Effects of the COVID-19 on the Indian energy consumption

By

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Abstract

Just after the Indian government issued the first lockdown rule to cope with the increasing COVID-19 cases in March 2020, the energy consumption in India plummeted dramatically. However, as the lockdown relaxed, energy consumption started to recover. The study investigated how COVID-19 cases affected Indian energy consumption during the COVID-19 crisis by testing if the lockdown release has a positive impact on energy consumption and if richer regions are quicker to recover their energy consumption to level before the lockdown. Using the autoregressive distributed lag (ARDL) model, the study reveals that a long-run relationship holds between the COVID-19 cases and energy consumption and that the COVID-19 cases have a positive effect on the Indian energy consumption. This result indicated that as lockdown relaxes energy consumption starts to recover. However, such a positive impact was not apparent in the Eastern and North-Eastern regions, which are the poorest regions among the five regions investigated in the study. This implies that poorer regions need special aid and policy to recover their economy from the damages suffered from the COVID-19 crisis.

1. Introduction

The COVID-19 pandemic has forced governments around the world to impose tough restrictions on daily life to prevent the spread of the virus. With these restrictions, roads and airports are nearly empty, shops and restaurants are closed, and industrial activities are largely at a halt worldwide. As strict lockdown was imposed all over India from 25 March 2020 to May 2020, a significant decline in power demand was seen: a nearly 20% to 40% drop. Conversely, this declining trend started to reverse from May 2020. According to Pillay 2020, the rate of the demand for energy depreciation has recovered from 22% to 17% and residential demand emerged compared to the industrial demand in May compared to April. India's power consumption shrunk 9.24% and 22.75% in March and April, but this slump in power consumption narrowed down in May to 14.16% (The Economic Times, 2020a, b). The Economic Times 2020c suggests that this recovery of the energy demand is related to the government starting to give relaxations for economic activities and increased use of air-conditioners as the mercury soared beyond 45-degree in May. Besides, the country's electricity consumption fell by nearly 19% on April 3, 2020, and coal-based power generation reduced by 26% in two weeks just after the lockdown began (Aggarwal, 2020), but levels of electricity demand recovered in late May as the lockdown relaxed.

International Energy Agency (IEA, 2020) asserts that the reduction in the energy demand after the lockdown occurs due to a decrease in the demand from the service and industry sector but a study shows that the domestic household consumption tends to increase during the lockdown (The Earth Institute, 2020). However, the amount of energy consumed in the service and industry exceeds the household use, and thus, lockdown, in general, have a negative impact on energy consumption. Therefore, in many countries, the energy demand plummeted after the lockdown as the level of industrial activities shrunk, and it only started to surge when business restarted as restrictions relaxed.

The outbreak of COVID-19 is indeed causing dramatic impacts on energy consumption as explained above. However, since the world is still far from controlling the pandemic, not much is known about how increased COVID-19 is affecting energy consumption. To shed light on this issue, this study seeks to provide how changes in the total number of COVID-19 cases have influences on energy consumption by investigating the cases of India. As of June 12, 2020, India is ranked the fourth in the world on its COVID-19 caseload and is one of the most populated countries among the emerging economies. Hence, understanding the effects of the COVID-19 cases on energy consumption for India provides valuable information for other developing countries struggling to supply energy effectively during the COVID-19 crisis and seeking their energy policy plans afterward. What is innovative about the current study is that we investigate how COVID-19 cases influenced energy consumption not only at the national level but also from the regional level. We compare and find out if income gaps among the Indian regions will lead to differences in the way their energy consumption is affected by the COVID-19 cases.

In many countries, lockdown measures have softened when the growth of new COVID-19 cases declines. This was also the condition of lockdown release in India, but in India, the relaxation process was conducted gradually by extending the lockdown five times (ACKO General Insurance, 2020). Although the number of cases itself continued to increase during each successive lockdown period, the growth rate of the cases slowed down and regulations have been relaxed as time passed from the first lockdown rule on 25 March 2020 to the latest Lockdown 5.0 extended on 1 June 2020 (ACKO General Insurance, 2020; Rukmini, 2020). Hence, we expect that the changes in the number of COVID-19 cases will have a positive impact on energy consumption, and based on this anticipation, we stated the following hypothesis.

H1: As lockdown releases, energy consumption in India is inclined to increase to levels before the lockdown.

As half of India's annual power consumption comes from industries and offices, we conjecture that increase in the energy consumption after the lockdown release will be more apparent in regions with a higher income level since most of the major industries and large companies in India are located in these regions. Thus, the following hypothesis is also tested in this study.

H2: Regions with higher income levels are quicker to recover their energy consumption to levels before the lockdown.

Pachauri (2004) identifies in India, the household income level is the most important factor to increase the level of energy requirements. We expect that the economy of regions with low average energy consumption is more susceptible to the impact from the COVID-19 crisis, and hence, we anticipate that these regions are slower at recovering their energy consumption. Studies have investigated the impact of COVID-19 on air pollution (Bao and Zhang, 2020; Sarfraz et al., 2020), but yet, no studies have examined the effects of the COVID-19 pandemic on energy consumption which is an important issue for countries like India that is on the verge of development. In the next section, we discuss the previous studies relevant to the study. The third section describes the methods of the study, and the fourth section displays the results and provides discussions based on the results. Finally, we conclude in the last section.

2. Literature Review

The current pandemic situation has made a remarkable socioeconomic, health, and environmental impacts due to the imposition of strict restrictions worldwide. There was an immediate positive effect on global CO_2 emission witnessing a 17% dropped in April 2020 compared to the average emission level of 2019 (Le Quéré et al., 2020). NASA released an image on 21 April 2020 that showed aerosol levels at a 20-year low for this time of the year in northern India – an area that is among the most highly polluted regions of the world (Aggarwal, 2020).

On the economic side, the creation of recession due to the COVID-19 on the global economy is unavoidable. The impact of the current pandemic on economic activity and energy demand has been unexpectedly severe compared with the 2008–2009 financial crisis (Suehiro, 2020; Tahir and Sohaib, 2020). A recent study of the impact of the COVID-19 on household energy and food security in Kenya showed that 25% of the respondents are paying more for primary fuel than the normal situation (Shupler et al., 2020). Another study highlights that shutting down all modes of travel have caused a massive fall in the crude oil price (Mehta and Jha, 2020). Governments are putting huge stimulus packages for these sectors to recover from the damages (Mori et al., 2020).

Especially, COVID-19 has an adverse impact on the energy sector directly and indirectly. A study on crises and opportunities in terms of energy and Artificial Intelligence (AI) technologies during the COVID-19 pandemic for India found that the decline in electricity demand has directly resulted in a decrease in the use of coal by power plants (Wang et al., 2020). India's energy demand fell 26% within 10 days after imposing lockdown (Energy World, 2020). This drop is much larger than the average global energy demand reduction of 6% (IEA, 2020). Another study observed that before starting the lockdown, the daily energy consumption across the country attained a greater magnitude around 3500 GWh. Then, its consumption started to fall and reached near 2500 GWh on April 1, 2020 (Shafiullah et al., 2020).

Quite a few studies investigate economic growth and energy consumption for India. For example, Nain et al., 2017 examine the short-run and long-run causal relationships among economic growth, energy consumption, and CO_2 by using aggregate and disaggregate (sectoral) energy consumption measures from the annual data (1971 – 2011). The study applied the Toda-Yamamoto causality test and the result showed that there are no symmetrical relationships among the variables included in the model. There is a significant number of studies examining the direction of the causal relationship between energy consumption and economic growth for India (Paul and Bhattacharya, 2004; Nain and Ahmad, 2012).

Among the studies investigating the effects of a crisis on energy markets, most of them focus on the global oil shocks in the 1970s and 1980s ((Lonergan and Cocklin, 1990; Mukhopadhyay and Chakraborty, 1999; Hunt, 2006), energy shocks after the 2008-2009 financial crisis (Sinha, 2015; Kayalar et al., 2017; Sadorsky, 2020), and the shocks after the Fukushima disaster (Vivoda, 2012; Hayashi and Hughes, 2013; Aruga, 2020). More studies will likely be coming out after the COVID-19 crisis, but at the moment, not many studies exist analyzing the energy shocks from a global pandemic.

For studies exploring the impact of the COVID-19 outbreak, Bao and Zhang (2020) test how the lockdown has affected the level of air pollution in northern China cities. They find that the emissions of the five air pollutants (SO2, PM2.5, PM10, NO2, and CO) have decreased after the lockdown restrictions suggesting that the air quality has improved after the COIVD-19 outbreak. Similarly, Sarfraz et al., 2020 find evidence of air pollution improvement in Delhi and Mumbai after the spread of COVID-19. They reveal that the NO_2 emissions have declined after the lockdown started. Therefore, the lockdown is suggested to have a positive effect on the environment. Our study is different from these studies because the focus is on the effects of the pandemic on energy consumption and how the energy consumption might recover as lockdown relaxes.

As the use of the autoregressive model is becoming popular for analyzing the changes in the spread of disease through time (Allard, 1998), our study is also modeled under this model. For example, Laguna et al., 2017 test how climatic variables such as local rainfall, temperature, and humidity affects the weekly cases of malaria using the autoregressive distributed lag (ARDL) model, and Upshur et al., 1999 examine the relationship between the number of influenza isolates and hospital admissions for pneumonia. Recently, the importance of considering the effects of spatial autocorrelation in the autoregressive model is suggested (Corizzo et al., 2019; Ceci et al., 2019), but the current study used the simple ARDL model since our study applied a separate ARDL model for each Indian regions, not using panel data.

The current study is the first study to investigate how energy consumption is affected by the COVID-19 pandemic in India and how the effects might be different among the five geographical regions of India. As the COVID-19 is causing devastating impacts on the world's energy markets, the study will not only contribute to understanding how the coronavirus shock has influenced the Indian energy sector but will also become a good reference for analyzing the effects of the pandemic on the other countries' energy sector.

3. Overview of the energy consumption and COVID-19 cases of India

3.1. Geographical regions

Table 1. All states of India with regions

Regions	States
Northern Region (NR)	Punjab
	Haryana
	Rajasthan
	Uttar Pradesh
	Uttarakhand
	Himachal Pradesh
	Jammu and Kashmir (UT) and Ladakh (UT)
Western Region (WR)	Chhattisgarh
	Gujarat
	Madhya Pradesh
	Maharashtra
	Goa
Southern Region (SR)	Andhra Pradesh
	Telangana
	Karnataka
	Kerala
	Tamil Nadu
Eastern Region (ER)	Bihar
	Jharkhand
	Orisha
	West Bengal
	Sikkim
North-Eastern Region (NER)	Arunachal Pradesh
	Assam
	Manipur
	Meghalaya
	Mizoram
	Nagaland
	Tripura

India is one of the South Asian countries, with a rich cultural heritage and versatile socio-economic progress since its independence. It is the second-largest country in terms of population and has the world's seventh-largest area (IBEF, 2020). Unofficially, there are 29 states which are grouped into six regions for developing a cooperative working environment within these states. According to the Power System Operation Corporation Limited (POSOCO) electricity consumption data for a regional basis, India is classified into five major geographical regions: Northern (NR), Western (WR), Southern (SR), Eastern (ER), and North Eastern (NER) (POSOCO, 2020). In the current research, we have done our analysis based on this regional classification. Table 1 presents the list of the states consisting of the five regions.

Karnataka is the richest state followed by Maharashtra, Telangana, Gujarat, and Tamil Nadu among the rich states whereas, Uttarakhand of the NER is ranked the top among the Hill States of India (Handbook of Statistics, 2017). On the other hand, Bihar, Uttar Pradesh, Manipur, Jharkhand, and Assam are the top 5 poorest states. Gross State Domestic Product (GSDP) per capita of Goa is 3.56 times more than the Indian average and 11.0 times greater than the lowest-ranked Bihar. Maharashtra has the highest GSDP among the 29 Indian States (MOSPI Net State Domestic Product, 2020).

The Northern Region (NR) is mainly agrarian but is changing fast with rapid economic growth that has ranged above 8% annually. As a consequence of the Green Revolution, several parts of North India have prospered including Punjab, Haryana and Western Uttar Pradesh, and have experienced both economic and social development. Due to the unavailability of jobs locally, a large number of unskilled and skilled workers have moved to Southern India and other nations. As shown in Table 2, it is ranked the third for both GSDP and Net State Domestic Product (NSDP) per capita among the five regions.

Table 2. GSDP and NSDP per capita of the five regions (USD)

Regions	2017 GSDP	2018-2019 Average NSDP per capita
WR	$812 billion	$3,026
NR	$438 billion	$2,167
SR	$1.1 trillion	$2,819
ER	$365 billion	$1,994
NER	$80 billion	$1,627

Source: IMF (2020) and Ministry of Statistics and Programme Implementation, Gov. of India

The Western Region (WR) is highly industrialized, with a large urban population. WR comprises of Goa, Gujarat, Maharashtra, Chhattisgarh, and the Madhya Pradesh, where Gujarat is highly industrialized, Goa and Rajasthan are tourist magnets. The WR generates 24% of the national GDP of the country, with an annual growth rate of 14.5% as of 2006. The states engender about 23% of the tax returns of the country. More than 85% and 65% of the households have access to electricity and television facilities, respectively (Parthasamy and Sudarshan, 2006). It has the highest NSDP and is the second for its GSDP among the five regions (see Table 2).

The Southern Region (SR) consists of the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana having GDP per capita of 2,964 USD and is ranked the fourth among all Indian states. Telangana is the second most industrialized state in India next to Maharashtra. Tamil Nadu is among the most industrialized states in the country and is known for its automobile industry containing Chennai, which is the largest industrial center of the SR. The SR has the highest GSDP and the second NSDP per capita among the five regions.

The Eastern regional (ER) states of West Bengal, Bihar, Orisha, Jharkhand, and Sikkim are expected to contribute at least 25% of the country's GDP by 2035 [46]. The annual per capita income of the ER has been on a steady rise during 2019-2020 [46]. Among the Eastern region states, the West Bengal was the highest share of GSDP (39%), followed by Bihar at 18%, and Odisha at 15% (Business Line, 2020). ER's GSDP and NSDP are the fourth among the five regions.

These North Eastern Region (NER) includes Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura. The economy of the NER is primarily agrarian. A very insignificant land is available for settled agriculture (*jhum:* slash-and-burn) cultivation in the region. The inaccessible terrain and internal disturbances have made rapid industrialization difficult in the region (Nandy, 2014). Both the GSDP and NSDP of the NER are the least among the five regions (see Table 2).

There has been a significant reduction in overall power demand and associated coal consumption by power generation facilities across the country reported by the Centre for Research on Energy and Clean Air (CREA). For example, all coal-based power plants in the 300 kilometers radius of Delhi (Haryana, Punjab, and Uttar Pradesh) except two units at Dadri Power Plant have been shut down due to low demand caused by the lockdown imposed by the government of India (Aggarwal, 2020). Data from the POSOCO also shows the steepest decline in consumption in the Western region where it fell 35%to 771 GWh on March 26, 2020, as compared to 1,187 GWh on March 18, 2020. Moreover, it is suggested that the power demand from the industrial hubs of Maharashtra, Gujarat, Rajasthan, and Tamil Nadu declined dramatically (The Economic Times, 2020d). However, in southern and western India, some increase in the energy demand occurred due to the hot weather conditions (The Economic Times, 2020d).

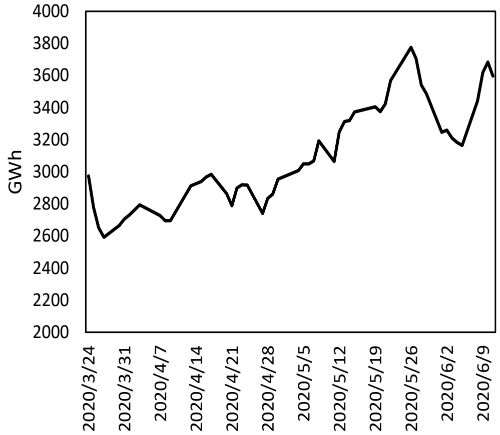
3.2 Energy consumption and COVID-19 cases of India

The daily energy consumption of the five geographical regions and entire India was obtained from POSOCO (2020), an independent company owned by the government of India. The COVID-19 cases for the regions and entire India are collected from Our World in Data (ourworldindata.org). The data period covered in this study is from March 24, 2020, to June 11, 2020. One reason for using March 24 as the initial period is because this is the date when the first COVID-19 cases were detected in North-Eastern India. Another reason is that on March 24, the Indian prime minister declared a nationwide lockdown and the first phase of the lockdown of India began on March 25. Since the lockdown announcement, the Indian government has extended its lockdown by relaxing its regulation little by little, but India is still under the lockdown restrictions as of June 2020.

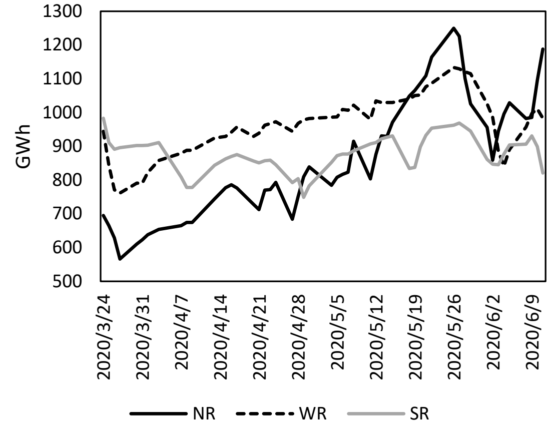
Table 3 illustrates the descriptive statistics of the energy consumption and COVID-19 cases of all India and five regions. It is observable that the order of the mean energy consumption and COVID-19 cases among the five regions are the same. In both mean energy consumption and COVID-19 cases, WR is ranked the highest, SR is the second, NR is the third, ER is the fourth, and with a gap, NER has the smallest mean.

Table 3. Descriptive statistics

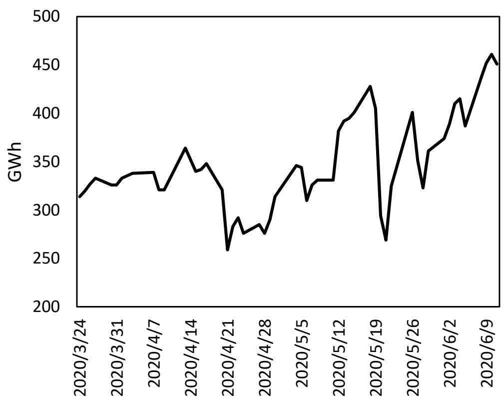
Variable	Mean	Median	Maximum	Minimum	Std. Dev.
All India energy cons.	3103.04	3049.50	3775	2592	320.96
WR energy cons.	963.94	975.50	1133	761	91.04
NR energy cons.	861.60	813.50	1250	566	177.89
SR energy cons.	877.94	877.00	983	749	52.81
ER energy cons.	347.67	335.50	461	259	50.21
NER energy cons.	37.65	37.00	52	28	6.12
All India COVID	84463.29	51193.50	298283	536	88997.86
WR COVID	40504.87	25412.00	135264	151	41838.18
NR COVID	12150.58	9099.00	40604	137	11728.35
SR COVID	15404.10	8491.00	56955	215	16196.14
ER COVID	4992.81	2259.00	20714	14	6066.16
NER COVID	799.48	115.50	5078	1	1391.82



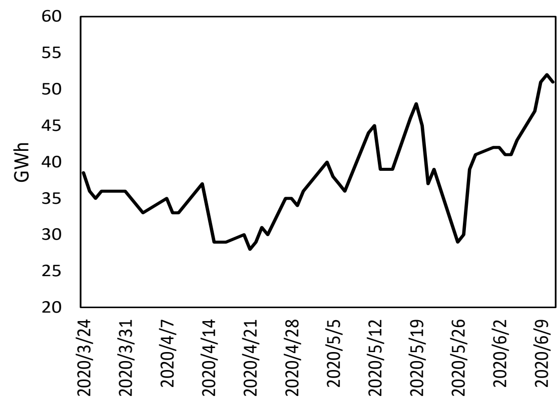
(a) All India



(b) NR, WR, and SR



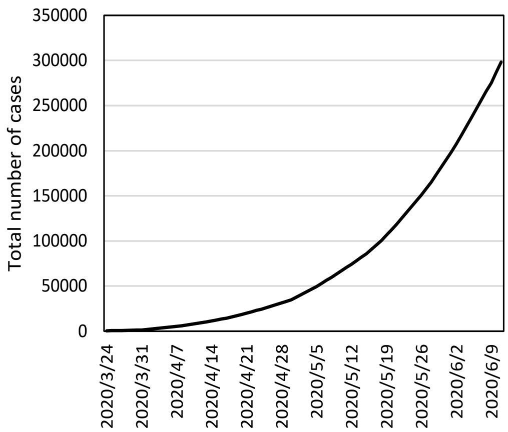
(c) ER



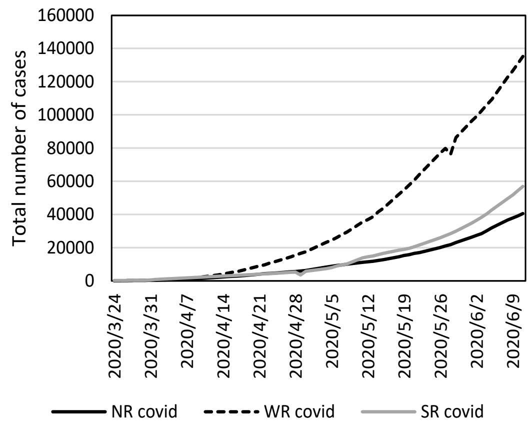
(d) NER

Figure 1. Energy consumption in India

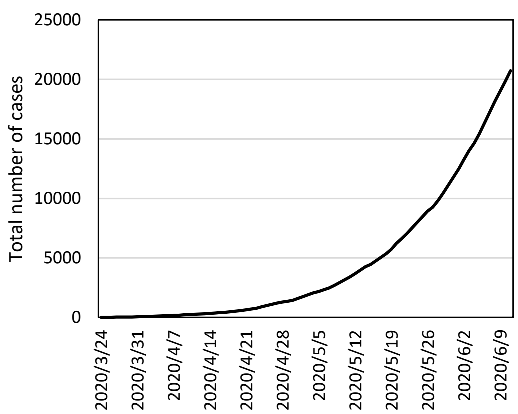
Figures 1 and 2 are the plots of energy consumption and COVID-19 cases. It is apparent from Figure 1 that in all regions except the SR, the energy consumption had an upward trend until mid-May when the Ministry of Home Affairs (MHA) issued the Lockdown 4.0, the fourth phase of the lockdown, on 18 May 2020. After the drop related to this new lockdown rule, the energy consumption of all regions except SR again started to increase. From Figure 2, we can see that in all figures there is a continuous upward trend in the total accumulative number of COVID-19 cases. However, the level of the growth of the cases is slower for the NR, WR, and SR compared to ER and NER. After mid-May, the growth of the former three regions was less than twofold but that of ER and NER was more than fourfold. This suggests that the growth rate of people getting infected with the virus was higher in ER and NER.



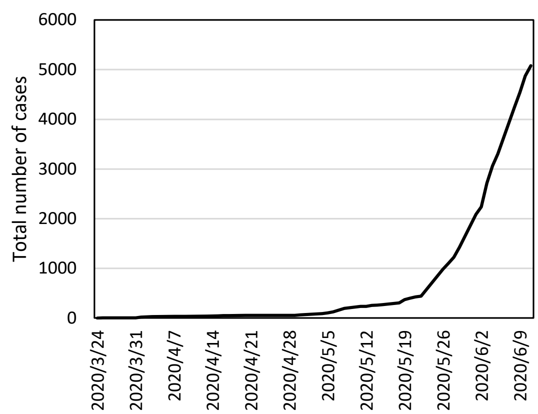
(a) All India



(b) NR, WR, and SR



(c) ER



(d) NER

Figure 2. COVID-19 cases in India

4. Methods

To capture the effects of the changes in the COVID-19 cases on energy consumption, we used the log series of the COVID-19 and energy consumption data. Hence, all our analyses are performed using the log form of the series. To identify both the short-run and long-run relationships between the Indian energy consumption and the number of accumulative confirmed COVID-19 cases, we used the ARDL model developed by Pesaran et al., 2001. As not much time has passed since the spread of COVID-19, it was not possible to obtain a large sample data. This is one of the main reasons we used the ARDL model because this model has its strength even when the sample size is small and can avoid omitted variables and auto-correlation issue. Figure 3 illustrates the steps of the methods followed in the study.

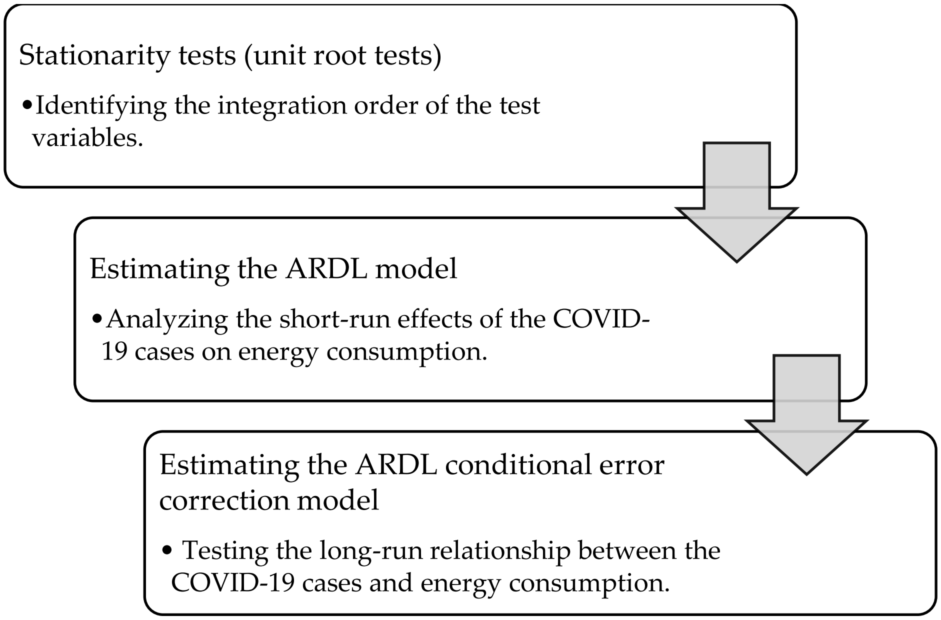


Figure 3. Overview of the steps of the methods

To use the ARDL model, the endogenous variables in the model must be either integrated of order zero or one. To test this, we initially performed the stationarity tests on energy consumption and COVID-19 variables. For this purpose, we performed the augmented Dickey-Fuller (ADF), Phillips–Perron (PP), and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) unit root tests. Table 4 illustrates the result of these tests. All three-unit root tests suggest that the Energy consumption variables of the WR, NR, and ER, and the COVID-19 variable for the SR are integrated of order one at the 5% significance level. The unit root tests suggest that the other variables are also either integrated of order zero or one, suggesting all our test variables satisfy the precondition of the ARDL model.

Table 4. Unit root tests

	Level						First differences					
	ADF		PP		KPSS		ADF		PP		KPSS	
All India energy cons.	-3.678	**	-3.658	**	0.219	***	-6.088	***	-6.273	***	0.112	
WR energy cons.	-2.664		-2.756		0.160	**	-4.397	***	-5.488	***	0.084	
NR energy cons.	-3.420	*	-2.862		0.072		-7.237	***	-8.305	***	0.073	
SR energy cons.	-3.638	**	-3.361	*	0.124	*	-5.185	***	-4.874	***	0.148	**
ER energy cons.	-2.089		-2.812		0.229	***	-8.044	***	-13.803	***	0.111	
NER energy cons.	-2.846		-2.862		0.109		-7.490	***	-8.305	***	0.082	
All India COVID	-7.220	***	-1.518		0.219	***	-0.981		-10.651	***	0.112	
WR COVID	-8.635	***	-1.278		0.230	***	-1.373		-9.847	***	0.112	
NR COVID	-5.994	***	-1.582		0.216	***	-1.042		-9.898	***	0.122	*
SR COVID	-2.477		-2.477		0.175	**	-10.313	***	-10.400	***	0.119	*
ER COVID	-4.453	***	-1.922		0.229	***	-2.381		-17.921	***	0.111	
NER COVID	-2.686		-2.807		0.088		-5.720	***	-5.673	***	0.106	

Note: All the unit root tests include both a constant and a linear trend. ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

The ARDL model used in this study has the following form:

$$energy\ cons_t = c + \sum_{i=1}^{p} \phi_i energy\ cons_{t-i} + \sum_{j=1}^{q} \theta_i COVID_{t-j} + \delta X_t + \varepsilon_t \quad (1)$$

where *energy cons* is the log of the daily energy consumption in gigawatt-hours (*GWh*), *c* is the constant term, *COVID* is the log of the accumulative number of COVID-19 cases, *X* includes the log converted fixed variables to control the effects from economic and energy-related factors that are likely to have influences on energy consumption, and ε_t is the error term. ϕ_i and θ_i are the coefficient parameters of the lags of *energy cons* and *COVID*. The optimal lag length of the ARDL model is identified by the Akaike Information Criterion (AIC). For the fixed variables, we used the *Nifty 50*, *Nifty Energy*, *Nifty Oil&Gas*, and *Nifty Auto* indices. These data are obtained from the homepage of the National Stock Exchange of India Ltd. *Nifty 50* is one of the major benchmark stock indices in India and added to the model to control the impact of the Indian economy on energy consumption. *Nifty Energy* consists of companies representing petroleum, gas, and power sector to consider the influence of the energy sectors. *Nifty Oil & Gas* and *Nifty Auto* are indices related to the gas and petroleum and the automobiles sectors (NSE, 2020). Using equation (1), we estimated the short-run effects of the COVID-19 cases on energy consumption for all India, and the five geographical regions (WR, NR, SR, ER, and NER).

To examine the long-run relationship between energy consumption and COVID-19 cases, the ARDL conditional error correction model was estimated with equation (2):

$$\Delta energy\ cons_t = c + \lambda EC_{t-1} + \sum_{i=1}^{p} \phi_i{}' \Delta energy\ cons_{t-i} + \sum_{j=1}^{q} \theta_i{}' \Delta COVID_{t-j} + \delta X_t + \varepsilon_t \quad (2)$$

where Δ is the first difference operator, EC_{t-1} is the error correction term which captures the long-run relationship between energy consumption and COVID-19 cases.

Based on this equation, the ARDL cointegration test is conducted, which is also known as the bounds testing. For the two variables of our interest to be cointegrated, the F-test statistic computed from the equation must be higher than both the lower and upper bound critical values provided in Pesaran et al., 2001. To check if the residuals of the ARDL model face the serial correlation and heteroskedasticity issues, the Breusch-Godfrey (BG) and Breusch-Pagan-Godfrey (BPG) tests were performed. Table 5 depicts the summary results of these tests based on all India and five geographical regions. It is discernible from the table that all our models do not have serial correlations. However, we found that the WR model has a heteroskedasticity problem. Thus, we used the Heteroskedasticity and Autocorrelation Corrected (HAC) standard errors proposed by Newey and West (Newey and West, 1987), which enables us to reduce the biases when measuring the standard errors of the ARDL models in the presence of heteroskedasticity.

Table 5. Serial Correlation and Heteroskedasticity tests

Model	BG F-stat.	BPG F-stat.
All India	0.632	1.203
NR	0.205	1.217
WR	1.691	5.418***
SR	0.317	0.994
ER	0.463	0.991
NER	1.877	1.893

Note: *** denotes significance at the 1% level.

5. Results and Discussions

We estimated the ARDL model to investigate if the daily changes in the total accumulative number of COVID-19 cases in India along with five regions have an impact on its daily energy consumption. The results of this model estimations are presented in Table 6. It is apparent from the table 6 that the daily changes in the accumulative number of COVID-19 cases had a statistically positive effect on the daily energy consumption of all India, NR, WR, and ER based on the 5% significance level. SR was only significant at the 10% level, but the direction of the impact indicates that the COVID-19 cases influence positively on energy consumption. It is also noticeable from the result of the SR and ER models that the total COVID-19 cases of one day before negatively impacted the energy consumption. Besides, COVID-19 did not have a significant short-run impact on energy consumption in the NER. As shown in Table 2, the NSDP per capita of NER is the lowest among the five regions and it could be that this region was less solvent compared to other regions for recovering its economic activities to period before the COVID-19 outbreak. Furthermore, as seen in Figure 2(d), the level of the growth of COVID-19 cases for NER was severer compared to other regions even after mid-May, and thus, its energy consumption remained stagnant after the lockdown relaxation. This could be also the reason for the NER not having a statistically significant effect from the COVID-19 cases.

Table 6. ARDL estimations

Variables	All India			Variables	NR		
	Coef.		t-stat		Coef.		t-stat
Intercept	7.33	***	3.16	Intercept	10.95	***	2.98
Energy cons.(-1)	0.80	***	5.64	Energy cons.(-1)	0.58	***	9.38
Energy cons.(-2)	-0.28	**	-2.42	COVID	0.08	***	3.69
COVID	0.03	**	2.55	NIFTY50	-0.68		-1.03
NIFTY50	-0.93	***	-2.85	NIFTY Oil&Gas	0.07		0.06
NIFTY Oil&Gas	-0.44		-0.70	NIFTY Energy	-0.77		-0.52
NIFTY Energy	0.45		0.58	NIFTY Auto	0.47		1.47
NIFTY Auto	0.49	***	2.70				
Variables	WR			Variables	SR		
	Coef.		t-stat		Coef.		t-stat
Intercept	5.34	***	3.59	Intercept	5.66	***	4.37
Energy cons.(-1)	0.91	***	8.21	Energy cons.(-1)	0.84	***	11.89
Energy cons.(-2)	-0.01		-0.06	Energy cons.(-2)	-0.43	***	-5.90
Energy cons.(-3)	-0.25	***	-4.93	COVID	0.07	*	1.84
COVID	0.02	***	3.18	COVID(-1)	-0.06	*	-2.01
NIFTY50	-0.42		-0.91	NIFTY50	-1.05	**	-2.62
NIFTY Oil&Gas	-0.48		-0.75	NIFTY Oil&Gas	-1.26	**	-2.26
NIFTY Energy	0.53		0.54	NIFTY Energy	1.39	***	2.85
NIFTY Auto	-0.04		-0.21	NIFTY Auto	0.62	**	2.18
Variables	ER			Variables	NER		
	Coef.		t-stat		Coef.		t-stat
Intercept	4.27		1.19	Intercept	-4.13		-0.66
Energy cons.(-1)	0.95	***	7.06	Energy cons.(-1)	0.79	***	9.04
Energy cons.(-2)	-0.51	**	-2.49	COVID	0.01		0.50
Energy cons.(-3)	0.30	***	4.60	NIFTY50	0.50		0.52
COVID	0.18	***	5.61	NIFTY Oil&Gas	-0.64		-0.30
COVID(-1)	-0.19	***	-4.25	NIFTY Energy	0.70		0.30
NIFTY50	-1.14		-1.44	NIFTY Auto	-0.12		-0.26
NIFTY Oil&Gas	2.07		1.41				
NIFTY Energy	-2.06		-1.19				
NIFTY Auto	1.15	***	2.73				

Note: ***, **, and * denote significance at 1%, 5%, and 10% levels respectively.

To find out if cointegration relationships sustained between the COVID-19 cases and energy consumption during our whole test period, the bounds F-test was conducted. According to Table 7, cointegration relationships exist in all India, NR, WR, and SR models indicating that there is a long-run relationship between the COVID-19 cases and energy consumption in these regions. Meanwhile, the table suggests that such linkages do not hold in ER and NER. To identify if the long-run relationship is sustained through the effects of COVID-19 cases, we examined the coefficients of the cointegrating equation.

Table 7. Bounds F-test for cointegration

Models	F-stat.
All India	7.09***
NR	4.87**
WR	9.19***
SR	9.82***
ER	1.92
NER	1.80

Note: ***, ** and * denote rejecting the null hypothesis of no cointegration (I (1)) at the 1% and 5% levels, respectively. The 1% and 5% lower bound (I (0)) critical values are 4.94 and 3.62 and those of the upper bound (I(1))critical values are 5.58 and 4.16, respectively.

Table 8. Long-run coefficients estimation

Models	Variables	Coef.		t-value
All India	Intercept	15.161	***	3.793
	COVID	0.055	***	3.095
NR	Intercept	25.992	***	2.785
	COVID	0.189	***	4.036
WR	Intercept	15.177	***	2.868
	COVID	0.066	**	2.556
SR	Intercept	9.473	***	3.643
	COVID	0.004		0.134
ER	Intercept	16.312		0.288
	COVID	-0.057		0.385
NER	Intercept	-19.918		-0.652
	COVID	0.031		0.543

Note: *** and ** denote significance at the 1% and 5% levels, respectively.

As seen in Table 8, all India, NR, and WR had long-run impacts from the COVID-19 cases on energy consumption but SR, ER, and NER did not have the effects from the COVID-19 cases. Thus, the results of Tables 7 and 8 suggest that the long-run relationship was caused by the COVID-19 cases in all India, NR, and WR but not for SR, ER, and NER. The reason for ER and NER not having effects from the COVID-19 cases is likely to be related to the same reason as the case of the short-run relationship. ER and NER are the poorest regions among the five regions and are the regions where the growth of COVID-19 cases continued to be high even after mid-May. It is believable that these factors have slowed down the recovery of the energy consumption levels for these regions. SR not revealing impacts from the COVID-19 cases on energy consumption is perhaps because as seen in Figure 1(b) SR did not have an increasing trend in its energy consumption during our test period. Although the cool weather kept the power demand low despite a partial easing of the lockdown from April 20, the temperature of SR is generally hot, which makes less variation of electricity consumption even during the COVID-19 crisis.

Table 9. Conditional error correction ARDL estimations

Variables	All India			NR			WR		
	Coef.		t-stat	Coef.		t-stat	Coef.		t-stat
Intercept	7.331	***	3.151	10.949	**	2.442	5.343	**	2.470
Energy cons.(-1)	-0.484	***	-4.571	-0.421	***	-3.681	-0.352	***	-5.231
COVID	0.027	**	2.346	0.080	***	2.846	0.023	**	2.621
ΔEnergy cons.(-1)	0.280	**	2.283	na			0.258	**	2.437
ΔEnergy cons.(-2)	na			na			0.249	**	2.338
NIFTY50	-0.931	**	-2.238	-0.682		-0.876	-0.423		-1.167
NIFTY Oil&Gas	-0.438		-0.654	0.069		0.055	-0.481		-0.759
NIFTY Energy	0.447		0.550	-0.766		-0.481	0.534		0.680
NIFTY Auto	0.487	**	2.268	0.473		1.185	-0.036		-0.221

Note: ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

Finally, as all India, NR, and WR had a cointegration relationship between the COVID-19 cases and energy consumption, we present the error correction model of these regions. As seen in Table 9, all these regions show a positive impact from the COVID-19 cases to their regional energy consumption levels. This indicates that in these regions, the COVID-19 cases had a positive impact on their energy consumptions.

6. Conclusions

As the COVID-19 spread out worldwide, India was not an exception to have many people getting infected to the virus and the government had to impose severe stay-at-home restrictions. The energy consumption in India plummeted dramatically by the end of March 2020 because of this lockdown regulation. However, since the end of April, energy consumption started to recover as the regulation relaxed. This study investigated how India has recovered its energy consumption after the decline in its energy consumption in March 2020. We investigated if the release of lockdown positively influences the energy consumption (H1) and if this positive reaction differs among regions at different average income levels. We examined if regions with higher income levels are more likely to recover their energy consumption to pre-crisis levels faster than those with lower income levels (H2). The results of our analyses indicated that both hypotheses H1 and H2 prevailed. This implies that even during the middle of the spread of the pandemic, energy consumption increases as lockdown regulation relaxes.

However, we found that this recovery of energy consumption is not occurring in the ER and NER. These two regions are the poorer regions among the five geographical regions investigated in this study. In India, the level of energy consumption is strongly connected to household income levels (Pachauri, 2004) and reduction in energy consumption indicates that the individual's economic conditions are deteriorating. Therefore, the result of our study revealing poorer regions struggling to recover their energy consumption to levels before the pre-COVID-19 crisis implies that the economic damages on these regions were more critical than the regions with a higher average income level. This suggests the importance of providing special economic aids and policies for these two regions to recover their economy to levels before the pre-COVID-19crisis. Our study is limited in a way that it only used short-term data since the study was performed in the middle of the COVID-19 pandemic. We would like to notice that the results are likely to change when the same analyses are performed using different periods since the effects of the COVID-19 is changing as time passes.

References

ACKO General Insurance. New lockdown rules from June 1: what is allowed and banned in green, orange, and red zones. ACKO General Insurance. May 5, 2020. Available online: https://www.acko.com/health-insurance/new-lockdown-rules-what-is-allowed-banned-green-orange-red-zones/ (accessed on 22 June 2020).

Aggarwal, M. India's power consumption falls by 19 percent during COVID-19 lockdown. 2020. Available online: https://india.mongabay.com/2020/04/indias-power-consumption-falls-by-19-percent-during-covid-19-lockdown/ (accessed on 17 June 2020).

Aggarwal, M. Within 10 days of the lockdown, India was consuming 20% less power than usual. 2020. Available online: https://qz.com/india/1844956/indias-coronavirus-lockdown-drastically-cuts-power-consumption/ (accessed on 20 June 2020).

Allard, R. Use of time-series analysis in infectious disease surveillance. *Bull. W. Health. Org.* **1998**, 76, 327–333, doi: 10.1186/s12917-017-1247-5.

Aruga, K. Analyzing the condition of Japanese electricity cost linkages by fossil fuel sources after the Fukushima disaster. *Energy Transit.* **2020**, 4, 91-100, doi:10.1007/s41825-020-00025-y.

Bao, R.; Zhang, A. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Sci. Total Environ.* **2020**, 129052, doi: 10.1016/j.scitotenv.2020.139052.

Business Line. Eastern region to contribute 25% of India's GDP: KPMG. 2020. Available online: https://www.thehindubusinessline.com/economy/eastern-region-to-contribute-25-of-indias-gdp-kpmg/article10048013.ece (accessed on 19 June 2020).

Ceci, M.; Corizzo, R.; Malerba, D.; Rashkovska, A. Spatial autocorrelation and entropy for renewable energy forecasting. *Data Min. Knowl. Disc.* **2019**, 33, 698-729.

Corizzo, R.; Ceci, M.; Japkowicz, N. Anomaly detection and repair for accurate predictions in geo-distributed big data. *Big Data Res.* **2019**, 16, 18-35, doi: 10.1016/j.bdr.2019.04.001.

Energy World. Coronavirus impact: Within ten days, a 26 percent fall in India's energy consumption. 2020. Available online: https://energy.economictimes.indiatimes.com/news/power/coronavirus-impact-withinten-days-26-per-cent-fall-in-indias-energy-consumption/74854825 (accessed on 21 June 2020).

Handbook of Statistics. Reserve Bank of India–Publications. 2017. Available online: www.rbi.org.in. (accessed on 13 June 2020).

Hayashi, M.; Hughes, L. The policy responses to the Fukushima nuclear accident and their effect on Japanese energy security. *Energ. Policy* **2013**, 59, 86-102, doi: 10.1016/j.enpol.2012.08.059.

Hunt, B. Oil price shocks and the U.S. stagflation of the 1970s: some insights from GEM. *Energ. J.* **2006**, 27, 61-80.

IEA. Global energy demand to plunge this year as a result of the biggest shock since the Second World War. 2020. Available online: https://www.iea.org/news/global-energy-demand-to-plunge-this-year-as-a-result-of-thebiggest-shock-since-the-second-world-war (accessed on 21 June 2020).

IEA. International Energy Agency, COVID-19 impact on electricity. 2020. Available online: https://www.iea.org/reports/covid-19-impact-on-electricity (accessed on 16 June 2020).

IMF. Report for Selected Countries and Subjects. IMF. 2020. Available online: https://www.imf.org/external/pubs/ft/weo/2017/01/weodata/weorept.aspx?pr.x=31&pr.y=13&sy=2016&ey=2020&scsm=1&ssd=1&sort=country&ds=.&br=1&c=534&s=NGDPD%2CNGDPDPC%2CPPPGDP%2CPPPPC&grp=0&a= (accessed on 12 June 2020).

India Brand Equity Foundation (IBEF). India: A Snapshot. 2020. Available online: https://www.ibef.org/economy/indiasnapshot/about-india-at-a-glance (Accessed on 25 June 2020).

Kayalar, D.E.; Kucukozmen, C.C.; Selcuk-Kestel, A.S. The impact of crude oil prices on financial market indicators: copula approach. *Energ. Econ.* **2017**, 61, 162-173, doi: 10.1016/j.eneco.2016.11.016.

Laguna, F.; Grillet, M.E.; Leon, J.R.; Ludena, C. Modelling malaria incidence by an autoregressive distributed lag model with spatial component. *Spat. Spatio-temporal Epidemiol.* **2017**, 22, 27-37, doi: 10.1016/j.sste.2017.05.001.

Le Quéré, C.; Jackson, R.B.; Jones, M.W. et al. Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nat. Clim. Chang.* **2020**, 1-8, doi:10.1038/s41558-020-0797-x.

Lonergan, S.C.; Cocklin, C. In the aftermath of the energy crisis: New Zealand's energy policy in the 1970s and 1980s. *Energ. Policy* **1990**, 18, 100-116, doi:10.1016/0301-4215(90)90176-5.

Mehta, K.; Jha, S. S. COVID-19: A Nightmare for the Indian Economy. *SSRN Electronic Journal*, **2020**, *31(20),* 333–347, doi:10.2139/ssrn.3612676.

Mori, H.; Takahashi, Y.; Zusman, E.; Mader, A.; Kawazu, E.; Otsuka, T.; … ;Takai, E. Implications of COVID-19 for the Environment and Sustainability. Institute for Global Environmental Strategies: Hayama, Japan, 2020. Available online: https://www.iges.or.jp/en/pub/covid19-e/en (accessed on 18 June 2020).

MOSPI Net State Domestic Product. Ministry of Statistics and Programme Implementation, Government of India, 2020. Available online: http://www.mospi.gov.in/ (Accessed on 17 June 2020).

Mukhopadhyay, K.; Chakraborty, D. India's energy consumption changes during 1973/74 to 1991/92. *Econ. Syst. Res.* **1999**, *11(4)*, 423-438, doi: 10.1080/09535319900000030.

Nain, M. Z.; W. Ahmad; B. Kamaiah. Economic growth, energy consumption and, CO_2. *Int. J. Sustain. Energy* **2017**, *36(8)*, 807-824, doi: 10.1080/14786451.2015.1109512.

Nain, Z.; W. Ahmad. Energy Consumption and India's Economic Growth. A disaggregated Analysis. *Indian Econ. J*. **2012**, *60(3)*, 41–59, doi:10.1177/0019466220120304.

Nandy, S N. Agro-Economic Indicators: A Comparative Study of North-Eastern States of India, *J. Land Rural Stud*. **2014**, *2 (1)*, 75-88, doi:10.1177/2321024913515127.

Newey, W.; West, K. A simple positive sei-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica* **1987**, *55 (3)*, 703–708, doi: 10.2307/1913610.

NSE (National Stock Exchange of India Ltd). NSE Indices limited: methodology document for NIFTY indices. 2020. Available online: https://www1.nseindia.com/content/indices/Method_NIFTY_Equity_Indices.pdf (accessed on 18 June 2020).

Pachauri, S. An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. *Energ. Policy* **2004**, 32, 1723-1735, doi: 10.1016/S0301-4215(03)00162-9.

Parthasamy, R.; Sudarshan, I. New Development Paradigms and Challenges for Western and Central India; Concept Publishing Company: New Delhi, India, 2006; Volume 85, ISBN 9788180692802.

Paul, S.; R. N. Bhattacharya. Causality between energy consumption and economic growth in India: a note on conflicting results, *Energ. Econ.* **2004**, *26 (6)*, 977-983, doi: 10.1016/j.eneco.2004.07.002

Pesaran, M.; Shin, Y.; Smith, R. Bounds testing approaches to the analysis of level relationships. *J. Appl. Econom.* **2001**, *16*, 289-326,doi:10.1002/jae.616.

Pillay, A. Lockdown knocked power consumption down by up to 40% in large cities. The Business Standard. 2020. Available online: https://www.business-standard.com/article/printer-friendly-version?article_id=120061800951_1 (accessed on 18 June 2020).

POSOCO. Power System Operation Corporation Limited. National Load Despatch Centre, Daily Reports–2020-21. 2020. Available online: https://posoco.in/reports/daily-reports/daily-reports-2020-21/?fbclid=IwAR1WE51WnwwJcYjXMV37pJHsNQyQHafn2BlO_rMrxGyP1FXKiYElaT8ZFWk (accessed on 13 June 2020).

Rukmini, S. What has changed from Lockdown 1.0 to Lockdown 3.0? India Today. May 14, 2020. Available online: https://www.indiatoday.in/diu/story/india-coronavirus-what-has-changed-from-lockdown-1-to-lockdown-3-1677824-2020-05-14 (accessed on 22 June 2020).

Sadorsky, P. Energy related CO2 emissions before and after the financial crisis. *Sustainability* **2020**, 12, 3867, doi: 10.3390/su12093867.

Sarfraz, M.; Shehzad, K.; Meran Sha, S.G. The impact of COVID-19 as a necessary evil on air pollution in India during the lockdown. *Environ. Pollut.* **2020**, 115080, doi: 10.1016/j.envpol.2020.115080,

Shafiullah, G.; Raju, K.; Jamal, T.; Reddy, S. K. COVID-19: Impact Analysis and Recommendations for Power and Energy Sector Operation EnerarXiv-preprint Preprint, **2020**. Available online: https://www.researchgate.net/publication/341204513%0ACOVID-19: (accessed on 22 June 2020).

Shupler, M.; Mwitari, J.; Gohole, A.; Anderson de Cuevas, R.; Puzzolo, E.; Cukic, I.; Nix, E.; Pope, D. COVID-19 Lockdown in a Kenyan Informal Settlement: Impacts on Household Energy and Food Security. *MedRxiv*, **2020**, doi:10.1101/2020.05.27.20115113.

Sinha, A. Nature of Energy index volatility in post financial crisis period: evidences from India. *Enrgy. Proced.* **2015**, 75, 2556-2562, doi: 10.1016/j.egypro.2015.07.293.

Suehiro, S. Impact of Covid-19 on Energy Demand. IEEJ e-Newsletter **2020**, 184, 3. Available online: https://eneken.ieej.or.jp/data/8938.pdf (Accessed on 24 June 2020).

Tahir, M. B.; Sohaib, M. Social and Environmental Impact of COVID-19: positive and negative aspects. *J. Jpn. Soc. Pediatr. Surg.* **2020**, *8(2)*, 255–256, doi:10.11164/jjsps.8.2_255_5.

The Earth Institute, Columbia University, 2020. New Data Suggest COVID-19 Is Shifting the Burden of Energy Costs to Households. Available online: https://blogs.ei.columbia.edu/2020/04/21/covid-19-energy-costs-households/ (accessed on 22 June 2020).

The Economic Times. Covid-19 lockdown impact: Power demand drops as offices stay plugged out. 2020d. Available online: https://economictimes.indiatimes.com/industry/energy/power/power-demand-drops-as-offices-stay-plugged-out/articleshow/74819188.cms?from=mdr (accessed on 20 June 2020).

The Economic Times. India's power consumption shrinks 9.24% at 100.13 BU in March. 2020a. Available online: https://economictimes.indiatimes.com/industry/energy/power/indias-power-consumption-shrinks-9-24-at-100-13-bu-in-march/re_show/74933363.cms (accessed on 12 June 2020).

The Economic Times. The Economic Times, Lockdown pulls down power consumption by 22.75% to 85.05 BU in April. 2020b. Available online: https://economictimes.indiatimes.com/industry/energy/power/lockdown-pulls-down-power-consumption-by-22-75-pc-to-85-05-bu-in-apr/articleshow/75533685.cms (accessed on 12 June 2020).

The Economic Times. The Economic Times: India's fuel demand nearly doubles in May as lockdowns ease. 2020c. Available online: https://economictimes.indiatimes.com/industry/energy/oil-gas/indias-fuel-demand-nearly-doubles-in-may-as-lockdowns-ease/articleshow/76308664.cms (accessed on 13 June 2020).

Upshur, R.E.G.; Knight, K.; Goel, V. Time-series analysis of the relation between influenza virus and hospital admissions of the elderly in Ontario, Canada, for pneumonia, chronic lung disease, and congestive heart failure. *Am. J. Epidemiol.* **1999**, 149, 85-92, doi: 10.1093/oxfordjournals.aje.a009731.

Vivoda, V. Japan’s energy security predicament post-Fukushima. *Energ. Policy* **2012**, 46, 135-143, doi: 10.1016/j.enpol.2012.03.044.

Wang, B.; Yang, Z.; Xuan, J.; Jiao, K. Crises and opportunities in terms of energy and AI technologies during the COVID-19 pandemic. *Energy and AI*. **2020**, 100013, doi:10.1016/j.egyai.2020.100013.