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# Impact of COVID-19 on Karnataka's Electricity System – A Supply-Side Perspective

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**Abstract**

The COVID-19 is perhaps one of the most severe pandemics in the history of humankind. It has disrupted people and their livelihoods all over the globe. This, in turn, has impacted the demand and supply dynamics of electricity systems. Studies have observed certain typical trends in electricity demand patterns globally, but the supply side modalities have not been adequately captured. This study attempts to closely examine the changes in Karnataka's electricity system during the COVID-19 months of April, May, and June 2020, specifically from a supply side viewpoint.

We observe that in-line with the rest of the world, there has been a decline in electricity consumption in this period in Karnataka as well. This reduction in demand has been met primarily by curtailment of thermal generation, creating a temporary high RE scenario in the state. The hydro power plants were stepped up to balance the intermittencies induced by solar and wind generators. With the curtailment of around 3021 GWh, we estimate an avoidance of 0.56 million tonnes of CO2 emissions. We also estimate a revenue loss of INR 1.8 billion for the thermal power plants in these three months.

***Keywords:*** *Karnataka Electricity System, Thermal Generation Curtailment, COVID-19 Impact on Electricity,* $CO_2$ *Emission Reduction.*

## 1. Introduction

The Coronavirus disease or COVID-19 pandemic has infected over 165 billion people globally and has disrupted the way the world functions [1]. The irregularities in normal business operations have reduced the national grid's energy demand due to social restrictions, travel ban, working from home policy and layoffs. The industries have reduced their numbers of operating shifts. Travel ban almost collapsed the transport, rail and aviation industries. The mini and micro enterprises has almost stopped. Schools and universities have moved to online mode – all of which has adversely affected the global economy [2], [3]. These sudden shift of organisations from offline to online mode, partial working of industries etc., have affected the power systems operations [4]. The overall electricity demand has declined by almost 10% during this period [5,6]. In India too, the pandemic has radically slowed down the economic activities due to industries' slow-down production. The Government of India announced a twenty one day nationwide lockdown on March 25, 2020, which was extended till 30th May with progressive changes in restrictions with time [7].

The total electricity demand dropped by 25% due to a significant drop in industrial and commercial consumption due to lockdown. Although the residential consumption increased due to work from home, it was not large enough to offset the opposing reduction trends [8,9]. In electricity generation, renewables energy continued to generate in full load as they enjoy 'must run' status while the generation from coal generation reduced by 26% [10–12].

Studies across countries show three distinct trends in electricity consumption/supply patterns during the COVID-19 months – 1. There was an overall reduction in electricity consumption; 2. Industrial and commercial consumption had reduced, but there was a surge in domestic consumption; and 3. Generation from conventional sources had dipped, creating a temporary high-RE scenario.

This paper explores the effects of COVID-19 on Karnataka's electricity supply trends and its consequent implications. The article is organised as follows: Section **Error! Reference source not found.** reviews the studies which look into the impact of COVID-19 on electricity systems across the world. Section 3 gives a broad overview of electricity generation in Karnataka. Section 4 tracks the changes in electricity demand patterns and its implications on the supply side. Section 5 proposes a methodology to estimate the quantum of generation curtailed from the thermal generating stations. Section 6 explores the implications of generation curtailment on the Karnataka's electricity system dynamics, and section 7 draws some important policy recommendations from the lessons learnt through the pandemic.

## 2. Literature Review

Kuzemko et al. (2020) studied the impact of COVID-19 on the socio-political setup of nations. It found that, on the whole, the financing and investments in fossil fuel projects have taken a downward turn changes in the energy system characterized by a reduction in demand in the short run. In the medium-term, the focus would be on economic recovery, and the fossil fuel-based generating assets would require financial support to cope with the sudden demand reduction shock. In the long-term, system transition would be driven by the effectiveness of economic recovery. Furthermore, there would be a paradigm shift in people's working habits – work from home would be the preferred option, which would impact the preferred modes of travel and reduce pollution levels. Seeing the environmental benefits, it is likely that green initiatives will likely get an upthrust in the post-COVID era [13].
Siddique et al. (2021) found that COVID-19 posed a significant setback to the energy resources at large. The hit to the oil industry and oil-producing economies realized, by lowering carbon emissions by 9% in 1st half of 2020. In India, projections are 18% and 20% reduction in wind and solar installations due to demand decline. Hosseini (2020) also observed that COVID-19 had put a short-term break on the wave of RE development globally. The lesson from this is that governments across the globe must expedite their implementation pathways for their RE policies before the subsequent waves of COVID-19 take over or a new pandemic hits altogether [14].

Abu-Rayash & Dincer (2020) developed an index for smart cities' classification and performance evaluation and studied the electricity demand trends pre- and post-COVID-19 for Ontario. Its overall electricity consumption during the COVID-19 months dipped by 14%, with higher reductions during the weekends owing to heavy curtailment in recreational activities. The peak consumption in the pre-COVID era used to be on Mondays and Tuesdays, and now it shifted from Wednesdays to Fridays during the COVID-19 months [15]. Kanda & Kivimaa (2020) observed that COVID-19 has brought in specific distinct patterns in mobility and electricity, based on their exploratory study in the context of Finland and Sweden. The changes in working styles have brought a shift in mobility service options. The electricity sector has seen a reduction in demand and supply, prices, and local and sustainable supply options have gained preference [16]. Norouzi et al. (2020), through an empirical study on the Chinese petroleum and electricity markets, observed that among the infected people, the elasticity of demand was (-) 0.1% and (-) 0.65% for petroleum and electricity, respectively [17].

Edomah & Ndulue (2020) found that the electricity consumption patterns have undergone significant transitions through various phases of the COVID-19 lockdown in Nigeria. Whereas some changes were just momentary, some were temporary and some permanent. Overall, there was an increase in consumption in the residential sector, but industrial and commercial sectors saw a decline in consumption [18]. Cheshmehzangi (2020) explored the impact of COVID-19 on the energy use patterns of Chinese households. It found a long-term increase in electricity costs for lighting, heating, and cooling among household items. A long-term shift observed from the preference of using public transport facilities to private modes. Energy consumption for household entertainment seems to have achieved a long-term growth, whereas there is a short-term spike in the energy used for household entertainment in China [19].

Bahmanyar et al. (2020) studied the impact of the restriction imposed by various European governments during the COVID-19 months on electricity consumption patterns. In the restrictive countries like Spain, Italy, Belgium, and the UK, the overall electricity consumption went down. And the pattern looked similar to that of the weekends of 2019. However, this pattern wasn't there in the less-restrictive nations like the Netherlands or Sweden [20]. Werth et al. (2021) studied the impact of COVID-19 on electricity consumption in 16 European countries using the OxCGRT indices. He found the following – 'Stay at home, 'School closing,' 'Restriction on internal movements,' and 'Workplace closing' have significant correlation with the reduction in load; 2. Scandinavia and Switzerland had lesser load drops, perhaps due to less restriction; 3. Generation from coal, oil, and nuclear dropped significantly [21]. Han et al. (2020) estimated an overall carbon emission reduction of 257.7 mT (11%) in Q1 of 2020 across all sectors in China [22]. Eryilmaz et al. (2020) conducted a study to understand the effect of the pandemic on the generation mix in NYISO, MISO, and PJM regional markets. It observed that the impact of pandemic was not uniform across regions. Different markets have been affected differently in terms of generation mix from baseload, peak load, and renewables [23]. Haxhimusa and Liebensteiner (2021) have explored the relationship between electricity demand shocks and heterogeneous generation technologies in the power sectors for 16 major European countries from January to March 2020 by using an econometric model. They have found that electricity demand reduced by 19% while emissions fell by 18.4% [24].

Beyer et al. (2020) found that electricity consumption in India dipped by 28.5% immediately after a lockdown in March 2020. After that, in April and May, it was below the expected levels by 25.8% and 14% respectively and from June onwards, by 6-9%, indicating that lockdown had a substantial impact on electricity consumption. The effect, however, varied from state to state [25]. Kantikar (2020) empirically found that the reduction in electricity demand, met by a 26% reduction in supply from coal plants [12]. Deshwal et al. (2021) have accessed the impact of COVID-19 pandemic on power demand, the economic condition of power distribution companies, impact on electricity generation. The author has taken solar sector as a case study where they have explored various challenges w.r.t manage the load demand, actions taken by the utilities/power sector for the smooth operation of the electricity system. The author has suggested policy strategies in overcoming the pandemic crisis in future [26]. Thus, taking the cue from these studies, we can infer that few works have focused on supply-side impact effects due to pandemics. This study makes an attempt to explore the impact of COVID-19 on the supply-side dynamics of the electricity system.

## 3. Karnataka's electricity system – an overview

Karnataka is a state in the southwestern region of India, having the coordinates 12.97°N 77.50°E. The electricity system in Karnataka is one of the major systems in the country, where the transition shift from Hydro to Thermal to Renewable is occurring rapidly over the past two decades. The dominance of renewable energy technologies characterizes Karnataka's electricity system, with more than half of its installed capacity comprising solar, wind, small hydro, and biomass. The installed capacity mix of Karnataka at the beginning of the first wave of COVID-19 in India, i.e., March 2020, is as shown in Figure 1 below:

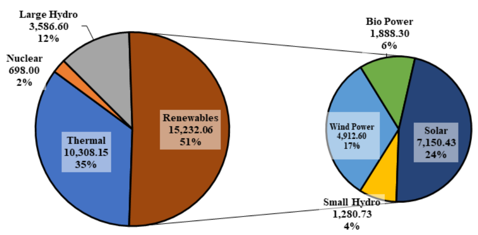


**Figure 1 - Karnataka Energy Generation Mix as on 31 March 2020 [27]**

The total installed capacity of Karnataka is around 2.26 times the peak demand which makes it a power surplus state [28].

## 3.1 Sources of power

Karnataka has the fourth highest installed generation capacity and, is the forerunner in renewable energy installations among the Indian states. It houses the 2050 MW solar park at Pavagada – world's second-largest solar photovoltaic park [29]. It became the first state in India to cross the mark of 50 percent renewable energy in its installed capacity. Table 1 lists out the major thermal and hydro power stations in Karnataka.

**Table 1 - List of major Thermal and Hydro power stations in Karnataka [30] [27][31][32]**

| Generating Technology | Power Station | Commissioned Year | Capacity (MW) |
|---|---|---|---|
| Thermal | Raichur Thermal Power station (RTPS) | 1986-2013 | 1720 |
| | Bellary Thermal Power Station (BTPS) | 2007-2016 | 1700 |
| | Yermarus Thermal Power Station (YTPS) | 2015-2017 | 1600 |
| | JSW Vijayanagar Power Station (Merchant Power Plant) | 2000-2009 | 1460 |
| | Udupi Thermal Power Plant (UPCL) | 2012 | 1200 |
| | Kudigi Thermal Power Station | 2016-2018 | 2400 (50% share for Karnataka) |
| Hydro | Sharavathi | 1964 | 1035 |
| | Nagjhari | 1980-84 | 900 |
| | Varahi River | 1989-1993 | 460 |
| | Almatti Dam | 2005 | 290 |
| | Gerusoppa | 2001-2002 | 240 |
| | Kadra Dam | 1997-199 | 150 |
| | Kodasalli Dam | 1998-1999 | 120 |
| | Supa Dam | 1985 | 100 |
| | Mahatma Gandhi Hydro Electric Station 1 & 2 | 2007 | 139.2 |
| | Linganamakki Dam | 1979-1980 | 55 |
| | Bhadra right bank-1&2 | 1998 | 13.2 |
| | Bhadra left bank-1&2 | 1998 | 26 |
| | Mani | 1993 | 9 |
| | Ghataprabha | 1997-2012 | 32 |
| | Shivanasamudra-1 | 2007 | 24 |
| | Shimshapura | 1940 | 17.2 |
| | Munirabad-1 &2 | 1962 | 28 |

### 3.1.1 Thermal generation

Raichur Thermal Power Station (RTPS) is the largest state-owned coal-based thermal power plant consisting of 8 units. They are followed by the three units of Bellary Thermal Power Station (BTPS) and Yermarus Thermal Power Station (YTPS), having two units. The major private participants include Udupi Thermal Power Plant and JSW's Vijaynagar Thermal Power Station.

Apart from these, Karnataka has share allocations from various central owned power stations, which sum up to 3314.45 MW [33].

### 3.1.2 Hydro generation

The state has numerous waterfall regions due to its coastal terrain. Shivanasamudra, Sharavati, and Nagjhari are the few significant waterfalls in the state. It was the first state in India to recognize hydropower potential for electricity generation and made a beginning by commissioning a megawatt-sized project in Shivasamudram (3.2 MW) on the Cauvery river banks in 1902. The longest transmission line of 147 km in the World was installed during that time [34]. Seven major river systems cover the entire state along with their tributaries and distributaries. Around 18 major state-owned hydel plants in the state built over 16 reservoirs, the largest being Sharavathy with ten units [35].

### 3.1.3 Renewable energy systems

Karnataka, as a state, has the highest solar installation in the country. The 2.05 GW solar park at Pavagada is the world's second-largest solar PV park (after Bhadla, Rajasthan – 2.245 GW) [29]. Apart from this, around 2.24 GW of solar installations have come up through competitive bids, 1.26 GW of privately owned plants, 22.63 MW of off-grid captive capacity, and others [36].

With the advantage of its location and terrain, the state of Karnataka has a vast coastline and hills. Over a thousand private wind plants installed in the state have a cumulative capacity of nearly 5 GW, along with 14 central government projects of 68.4 MW and state government installations of around 33 MW [30]. Other renewable energy installations comprise biomass–bagasse–based cogeneration, non-bagasse, and waste-to-energy plants, which contribute to 6% of the installed capacity mix.

### 3.1.4 Inter-state exchange

Karnataka has power links with its neighboring states – Maharashtra, Goa, Kerala, Tamil Nadu, Telangana, and Andhra Pradesh through various interstate transmission lines. Over 20 interstate transmission lines are connecting the Karnataka grid with the neighboring states. These lines are of different voltage levels ranging from 66 kV to 765 kV. These lines primarily transmit power from various central owned generating plants located in Karnataka and its neighboring states as per their respective share allocations and are also used for undertaking short-term power transactions through multiple modes [37].

## 4. Transformations in Karnataka's power supply due to COVID-19

In tune with the entire world, the state of Karnataka has also experienced a heavy setback in the levels and pattern of human activity, which is consequently reflected through a downfall in electricity consumption.

### 4.1 Changes in demand pattern

Table 2 below shows the reduction from official estimates in overall consumption and peak demand during the COVID-19 months in the state of Karnataka, the Southern region, and India as a whole.

**Table 2 - Deviation of Actual Energy Requirement and Peak Demand [28]**

| | Karnataka | | Southern Region | | India | |
|---|---|---|---|---|---|---|
| | Apr-20 | May-20 | Apr-20 | May-20 | Apr-20 | May-20 |
| **Energy Consumption (GWh)** | 16 % | 32 % | 24 % | 15 % | 28 % | 21 % |
| **Peak Demand (MW)** | 13 % | 28 % | 19 % | 12 % | 30 % | 15 % |

The peak-to-average load ratio from April-June 2019 was 1.39, whereas, for the same months in 2020, it was 1.43. Figure 2 and Figure 3 show the average hourly load curve for weekdays and weekends during April, May, and June of 2019 and 2020 [Data Source: Karnataka Power Transmission Corporation Limited].

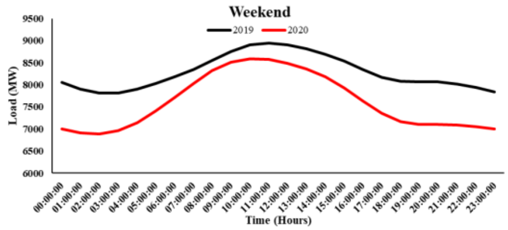


**Figure 2 - Average Hourly Load Curve for the weekends of April, May, and June 2019 and 2020**

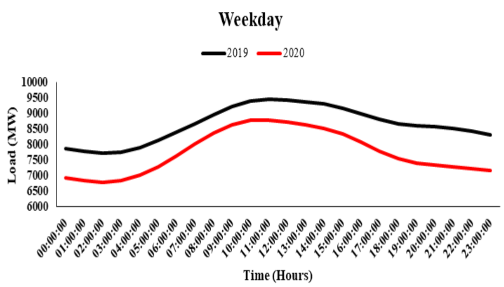


**Figure 3 - Average Hourly Load Curve for the weekdays of April, May, and June 2019 and 2020**

These capture the changes brought about by the pandemic on the energy use pattern. With the shift in human activity patterns to work from home and indoor entertainment, the energy use patterns in the weekdays and weekends have scaled down. The electricity load on the weekends had declined by 8.14%, while on weekdays, it is reduced by 10.34% during the covid affected months of 2020 compared to 2019 data.

## 4.2 Changes in supply pattern

A close look at the technology-wise supply profiles of the state reveals that the reduction in demand has been met primarily by curtailment of generation from the thermal power plants. We observe a significant reduction in thermal generation in the state compared to the preceding year during the months of COVID-19 lockdown. On the contrary, generation from hydropower stations increased remarkably, while other renewable technologies like solar, wind, and biomass have maintained similar generation levels. Thermal generation decreased by 47.3 % (3075.66 GWh) from 2019 to 2020 during the COVID-19 months, while hydro generation increased by 27.5 % (1034.32 GWh). Figure 4**Error! Reference source not found.** shows the comparison of technology-wise generation during COVID-19 months of 2020 vs the corresponding months of 2019.

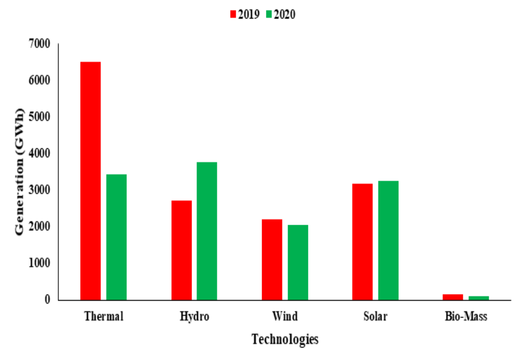


**Figure 4 - Comparison of technology-wise generation during COVID-19 months of 2020 vs the corresponding months of 2019.**

Figure 5 compares generation from various thermal plants during COVID-19 months of 2020 vs the corresponding months of 2019.

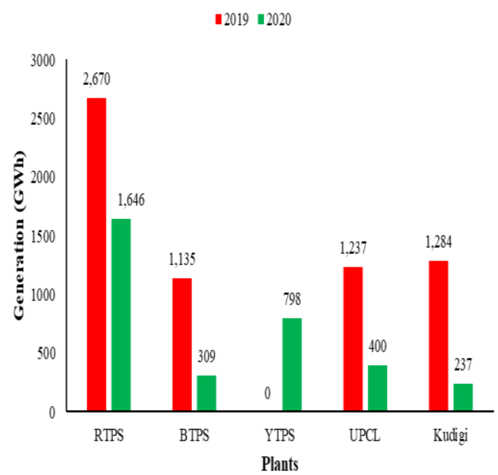


**Figure 5 - Cumulative thermal plant wise generation for April to June in 2019 and 2020**

It is observed that RTPS and Kudigi power plants are seen to have the highest difference in generation from their 2019 levels. In contrast, YTPS, which was not in operation during the months of April-June 2019, generated 798 GWh of electricity during the corresponding months of 2020.

## 5. Estimation of quantum of generation curtailment from thermal power plants

In section 4, we have described the quantum of electricity load reduction and changes in the share of generation among thermal and renewable energy resources during COVID-19 lockdown months. Here, we estimate the quantum of generation curtailment caused by COVID-19 from each thermal plant. For doing so, we compare the actual generation with the forecasts provided in the Load Generation Balance Report (LGBR) published by the Central Electricity Authority, Govt. of India. We make the following assumptions – (i) the mismatch in actual generation from LGBR forecasts during the COVID-19 months accounts for all the generation curtailment and, (ii) only the thermal generating plants have been subjected to curtailment. The computation of total supply shortfall from forecasts has been presented in Table 3.

**Table 3 - Computation of curtailed generation**

| Months | Generation Forecasted in LGBR (GWh) | Actual Generation (GWh) | Curtailment (GWh) |
|---|---|---|---|
| | (1) | (2) | (1) – (2) |
| April | 7,368 | 6,157 | 1,211 |
| May | 7,023 | 6,081 | 942 |
| June | 6,164 | 5,295 | 869 |
| **Total** | **20,555** | **17,534** | **3,021** |

Now, with the assumption that all the generation curtailed is only from the thermal generating pants, we attempt to estimate the generation curtailed from each of the five thermal generating plants in the state. For this, we first find the share of each plant in total thermal generation in 2019 (before COVID), and we find the share mix as shown in Figure 6.

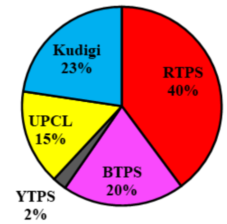


**Figure 6 - Share of the thermal power plants during covid lockdown months**

Apportioning the generation curtailment in the ratio of their generation in 2019, we obtain the plant-wise curtailment for the COVID-19 months as computed in Table 4.

**Table 4 - Thermal Power Plant Wise Curtailment during the COVID-19 months**

| Power Stations | Share of generation in 2019 (GWh) | Generation curtailment (GWh) |
|---|---|---|
| RTPS | 40% | 1,204.70 |
| BTPS | 20% | 596.61 |
| YTPS | 2% | 68.48 |
| UPCL | 15% | 467.95 |
| Kudigi | 23% | 683.48 |
| **Total** | **100%** | **3021.21** |

## 6. Impact of the transformations in demand/supply – key observations

COVID-19 has brought about a disruption in the electricity systems globally with a sudden transition in demand and supply patterns which has paved the way for re-imagining the sector's traditional ways of operating. The following sub-sections highlight the key findings from Karnataka's electricity sector in the light of COVID-19.

### 6.1 Short-run high RE scenario

Backing down of 47.3 % generation from thermal power plants augmented the share of

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renewables in total energy mix during the COVID-19 months. Figure 7 compares the generation mix during the COVID-19 months with the immediately previous quarter the corresponding months of the last year.

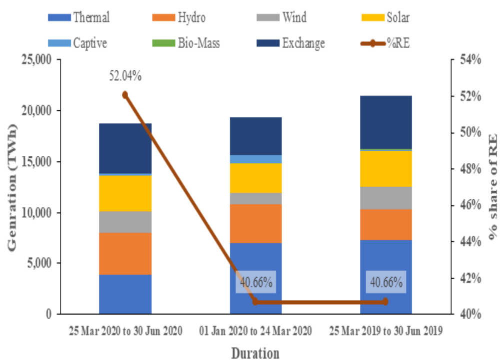


**Figure 7 - Electricity generation mix for Karnataka, India [27]**

The share of renewables in the generation mix during the COVID-19 months went up by around 12 percentage points, and there was a dip in the total consumption.

### 6.2 Reduction in CO2 emissions

As the thermal generation is one of the most significant contributors to CO2 emissions worldwide,in the same way avoided thermal generation translates to avoided CO2 emissions. The specific emissions of each plant is taken from the Central Electricity Authority CO2 Baseline database [38]. Thus, during this period, the thermal power plants avoided 2.87 million tonnes of CO2 as computed in Table 5 below:

**Table 5 - Total Emission avoided due to Curtailed generation**

| Power Plant | Curtailed generation (GWh) | Specific emissions (tonnes of $CO_2$ per MWh) | Total emissions avoided (Million tonnes of $CO_2$) |
|---|---|---|---|
| | (1) | (2) | (1) × (2) |
| RTPS | 1204.70 | 1.01 | 1.21 |
| BTPS | 596.61 | 0.97 | 0.58 |
| YTPS | 68.48 | 1.02 | 0.07 |
| UPCL | 467.95 | 0.89 | 0.42 |
| Kudigi | 683.48 | 0.86 | 0.59 |

### 6.3 Revenue loss for thermal generating plants

As the load decreased due to the pandamic, the thermal plants has to incur losses due to curtailment. Table 6 provides the details of the total loss occurred by each thermal power plant due to curtailment. The variable cost of each plant is taken from the tariff order power purchase report published by the government of Karnataka [39]. The revenue loss due to the curtailment INR 9.19 billion.

**Table 6- Revenue Loss for Thermal Generating Power Plants**

| Plants | Variable Cost (Rs/Kwh) | Curtailed Units (in kwh) | Total Loss (in Million Rs) |
|---|---|---|---|
| | (1) | (2) | (1) × (2) |
| RTPS | 2.97 | 1204.70 | 3577.96 |
| BTPS | 2.96 | 596.61 | 1765.96 |
| YTPS | 2.90 | 68.48 | 198.59 |
| UPCL | 2.74 | 467.95 | 1282.18 |
| Kudigi | 3.46 | 683.48 | 2367.57 |

## 7. Conclusions and policy recommendations

The COVID-19 pandemic has disrupted the way power systems operate. Looking closely, at the Karnataka's electricity system, we observe that there was an overall decline in electricity demand during the COVID-19 months (April-June 2020) in comparison with the corresponding months of the previous year. The decline was less over the weekends (8.14%) and more on the weekdays (10.34%) which indicates the change in lifestyle pattern of people in the 'new normal' days. On the supply side, thermal power plants saw a 47.3% (3021 GWh) dip in their output during the COVID-19 months (April-June 2020) from their generation during the corresponding months in 2019. While solar, wind and biomass maintained a similar generation profile as 2019, hydro plants experienced an increase in generation by 27.5%. With reduction in thermal generation, the share of RE in the energy portfolio of the state went up by around 12 percentage points and resulted in avoidance of 2.87 million tonnes of CO2 in these three months. However, the thermal plants faced a revenue loss of INR 9.1 billion.

We find some critical insights which must be duly considered while designing decarbonisation policies. Firstly, we observe that increasing share of solar and wind have brought in intermittencies in the grid and in order to balance that, hydro generation had to be stepped up. This highlights the importance of hydro generators, not only as a generating technology but also as a balancing mechanism. Secondly, this study gives a glimpse of the environmental benefits of including higher share of RE technologies in generation portfolio, in terms of reduction in CO2 emissions. Third, it shows that electricity system transition towards RE would mean financial losses to the thermal generation sector.

This forced short-term energy transition caused by COVID-19 induced restrictions gives a glimpse of the decarbonised future being envisaged. This may be used as a pilot study to foresee the challenges and implications that might arise with high RE penetration. This study has demonstrated the readiness of renewable energy sources and the effects of thermal power plants in Karnataka due to the sudden change in the demand pattern and may be considered as a stepping stone in the policy-making process for the promotion of renewable energy.

## 8. Data Sources

Most of the data points have been obtained from public domain like CEA etc. and have been appropriately cited. Information on plant-wise hourly electricity generation in Karnataka has been obtained from Karnataka Power Transmission Corporation Limited (KPTCL) vide a confidentiality agreement and thus, it cannot be shared. The agreement however, allows us to perform analyses on the data and publish the results.

## 9. Acknowledgment

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