship between the severity of the confinement and demand reduction is evidenced by **Kuwait**, where the stay-at-home phase (March 13–March 21) recorded a 2.2% reduction in power generation while the partial curfew (March 22–May 10) and full lockdown (May 11–May 30) phases showed 13.7% and 17.6% reductions respectively, relative to the 2020 forecasted values [29]. López Prol and O [8] also showed a direct relationship between the severity of the containment measures and the reduction in electricity demand. However, they find a non-linear shape of this relationship, which suggests that moderate measures may have a small impact on electricity consumption. In addition, they find that European countries that experienced a more substantial decline in the first weeks of the pandemic (Italy, France, and Spain) recovered faster than those with lower initial decline measures (Germany and Great Britain). Taking advantage of the relationship between the severity of the pandemic and the reduction in electricity demand, and the connection between power demand and economic activity, Fezzi et al. [40] used high-frequency electricity market data to estimate the short-run impacts of COVID-19 on the economy.

3.2.2. Stabilizing energy demand as an economic indicator

Due to the strong relationship between confinement measures and electricity demand reduction, the demand is expected to recover gradually after relaxing lockdown measures. Thus, electricity demand can be used as an indicator of economic recovery compared to the pre-pandemic period. Jiang et al. [41] indicated that the energy consumption recovered normal consumption levels three months after relaxation of containment in China. In the U.S., the reduction in electricity demand

between February and April rebounded rapidly in June, with demand levels similar to June of previous years [7]. Wang et al. [42] studied the time it took for different economic sectors in China to recover to pre-pandemic electricity consumption levels. According to their data, the sectors that recovered the fastest were “agriculture”, “health”, “internet services” and “animal husbandry”. With a much slower recovery in the sectors of “sports”, “accommodation”, “entertainment”, “catering” and “railway transportation”. However, the worldwide recovery time duration should differ due to policies, sociological factors, and geographical factors, as is evidenced in the study of Aruga et al. [43], who investigated how COVID-19 affected Indian energy consumption during the COVID-19 crisis. The study revealed that energy consumption began to be restored as soon as the confinement measure were relaxed but with more difficulty in the poorer regions of India.

3.3. New power demand profiles during the pandemic

3.3.1. Changes in energy consumption patterns

Along with reducing electricity demand, changes in consumption patterns during the confinement period have been reported. In the course of a **week**, the demand reduction is not the same on working days as on weekends across the countries due to differences in work from home policies and differences in the severity of weekday versus weekend confinement measures. In **Spain**, the electricity demand was reduced on working days by 14.53%, while on weekends, electricity consumption was reduced by 10.62% in the period from March 14 to April 30 in 2020 compared with an average value for the same period in the previous five years [9]. On the contrary, Ontario’s most significant daily demand reductions were observed on weekends, with an average of 18% daily reductions [44].

In the course of a **single day**, the reduction in electricity consumption has taken place at the morning peak and during the night peak. In the morning, an apparent curve flattening and a more gradual morning ramping have been observed due to the closure of economic activities. At night, demand peaks are shorter due to the paralysis of some sectors such as restaurants and leisure [9,44]. However, it has been observed that the power not consumed in the morning is being shifted to midday. Chen et al. reported a 30% increase in midday consumption in the **U.K.** and a 23% increase in the **U.S.** during the typical working hours [45]. Demand over working days may also change, with reports of a shift in demand from Wednesday to Friday, to the first part of the week in **Ontario** [44].

3.3.2. Increase in residential electricity demand

Several reports indicate that residential electricity demand increased as people spent more time at home. On the contrary, industrial and commercial electricity demand has decreased due to the shutdown of businesses. These new demand profiles have resulted in a reduction in overall demand. In **China**, the demand in the construction and manufacturing industry dropped by 12% [21]. In some European countries, the residential demand during the week was up to 40% higher than in the same weeks in 2019 [21]. In **Australia**, the residential electricity demand increased 14% during the lockdown in March, while the commercial and industrial demand decreased 7% and 1%, respectively [46]. These changes in residential electricity demand were due to new social practices that triggered changes in electricity consumption [47]. Edomah and Ndulue (2020) [47] analyzed the impact of confinement measures on electricity demand in **Nigeria**. They concluded that, within the residential sector, increased cooking, home laundry, showering, and some professional practices that moved to the homes impacted on higher electricity consumption. Cheshmehzangi et al. [48] studied the impacts of COVID-19 on household energy use in **China** and concluded that the primary household energy uses are leisure, cooking, entertainment, heating and cooling, and lighting. They also investigated changes that could last after the pandemic and concluded that household cooking is likely to be temporary. At the same

time, the electricity demand associated with heating, cooling, and lighting will largely depend on potential transitions to teleworking initiatives and more extended indoor stays.

These empirical reports on the change in residential demand have been accompanied by simulations that indicate similar results concerning the increase in residential electricity demand. Zhang et al. [49] evaluated the impact of containment measures on buildings energy demand in a virtual district in **Sweden**, proposing specific occupancy schedules related to different containment scenarios. They concluded that the variation in the total energy demand of the whole district depends on the confinement levels. Similarly, Cvetkovic et al. [50] simulated different scenarios to assess the link between people's behavior and the residential consumption of natural gas, electricity, and water during the COVID-19 outbreak in **Serbia**. Because of measures put in place, the electricity consumption increased from 1127 kWh in average conditions to 1700 kW, and this increase was in proportion to the presence of the household residents. This last point coincides with the results of Scarabaggio et al. [51], whose data suggest that the more significant the number of people staying at home, the higher increment in energy consumption.

3.4. GHG reduction due to demand reduction and mobility restrictions

Due to mobility restrictions, reduced energy consumption and transportation have caused an emission reduction, though with varying degrees across different sectors and emission sources. During the first four months of 2020, an 8% decline in the global emissions was experienced, associated with the leading world CO₂ emitters: China, the U.S., the EU, India, and Russia which declined their emissions by 315 M, 138 M, 145 M, 65 M, and 24 M tons of CO₂, respectively [52]. Regarding specific reports by country, in the EU, the CO₂ emissions went down by up to 20% during April 2020 compared to 2019 [53]. The economic slowdown immediately impacted CO₂ emissions in **France**, with an estimated 6.6% decrease in 2020 compared to the baseline path [53]. In **Pakistan**, a reduction in NO₂ emissions by 40% from coal-based power plants followed by 30% in major urban areas compared to the same period in 2019 was observed, and a 25% decrease in Aerosol Optical Depth (AOD) thickness in industrial and energy sectors was observed. However, no significant decrease was evident in urban areas [54]. In **Kuwait**, the total emissions reductions were around 119, 0.335, and 3.39 kilotons for CO₂, CO, and NO_x, respectively, based on 2020 forecasting, and May 2020 recorded the highest reduction of CO₂ emissions compared to the predicted values due to the total curfew, while March had the lowest [29]. In **Ontario**, the GHG emissions saving for April 2020 was approximately 40,000 tons of CO₂ [44]. Acharya et al. (2021) [55] dealt with the changes in Aerosol Optical Depth (AOD). Their results show a significant decrease in AOD over densely populated regions and a substantial reduction in NO₂ emission due to the imposition of lockdown measures in most south and south-east Asia, Europe, and the U.S. However, they observed a higher SO₂ emission for most areas in these regions during the lockdown period. The discrepancy in the concentrations of NO₂ and SO₂ suggests the restriction in traffic movement, one of the prime sources of NO₂ emission, leading to a reduction in NO₂ concentration. In contrast, the increase in SO₂ during the lockdown period was related to the emission from the power plants.

Although this data is promising, the indications thus far suggest that the reduction of greenhouse gas emissions because of COVID-19 is transient [56], and there is even a possibility of a carbon emission rebound. Wang et al. (2021) [57] stated that the existing studies of the decomposition of the carbon emission rebound after the 2008 financial crisis showed that, due to the impact of the global financial crisis, global carbon emission decreased by 1.19% in 2007–2009. However, global carbon emission rebounded violently in all industries in 2009–2010, reaching a far higher increase rate of 6.4%. As early evidence of a rebound associated with COVID-19, Samani et al. [27] studied the impact on climate change due to the COVID-19 pandemic. They reported

a notable reduction of all air quality indicators in 2020 in Lille (France), while Lisbon (Portugal) and Utrecht (the Netherlands) experienced a rebound effect in May 2020. Thus, although the financial crisis resulting from COVID-19 has different causes and consequences than the 2008 financial crisis, it is urgent to learn from the past and avoid or slow down the possible rebound effect [57].

3.5. Changes in demand patterns and their impact on the electricity supply chain

3.5.1. Impact of the confinement measures on electricity generation for different fuel types

As a result of the declining electricity demand, the spot price level in most electricity markets has seen a dramatic reduction, with European electricity markets experiencing the most significant price drop in the world [58], and in some cases reaching a spot price of 0 €/MWh [59]. Sadly, this reduction in the price of electricity will hardly be perceived by end-users due to the characteristics of the electricity markets. This spot price reduction has impacted the technological mix used to generate energy. This dynamic related to the demand, the spot price of energy, and generation technologies are shown graphically in Fig. 5. In general, renewable energies increased their share during the pandemic, as these technologies are first in the merit order of dispatch because they have no fuel costs. In some countries, fossil gas also increased its share. In contrast, generation from fossil coal and nuclear sources was reduced [60]. In the EU, the electricity generation from coal, natural gas, and nuclear sources decreased by 35%, 25%, and 20%, respectively, during the lockdown period, compared to 2019 [61]. In **Spain**, the electricity production from non-renewable sources decreased during the confinement period, while the renewable generation sources such as PV increased their percentage share [9]. In **Italy**, the share of energy supplied by renewable energy sources increased, reaching a daily renewable penetration higher than 40%, while the average seasonal value was about 23% [59]. In **Ukraine** in March 2020, compared to March 2019, generation at wind and solar power plants was doubled [26]. In **Belgium, Italy, Germany, Hungary, and East U.S.**, renewable energy sources substantially increased in the electricity generation mix with an hourly record of renewable energy shares [62]. In **India**, the daily supply from coal-based thermal power plants was reduced by almost 26% during the lockdown. This reduction implied a decrease in emissions of between 15 and 65 MtCO₂ [63,64]. In the U.S., comparing April 2020 to April 2019, in **PJM**, coal generation is about 38% lower, and generation from natural gas is 13% higher during the pandemic than in the prior period. In **MISO**, the generation from coal resources declined about 38%, and nuclear generation declined about 4%, while generation from wind was higher by about 10%, and generation from natural gas was higher by about 2%. In **NYISO**, the generation from non-wind renewable resources was higher by about 10%, generation from natural gas declined by 12%, and nuclear increased by about 3% [65]. In **Bangladesh**, even though grid-connected renewable electricity generation is almost negligible, solar contribution reached the highest generation record during the full-lockdown period [66]. In **Israel**, on April 4, 2020, the solar share reached 27% of the total generation, the maximum fraction of renewable energy ever measured in Israel. This record was broken again on April 5, in which the solar share reached 29% [67]. This historical presence of renewables in the energy mix has demonstrated the viability of a future rich in renewable energies and, on the other hand, has caused certain degree of optimism in the fight against climate change among some academics. For instance, Watts and Ambrose (2020) [68] believe the coal industry might never recover to post-pandemic levels because the crisis has proved that renewable energy is cheaper for consumers and a safer bet for investors. Dincer et al. (2020) [69] even stated that the pandemic will be a historical turning point for the hydrogen age and the closure for the carbon age.

The water resource has also been reviewed, and has been considered in different aspects, not only as a source of energy. As an energy

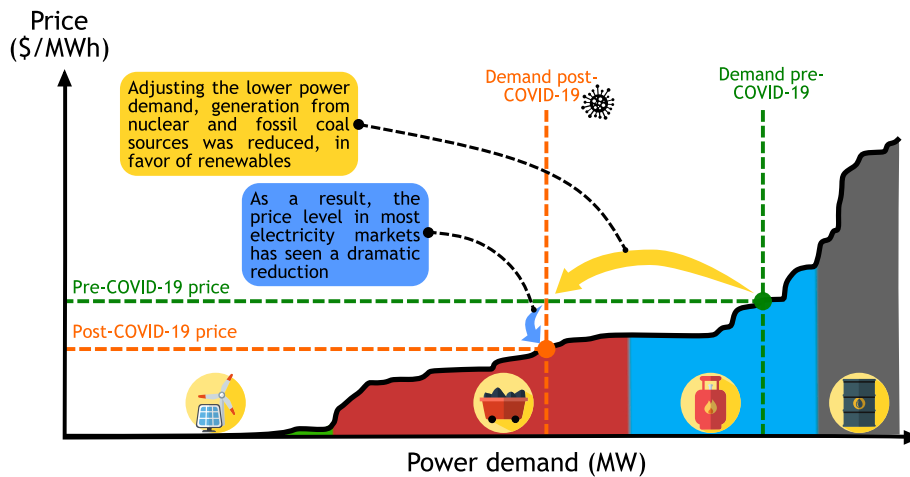


Fig. 5. Relationship between power demand reduction and energy spot price reduction.

resource, reports indicate a reduction in hydroelectricity generation in Colombia [27] and Brazil [18]. In the latter, the drop in demand contributed to the recovery of water levels in some areas. On the other hand, other reports indicate that renewable generation did not suffer significant changes concerning previous years [58,60]. Other papers highlight the flexibility that hydroelectricity provides to the system [58]. For example, this type of energy was a relevant actor in the 9-min lights-off event in India, with an estimated reduction of 13 GW. This exceptional demand reduction had to be managed with hydroelectric and gas resources [10,70]. Elevarasan et al. [71] reported that some utilities in South America increased the spinning reserve in large hydropower plants. Outside the energy sector, Cvetkovic et al. [50] simulated residential water, electricity, and gas consumption. Their results show that water consumption increased by 25% during the pandemic, while electricity consumption increased by 58%. Finally, as a spreading medium for COVID-19, Siddique et al. [72] and Usman et al. [73] examined the prevalence of SARS-CoV-2 and water quality at different stages of the water life cycle. Both highlight the presence of SARS-CoV-2 in wastewater.

The ability of hydropower to buffer the intermittency of wind and solar radiation is well known [12,13], but its high environmental impact has put the spotlight on small run-of-river hydropower plants. These plants are not environmentally harmless either and cause diverse ecological impacts: Kuriqi et al. (2021) [11] identified flow regime alteration, habitat degradation, and macroinvertebrates community composition simplification, among others. However, there are several efforts to make this energy more environmentally friendly. Kuriqi et al. (2019) [14] evaluated the consequences of energy production on flow regime alteration and provided a methodology to ensure sustainable development and proper operation of run-of-river hydropower plants by including information on biological, social, water supply, and irrigation aspects. In Chile, the Virtual DAM project will be inaugurated, which consists of an energy storage project with a lithium-ion battery bank installed in a run-of-river hydroelectric power plant [15], which avoids the need to build a mini regulation reservoir (pondage) which is one of the components with the most significant environmental impact of this technology. Thus, run-of-river hydropower is expected to be a great ally in the energy transition.

3.5.2. Socio-economic and financial challenges due to demand reduction

Unusual demand patterns caused by confinement measures have altered prices and the electricity generation mix. This unexpected situation has imposed severe financial challenges on the electricity sector. **First**, the impact on generating companies' revenues due to a reduction in demand and spot price is added to the increased costs of maintaining regular grid operation under such exceptional circumstances [58].

Second, mobility constraints have imposed restrictions on access to construction sites, reducing or canceling future orders and projects [74], and have delayed the acquisition of materials for construction [10]. These abnormal conditions have caused many companies to stop or reduce their capital outflow as much as possible, postponing most projects under construction and less critical investments [5,75]. This situation has harmed the companies' financial statements and unemployment rates. **Third**, the economic difficulties associated with the pandemic have impacted consumers' ability to pay their electricity bills. In many countries, energy regulators and government authorities have responded by extending or even suspending electricity bills or reducing the price of electricity, putting additional pressure on the utility sector because, in many countries, regulators did not provide clarity on how the debts would be resolved nor was it clear who would bear them, possibly leading to higher costs for DSOs [5,76]. These financial challenges, which are graphically summarized in Fig. 6, have impacted various sectors of society, from job destruction to renewable energy penetration targets.

3.5.3. Technical challenges due to demand reduction

The sudden changes in consumption patterns have affected the technical performance of the power systems, which have evolved to respond to a demand that has remained similar over the last decades. The first challenge is on the **power balance**, and Zhong et al. [58] highlighted two difficulties related to this issue. **First**, the increased generation of solar PV causes the load profile to evolve towards a duck curve with a "lower belly and longer neck," which has led to thermal

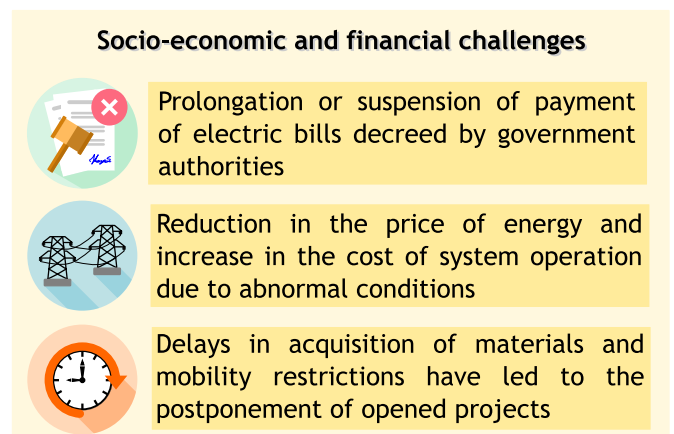


Fig. 6. Socio-economic and financial challenges faced by the electricity sector.

power plants shutting down to reduce over generation and more gas units committing to provide ramp-up flexibilities [58]. From India, Madurai et al. [10] reported that prosumers consume the maximum power generated by rooftop solar PV in urban areas due to the stay-at-home policy, which causes the energy sold into the grid to decrease, load curve shifts upwards, and the duck curve changes. Carmon et al. [67] explored how COVID-19 affected the technical operation of small grids and argued that a small grid with a higher share of renewables is likely to be less resilient to low demand events since consumption is low, renewable energy sources are prioritized over conventional power plants because of their lower cost. Lower conventional power plants in operation mean a lower spinning reserve and lower rotational inertia. Therefore, the frequency response is limited. The **second** challenge identified by Zhong et al. associated with the power balance is that the multi-stage generation scheduling process heavily relies on the accuracy of the load forecasts. Rapid changes in policies to prevent the spread of COVID-19 cause demand to be uncertain, making demand forecasting considerably more complex [58]. In addition to power balancing problems, **voltage regulation** challenges have been reported due to a sudden reduction in demand during lockdown [10]. Zhong et al. [58] argued that while demand has fallen during the pandemic, residential solar PV generation has remained at the same level. This excess net generation exacerbates the problems of voltage rise in some distribution networks. This problem is particularly prominent in areas with a large amount of commercial and industrial activity paralyzed due to the COVID-19 outbreak.

These technical problems in the grid have been accompanied by difficulties associated with mobility restrictions, social distancing protocols, and staff protection. These measures have led to the postponement or cancellation of regular maintenance activities [5,58] and the emergence of new cyber-risks due to employees working from home [10]. The technical challenges faced by the power systems during COVID-19 are graphically summarized in Fig. 7.

4. Impact of the lockdown measures in the wind and solar PV energy sectors

4.1. Challenges in the supply side: delay in the supply of clean energy components

In some countries, strict measures implemented to prevent the spread of COVID-19 have caused delays in the export of materials and components for the development of renewable energy projects [5]. In its international report “The post-COVID recovery” [80], IRENA indicates the magnitude of COVID-19’s impact on different segments of the

renewable energy value chain. The report mentions a high impact on manufacturing and procurement, transport and logistics, and construction and installation, and a low impact on project planning, operation and maintenance. Concerning the **solar energy sector**, materials and components used in the construction of solar arrays and panels have slowed down, as most of the manufacturing companies are located in China, South Korea, Vietnam, Singapore, Malaysia, and Thailand, countries that were strongly affected by COVID-19 [81]. A well-documented case is the impact of China’s near-total blockade, which banned the import and export of both goods and people, on India’s renewable energy sector, where almost 80% of PV modules were imported from China [82]. The **wind industry** was also interjected due to the outbreak of COVID-19. In India, due to problems as lack of project financing and bottlenecks in the supply chain, Siemens Gamesa, Vestas, and LM Wind Power -three of the main competitors in the wind energy market in India-halted production, which would cause a delay in the construction of 600 MW of wind power by 2022 [82]. The situation was different in Europe, where a survey indicated that 96% of manufacturing plants continued production despite the crisis, and only 18 of the most affected factories, mainly located in Italy and Spain, closed [83].

4.2. Challenges in the demand side: suspension of projects

In addition to the slowdown in the export of materials and components, the demand also declined considerably. On one hand, many projects under construction before the pandemic were temporarily suspended due to financial constraints faced by companies, permitting delays, and work stoppages [75,84,85]. On the other hand, new projects have been delayed due to the companies’ financial problems and restrictions on intermediation works, both for community energy projects and distributed PV installation. The latter is further aggravated by the declining income levels in the residential sector. Busch et al. (2021) [86] analyzed the impact of COVID-19 policies on community energy projects and conclude that we can expect a general delay in developing new community energy projects. Concerning distributed generation, Zhang et al. (2021) [87] simulated the market slowdown in the distributed PV sector across Japan, considering different months of lockdown duration. Their results show that under blocking policies from one month to three months, the loss of end-customer demand increases from 9.49% to 78.69%. Their results also show that, as the duration of the lockdown is prolonged, the spread of economic impacts eventually reaches households, leading to unemployment and lower income. IRENA’s “The post-COVID recovery” report [80] states that the impact of COVID-19 on distributed generation has been very high because the drop in demand has caused significant job losses among installers and technicians.

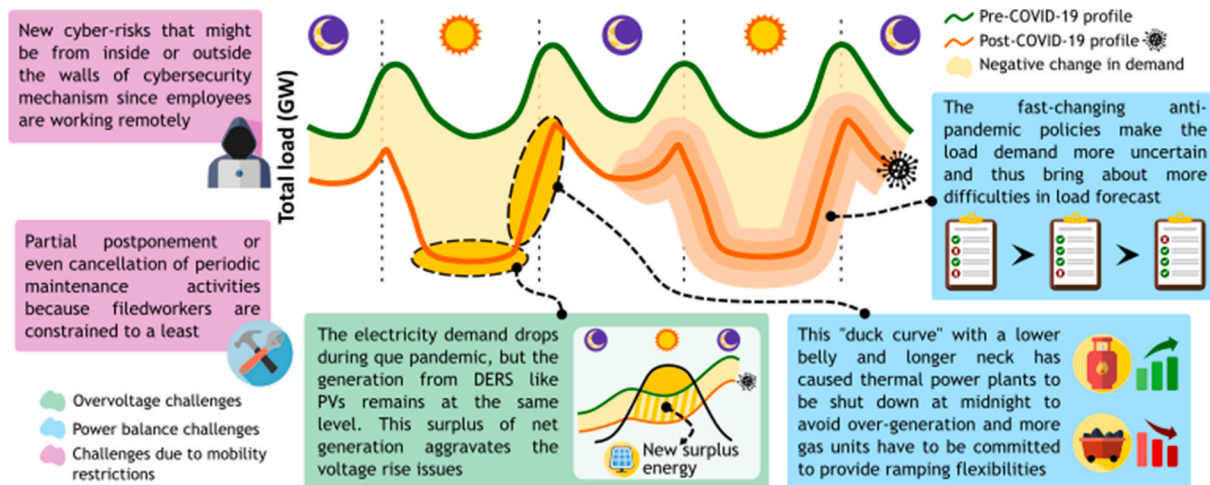


Fig. 7. Technical challenges in the electricity sector associated with demand reduction and mobility restrictions.

The reduction in demand for these kinds of projects has led to a freeze in the growth of renewable energy and the loss of clean energy jobs [88]. In India, COVID-19 has caused 300,000 people in the renewable energy sector to risk losing their jobs [30]. In the U.S., more than 600,000 workers in the clean energy sector lost their jobs by June 2020 [89]. The impact is most visible for off-grid energy companies in Africa because of their difficulties in reaching communities living off-grid, and customers' liquidity being stalled, decreasing distributed PV sales and making it difficult to maintain business [90]. These challenges that the renewable energy sector is facing are graphically summarized in Fig. 8. All these consequences of the pandemic in the renewable energy sector help to explain, in part, a cointegration relation between COVID-19 confirmed cases and government response stringency, and the stock prices of solar enterprises. Wang et al. [91] explored the long-run relationship between COVID-19 and solar enterprises' stock prices in 24 countries from December 2019 to June 2020. According to long-term parameter estimates, their data indicates that the COVID-19 pandemic has depressed the stock of prices of most solar energy sources. Furthermore, the data shows that the severity of containment measures impacts more on stock prices than the number of confirmed cases.

5. Short-term measures: emergency measures aimed at the protection of energy consumers

5.1. Impact of the pandemic on energy poverty

Each new restrictive measure introduced helps to contain the spread of the virus. However, it is followed by an increase in the demand for residential electricity, as people stay at home more than before the pandemic [11,92]; and a significant decrease in economic activity [40], which increases unemployment rates and exacerbates economic problems for informal workers, causing a decline in average households income [53,92]. This difficult economic situation can make it very difficult for people to finance their access to energy services [93], which is even more difficult in areas requiring constant heating due to their geographic location [92]. Nagaj et al. (2020) [92] determined the impact of the COVID-19 pandemic on Poland's level of energy poverty and proved that COVID-19 has contributed to the intensification of energy poverty in Poland. Thus, governments and authorities have been forced to introduce short-term interventions focused on the immediate

response to the public health emergency and the upcoming economic recession [94]. Many authorities have issued emergency orders suspending disconnections from natural electricity, gas, and water services during the pandemic, and some have also suspended service interruptions for internet and cable [93].

5.2. Reactionary measures aimed at the protection of energy consumers

The short-term pandemic response is characterized by great uncertainty on the depth and duration of the public health crisis and the magnitude of its economic implications. In this context, energy policy-makers must decide which energy policies to modify and implement [94]. Mastropietro et al. (2020) [11] reviewed and classified the energy policies implemented in several jurisdictions around the world in six policy groups: (a) disconnection bans, which imply the prohibition to interrupt the energy supply in case of non-payment; (b) payment extension plans, which provide the possibility for residential consumers to defer their energy bills until the lifting of confinement measures; (c) enhancement of energy assistance programs; (d) energy bills reduction or cancellation for residential customers during the lockdown; (e) measures for commercial and industrial users; and (f) creation of funds and other support measures for suppliers. Of these measures, the prohibition to interrupt the energy supply in the case of non-payment was the most widespread measure introduced by governments during the pandemic [11].

Qarnain et al. (2020) [95] reviewed the various short-term actions taken by G20 member countries towards electricity consumption while in a COVID-19 pandemic outbreak, and the policy groups proposed by Ref. [11] are easily identified: disconnection bans (Australia, Canada, U. S., India, Argentina, and the U.K.), payment extension (Australia, India, Germany, and Japan), bills reductions (Malaysia, Italy, China, and Indonesia), measures for commercial and industrial users (France) and support measures for suppliers (India and U.K.). Similarly, Akrofi and Antwi (2020) [96] reviewed how governments in Africa have responded in the energy sector. Their review revealed that immediate measures adopted included the provision of free electricity, waiver or reduction of electricity costs, and relief funds for renewable energy companies. These measures were also short-term, often spanning two to three or four months.

The regulatory measures implemented in Ibero-America are in line with those implemented by G20 members in Ref. [95] and those

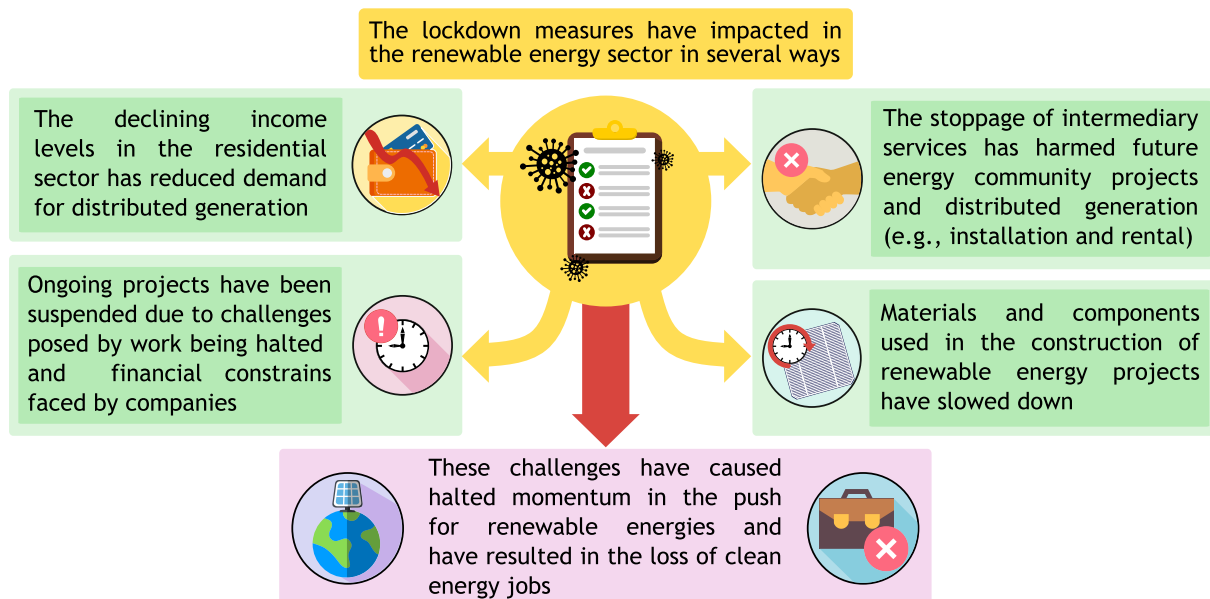


Fig. 8. Challenges faced by the renewable energy sector due to containment measures.

reported in Ref. [11], and can be classified into three categories: (a) economic measures oriented to final consumers; (b) measures to facilitate the isolation of customers, and (c) measures to secure the electricity supply chain and its staff of workers. In order to keep the length of the paper, this paper only focuses on the measures oriented to the final consumers. Within this category, 6 measures implemented in Ibero-America were identified:

- a. **Disconnection bans:** prevents the customer from losing electricity supply due to non-payment of invoices. This measure was applied in 19 of the 22 countries studied and includes among its beneficiaries all residential customers, customers connected at low voltage, regulated customers, and customers considered vulnerable due to their socioeconomic conditions prior to the pandemic or derived from the loss of their income as a result of the pandemic. Most countries where this measure was applied also include customers with debts, services already suspended, and unexecuted cut-off orders, who could request reconnection of their electric service. The periods that this measure was in force in the different countries where it was applied varied, and in most countries, customers had access to this benefit automatically, without any procedure or request.
- b. **Deferral of the payment period for electricity bills:** its purpose is to defer or extend the maximum date for payment of energy consumption bill debts. It was implemented in 18 of 22 countries. For the most part, the beneficiaries of these measures are the same as those who benefit from de disconnection bans, but in some countries, commercial and industrial customers were included. The deferral periods were different in all the countries where this measure was applied: some countries used a specific date as a reference, while other applied it until the end of the state of emergency. In most countries where this measure was applied, customers will not be charged any interest, penalties, or surcharges.
- c. **Installment payment facilities for energy bills:** its purpose is to defer the debt on electricity bills. It was applied in 16 of the 22 countries studied. As a consequence of the disconnection bans, outstanding payments could be deferred and subsequently divided into installments. Generally, the beneficiaries of this measure are the same beneficiaries of the bill deferral measure. In some countries, this payment facility was applied only to customers whose monthly consumption is below a certain threshold. The number of installments in which customers can pay their debts varies from country to country, ranging from 3 to 48 months. In most countries, no interest of charges will be applied to customers who benefit from this facility.
- d. **Energy vulnerability:** these measures consist of creating, expanding, or improving assistance programs for customers with some socioeconomic vulnerability. It was applied in 7 of the 22 countries through different programs and laws, offering different types of benefits and social support to vulnerable customers. Although energy vulnerability programs have been in place for some time, the pandemic forced them to be improved or expanded. The types of assistance offered by these programs generally take the form of reduced electricity bills. They all have in common that they were not universally applied to the entire population but only to the most vulnerable sectors.
- e. **Contractual flexibility:** these measures seek to grant flexibility to the obligations and commitments acquired in electricity supply contracts and were applied in 6 of the 22 countries studied. They were mainly aimed at industrial and commercial customers. Typically, these measures consisted of the suspension of the obligation to maintain consumption levels, the possibility of modifying their supply contracts, or requesting a new tariff categorization according to their new consumption patterns.
- f. **Price reductions:** includes all measures that affect the value of the final bill by reducing price, tariffs, charges, tariff components, or

taxes. This broad category includes eight measures: reduction of the price of energy, reduction of the demand charge, reduction of the fixed billing charge, reduction of taxes, reduction of over-consumption charges, change in the definition of peak hours, reduction of the final value of the electricity bill through a bonus or subsidy, and partial or total exemption from payment of the electricity bill. Of these measures, the energy price reduction was the most popular, applied in 10 of the 22 countries studied. This measure was applied to residential customers within a specific consumption band. The percentage reduction varied from country to country.

The Ibero-American countries have applied similar regulatory measures focused on the residential sector. However, each country is very different from the other due to different economic and social realities, different functioning of electricity markets, different consumption patterns, and different climates and geographical locations. In addition, there are multiple interactions between institutions, different types of congress (sometimes bicameral) and different political climates across countries, making it difficult to determine the specific reasons why each country has implemented each measure.

6. Post-pandemic green recovery

6.1. COVID-19 as the trigger for a green transition

The measures enacted to curb the spread of COVID-19 have caused a sudden slowdown in economic growth, which has spilled over the fight against climate change. In this regard, the most apparent impact of the pandemic has been the reduction in greenhouse gas emissions and air pollution due to the significant reduction of the transport sector [97,98], industrial sector, energy sector, and other activities [99]. Although this reduction in emissions is the result of temporary measures, these measures have demonstrated humanity's potential to adapt quickly to cultural changes in the face of a crisis through the reshaping of social norms, changes in lifestyle, and a reconsideration of mobility and behavior [88,100], with many possibilities for permanent changes connected to the digitalization of work [101,102], distanced learning approaches [71], and virtual meetings [103]. These changes were unthinkable before COVID-19, when technical solutions were preferred because they required minimal societal change and minimal disruption to the existing economic order [104]. These rapid cultural changes, added to the willingness and ability for cooperation at the government level [100,105], have made it possible to see this crisis as a strategic opportunity to work on the parallel design and implementation of economic and social recovery programs and the advancement of the global climate agenda towards a just transition [106,107].

However, the chances of a green recovery strongly depend on whether changes imposed in the lockdown result in long-term behavioral and structural change about issues like fossil fuel demand, air quality, and support for climate change mitigation [108]. This need for permanent change in the context of the looming economic crisis post-COVID-19 could be seen as extravagant, and an economic transition may not be prioritized for the sake of economic recovery [109]. Given the unknown long-term effects of the slowdown in the clean energy technology innovation [32] and the delay in the development of renewable energy projects [110] it is highly unlikely that the targets set by the climate agendas will be met.

6.2. Differences between developed and developing countries in dealing with a green transition

Both scenarios, optimistic and pessimistic, are likely to occur to varying degrees across the globe, and the COVID-19 crisis could end up exacerbating "the gulf between leaders and laggards of the global energy transition" [76]. On one hand, **developed countries** are trying to boost their recovery by directing economic stimulus towards existing clean

energy industries. In the EU, compared to the pre-crisis proposal, the COVID-19 crisis has created additional pressure for policy change to lead to more ambitious energy-friendly policies and climate action [111, 112], and it has been reported that there will be a reprioritization of the European Green Deal as a consequence of the response to the COVID-19 crisis. Some initiatives to increase private investment in renewable energy projects will be maintained to stimulate economic activity, but other programs will suffer funding cuts or delays [113]. Similarly, Germany, France, China, and the U.K. have each committed more than \$10 B of clean energy investment in their recovery programs [76]. In Asia, South Korea announced the Green New Deal policy as a strategy to build a climate-neutral economy, which was initially proposed as a post-COVID-19 stimulus plan [114].

On the other hand, two situations complicate the deployment of renewable energies in **developing countries**. First, declining tax revenues raise concerns about the sustainability of the public debt burden, leading to currency depreciation and higher borrowing costs [115], which disproportionately affect renewable energy projects due to their high capital intensity [76]. This situation, coupled with the lack of fiscal space to implement large-scale stimulus programs, has further deteriorated an already challenging investment climate for renewable energy [98] and could cause developing countries to turn to conventional energy sources to stimulate their economies [85]. Second, consumer defaults on electricity bills have put additional pressure on the utility sector in these countries, which will increase risks in the electricity sector, exacerbating the financing problems faced by new renewable energy projects [76]. In South America, these difficulties must be added to the outbreak of popular uprisings faced by Bolivia, Peru, Chile, Colombia, and Ecuador [116,117], called Latin Spring in some media reports [118]. However, unlike the Arab Spring, a wave of pro-democracy demonstrations in North Africa and the Middle East [119], the uprisings in South America have very varied motives and are not necessarily related to each other. It is still too early to determine whether the health crisis weakened these movements due to a change in the population's concern or, on the other hand, reinforced them due to dissatisfaction with the management of the pandemic [120].

6.3. *Compatibilities between the energy transition and economic recovery*

Economic and green recovery are not incompatible and can represent a win-win solution if the strategy implemented is well designed. The most robust connection between the energy transition and economic recovery is the creation of new jobs that renewable energy projects and energy efficiency practices create while reducing carbon emissions [121–125]. Thus, employment in the renewable energy sectors, which exceeded 11 M jobs worldwide in 2018, could expand to more than 84 M in all renewable energy fields by 2050 [126]. However, green stimuli to create green jobs are most effective in communities where workers have the skills needed for a green economy. Thus, these programs are less likely to provide immediate assistance to “brown workers,” who are primarily manufacturing jobs and have been heavily affected by the pandemic. These jobs require significantly different skills, training requirements, and experiences than those required by the green industry [127]. Fortunately, this is not the only compelling reason to promote the development of renewable energy projects in a post-pandemic economic recovery since renewable energies reduce countries' dependence on imported fuels, mitigating the impact of future economic and energy shocks, such as COVID-19 and countries' lockdown [128–130]. In addition, solar PV panels can have indirect effects outside the energy domain if the project is well designed and should be considered in the project evaluation. To give some examples, Kuriqi et al. (2021) [131] study how to accommodate solar PV panels over irrigation canals to reduce the evaporation rate in Egypt, and Li et al. (2018) [132] explore the use of a PV plant in the Gobi desert to curb desertification. Finally, telework initiatives could also help reduce energy consumption and transport use. However, there is no clear consensus as different studies'

methodologies, scope, and assumptions make it difficult to estimate average energy savings, and there may not even be any savings [133].

These technical arguments in favor of renewable energies must be developed within a framework that provides a standard procedure for managing the energy strategies of policymakers at every level, from global to municipal [134], and which also includes holistic solutions involving social and economic inequalities, environmental degradation, and resource depletion [135]. An essential aspect of this holistic solution is the cultural-epistemological sphere, which policymakers should look at to better achieve climate goals. Zuk et al. (2021) [135] argued that the reasons for the conflict over the abandonment of coal are political and ideological and conclude that “residents of large cities, better-educated people, and less religious people are more open to the energy transition”. Therefore, implementing green stimuli also require investment in the education and information campaign on climate neutrality policy. Within this same socio-cultural context, Chen et al. (2021) [136] studied low-income villages in China and concluded that villagers influence whether or not to adopt solar PV. This result suggests that technical-economic solutions such as state subsidies or green loans should be accompanied by the diffusion of personal experiences of neighbors rather than experts to attack the cultural aspect of the problem. While COVID-19 has greatly hampered diffusion efforts, Rosyidi et al. [137] demonstrated that the pandemic is not an obstacle to citizen participation in the digital age.

7. Conclusions

The COVID-19 pandemic has been the most severe global challenge ever faced by modern humanity, and to prevent the rapid spread of the virus among humans, countries worldwide have opted to implement severe containment and mobility restriction measures that have paralyzed commercial and industrial sectors and have forced people to spend long periods in their homes. This article provides a comprehensive literature review of the impact of reactionary measures to prevent the spread of COVID-19. Fieldwork accompanies this review on the impact of COVID-19 in Ibero-America, which adds extra value to this article by studying mainly developing countries and allows us to draw interesting conclusions that are very much in line with the literature review and the work in the developed world.

7.1. *Impact of COVID-19 on the power sectors*

According to the literature reviewed, there is consensus that the magnitude of the demand reduction is related to the severity of the confinement measures and the proportion of commercial and industrial customers present in the area. There is consensus that consumption patterns are not the same in the pre-pandemic period. However, there is no consensus on the new consumption patterns as they vary from place to place. Regarding the recovery of electricity demand, few papers examine this topic. Those who do have identified differences in recovery time between economic sectors and between different industries once confinement measures have been relaxed. There is consensus that there has been significant reduction in the levels of GHG emitted due to mobility restrictions. However, is too early to determine whether they will be permanent, return to baseline levels, or rebound and be higher than pre-pandemic era. Electricity spot price reductions have been experienced worldwide due to reduced demand, and renewables have increased their share rate in all countries reviewed. However, the share levels of the other technologies change from country to country, with no clear trend.

The new levels of demand and consumption patterns have imposed challenges on the utility sector: unpaid bills by end-users, reduction in the price of energy, increase in the cost of operating the power system under abnormal conditions, and delays in the acquisition of materials and suspension of projects under construction. Technical challenges have also been identified in the operation of electrical systems

associated with overvoltage, difficulties in balancing the system, and mobility restrictions that make maintenance work difficult. However, these challenges have been resolved without complications. The strict containment measures impacted the different segments of the renewable project development production chain, especially the delay of materials and components and the construction of projects. This generated green job losses in several countries and stalled the growth of renewable energy. Finally, developed countries will likely see this economic recovery as an opportunity to accelerate the energy transition, while developing countries will opt for economic recovery in the face of declining tax revenues and depreciating currencies. However, economic recovery and energy transition are compatible: developing renewable energies creates jobs and makes countries independent of fossil fuels.

7.2. Ibero-American regulatory response

Due to the characteristics of this crisis, which has forced people to work and study from home, governments rushed to ensure the continuity of the electricity supply and to decree the prohibition of interruption of the electricity supply for non-payment, although with different nuances throughout the world: with automatic access of upon request, state or private support, with and without retroactive application, among others. In Ibero-America, various payment facilities were granted: postponement of the payment period, debt installments, creation or improvement of energy assistance programs, and reductions in the price of electricity bills. Although these measures are similar, they vary from country to country in terms of time frame, beneficiaries, and amounts allocated. It is complex to identify the reasons why each country implemented specific measures due to the multiple interactions between institutions and different political climates in each country: the existence of state-owned generation and transmission companies in Ecuador facilitated the implementation of these measures, while the complicated political climate in Chile helped distribution companies to agree to the decreed measures.

The measures applied in Ibero-America are in line with what has been reported in research in the rest of the world, specially concerning guaranteeing basic energy needs. However, the financing of these measures has not been evident in all countries, which could aggravate the liquidity problems of energy suppliers, increase risk, or make the operation of the electricity system more expensive. On the other hand, the socioeconomic database in Ibero-American countries were not updated or scarce, which prevented the targeting of measures to the most vulnerable citizens. The economic aid was diluted in inhabitants who did not suffer relevant impacts due to the pandemic. Thus, the targeting of resources remains a challenge in the region.

7.3. Future research recommendations

Due to the intimate relationship between energy production and power demand, it is imperative to determine local factors that influenced the magnitude of the drop in power demand in different localities: seasonal factors, level of development, degree of electrification or even idiosyncrasy, in order to understand better the behavior of the electricity sector and industry in a similar scenario in the future. Likewise, there is scarce literature on the base level of electricity demand recovery times, both for countries and particular industries, and different socioeconomic sectors. There is much expectation on the role of telework once the pandemic is over. It will be necessary to determine whether these measures reduce electricity demand and carbon footprint or are more detrimental than face-to-face work.

Also, it is necessary to determine whether this forced and accelerated digitalization of many jobs will promote the development of developing economies. As for the recovery of GHGs, it is necessary to determine whether they recovered to baseline levels, remained below or whether a rebound effect caused them to increase during the economic recovery. Regarding technical challenges, it is crucial to determine the behavior of

different electricity systems with different degrees of integration of renewables and their response to both unpredictable demand and difficulties in exporting fuels. Finally, it is important to determine the pandemic's impact of the renewable energy sector, both in terms of delays in project construction and research development.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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