REDUCING WEIGHTED AVERAGE COST OF GENERATION IN PAKISTAN THROUGH TIME OF USE (TOU) PRICING MODELS OF FLEXIBLE ELECTRIC LOADS

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ABSTRACT

Pakistan has faced under and over supply of electricity over the past decades. Historically Pakistan has faced a shortfall of upto 7000 MW but at present the country has12000 MW of excess capacity even after meeting the peak summer demand. The undersupply curtailed the GDP growth and is a major cause of industrial slow down, but the present oversupply is constantly causing an incremental rise in electricity prices and circular debt. Intelligent management of electricity demand may help reduce electricity prices and may also curtail the circular debt accumulation.

Demand Side Management (DSM) techniques allow intelligent management of electricity load where electricity distribution companies provide various financial incentives to shift demand from peak to off-peak times to reduce the Weighted Average Cost of Generation (WACG). In this report we present a DSM tool that performs in-depthdata analytics to assess the impact of demand shifts at hourly basis. Using authentic andverified data from the power sector the tool provides impact of demand shifts on WACG.The tool encodes not only the tariffs of all generating units operating of Pakistan but alsoconsiders other financial conditions including mandatory capacity and energy payments from IPP agreements in calculating its results. The tool also incorporates the technical parameters of all generating units to create a digital twin of the generationsector. Moreover, the tool also calculates the impact on environment through operating various sets of generation units.

PREFACE

The electricity of Pakistan is facing major challenges of circular debt and rising prices.There are many causes to this but presently our goal should focus on finding ways tocurtail the relentless growth of circular debt. To this end, in this research endeavor wehave worked on ways to reduce the Weighted Average Cost of Generation (WACG) ofelectricity through Demand Side Management (DSM). DSM is set of interventions thatelectric utilities employ to improve their financial bottom-line through load management. However, DSM techniques work best when available energy data is available at one hourgranularity.

The Energy Informatics Group (EIG) at LUMS Energy Institute has developed a data repository in collaborationwiththepowersectorentitieslikeCPPA,NTDC,NEPRA,DISCOs, PITC and others. Much of the data from the power sector is available with EIG. The datasets from these entities are gathered through official MoUs and usage agreements.

Using the energy data in this research EIG has developed a tool to assess the impact of DSM interventions on WACG. The tool has all the available financial and technicaldata to assess impacts on WACG using myriad number of scenarios. Currently the tool assumes and copper plate assumption where it assumes that any load shift will have therequisite transmission and distribution capability.

We would like to especially thank Secretary Energy (Power Division) for his time wherewe presented results of our findings to the CPPA BoD. The CPPA technical teams areworking on incorporating suggestions made in this report in new tariff design. We alsowould like to thank Ms. Ayla Majid, Board Member, CPPA who visited LUMS and receiveda presentation on our work sponsored by RASTA grant.

We would like to acknowledge the help and support provided by various professionals like Tauseef-ur-Rehman and Yasoon Aslam from NTDC, Farooq Qurban from CPPA, Ahmad Nadeem, Tayyab Mahmood Chaudhry, Dr. Fiaz Chaudhry and Umar Farooq from LUMS Energy Institute.

Finally, this work is not possible without generous financial and mentoring support byRASTA. We would like to specially acknowledge the continuous feedback we receivefrom our mentors Dr. Junaid Alam Memon, and Dr. Heman Das Lohano. We would like to acknowledge the open and transparent grant management by RASTA team led by Dr. Nadeem ul Haq, Dr. Durre Nayab, Dr. Faheem Jehangir Khan and their team.

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AEDB	Alternative Energy Development Board
CPPA	Central Power Purchasing Agency
CPP	Capacity Purchase Price
DG	Distributed Generation
DHW	Domestic Hot Water
DISCOs	Distribution Companies
DSM	Demand-side Management
DR	Demand Response
DRM	Demand Response Management
ECC	Economic Coordination Committee
EPP	Energy Purchase Price
EV	Electric Vehicle
GENCOs	Generation Companies
HEMS	Home Energy Management System
HVAC	Heating Ventilation and Air Conditioning
IGCEP	Indicative Generation Capacity Expansion Plan
IPPs	Independent Power Producers
KE	Karachi Electric
LEI	LUMS Energy Institute
LV	Low Voltage
NEECA	National Energy Efficiency and Conversion Authority
NEPRA	National Electric Power Regulatory Authority
NTDC	National Transmission and Dispatch Company
OECD	Organization for Economic Co-operation & Development
PCRET	Pakistan Council of Renewable Energy Technology
PITC	Power Information Technology Company
PPIB	Private Power Infrastructure Board
RCP	Real-time Charge Pricing
RE	Renewable Energy
RTP	Real-Time Pricing
SOEs	State-owned Companies
TCLs	Thermostat Control Loops
ToU	Time-of-Use
WAPDA	Water and Power Development Authority
WACG	Weighted Average Cost of Generation
WBPS	Water Booster Pressure Systems
WPSS	Water Pumping and Storage Systems

INTRODUCTION

The power sector in Pakistan has undergone significant restructuring since 1994. The Water and Power Development Authority (WAPDA) was restructured, and its jurisdiction since then has been limited to hydel generation only. The Independent Power Producers (IPPs) have been provided the opportunity to begin operations in the country as a part of this restructuring. As public sector entities, electricity generation companies often referred as GENCOs, are responsible for operating thermal power plants. The Private Power Infrastructure Board (PPIB) was established in 1994 with the goalof serving as a one-window facilitator for the private sector in the development of power projects and associated infrastructure. National Electric Power Regulatory Authority (NEPRA) was established in 1997 to regulate the energy sector in Pakistan (Rauf, Wang, Yuan, Tan, & Reviews, 2015). National Transmission and Despatch Company (NTDC) was established in 1998 with the goal of managing power transmission from generation sites to the distribution network. Furthermore, the distribution sector was divided into eleven distinct electricity distribution companies (DISCOs) (Jamil, 2013). These DISCOs have their own regional jurisdiction and organizational autonomy and are still governed by the Government of Pakistan other than Karachi Electric (KE) which has the mandate to serve the entire city of Karachi with its own electricity generation, transmission, and distribution network. The Central Power Purchasing Agency (CPPA) was created in 2015 to alleviateNTDC's burden. The goal of CPPA is to regulate the energy sale and purchase between the GENCOs and the distributors.

Despite these significant transformations and developments, Pakistan continues to be troubled by large-scale outages and other key energy-related issues due to a lack of suitable capacity and other constraints. The concerned authorities have attempted several costly but often fruitless efforts to alleviate the country's generation gap during the last six years. Between 2014 and 2018, more than 10,000 MW of generation capacity was added. By 2025, more than 17,000 MW of additional generation capacity will be added to the system (CPPA-G, 2019). Pakistan's power sector has reached a surplus generation capacity in the last few years, with many generation units operating under the '*Take or Pay*' regime. The huge sum of capacity payments paid to compensate for the excess generation capacity has resulted in the accumulation of a large circular debt. The Economic Coordination Committee (ECC) of the Cabinet defined circular debt in 2014 as the amount of the fiscalshortfall that the CPPA cannot pay to power supply providers (Bacon, 2019). The key reasons for circular debt in Pakistan are:

- The gap between the actual cost and the tariff set by NEPRA
- The government's delayed or non-payment of subsidies
- The delay in determining and notifying rates

The cost of generation per unit (kWh) includes generation, transmission, and distribution costs, as well as cross-subsidies and government taxes. The cost of generation comprises energy payments and capacity payments. Figure 1 depicts an example of an industrial one-unit cost. We can identify from figure 1 that the capacity cost is the most significant component of the unit cost. Table 1 illustrates the energy and capacity payments from 2017 to 2021.

Figure 1: Demystifying One kWh of Energy in Pakistan.

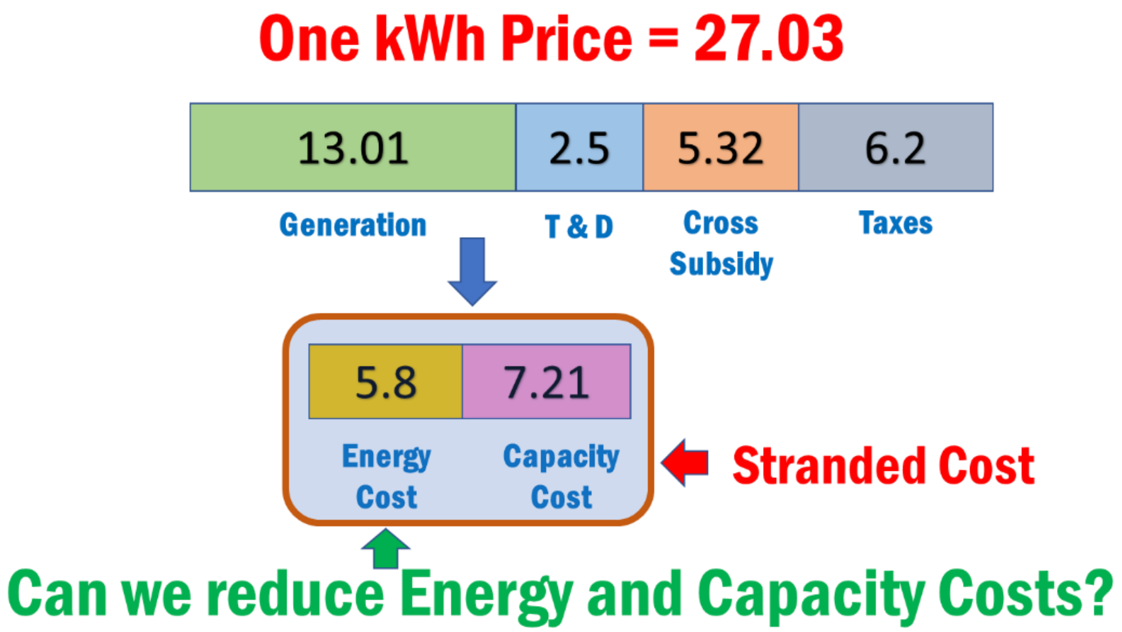


Table 1: Capacity and Energy Invoiced by Generators

S. No.	Fuel Ty	FY 2017-2018 (Rs. In Billions)		FY 2018-2019 (Rs. In Billions)		FY 2019-2020 (Rs. In Billions)		FY 2020-2021 (Rs. In Billions)	
1	WAPDA Hydel	25.6	3	60.7	.3	07.5	2.9	95.8	2.6
2	Thermal	8	19.5	60.5	165	0.1	77.8	31.7	58.6
3	Coal	37.4	4	81.7	112	199.5	80.5	205.6	201.9
4	Nuclear	7.3	9.1	71	9	5	9.8	91.3	11.3
5	IPP Hydel	0.6	0.5	4.5	.535	9.4	1.4	47.8	0.721
6	RFO	50.3	160	58.7	4.5	4.8	4.2	94	84.2
7	RLNG/Gas/HSD	62.7	208.8	09.3	97.7	32.5	02.2	126.1	304.3
8	Bagasse	.1	7.9	.3	.7	.3	.9	5.7	5
9	Wind	.8	0.3	5	9	85.8	0	76	0
10	Solar	0.03	12.9	.6	15.3	18.5	0	18.1	0
11	Import	0	0	0	0	0	5.5	0	5
12	Mixed	8	10.9	5.1	5.5	0.625	1.1	0.753	1.3
	Total	17.63	746.2	568.4	766.535	856.025	39.3	792.853	674.921

Pakistan's energy demand has substantial daily and seasonal variations, exacerbating the disparity between demand and available generation capacity. The Weighted Average Cost of Generation (WACG) has risen dramatically in recent years owing to the presence of a substantial amount of underutilized surplus generation capacity. Figure 2 shows the WACG forecasted till 2025 (Chaudhry, 2020). Figure 3 shows the share of the capacity and energy payments from 2015 till 2025(forecasted) (Chaudhry, 2020). Due to the increase in the capacity payments, the basket price of energy increases in Pakistan.

Figure 2: Projection of Weighted Average Cost of Generation (WACG) (Chaudhry, 2020)

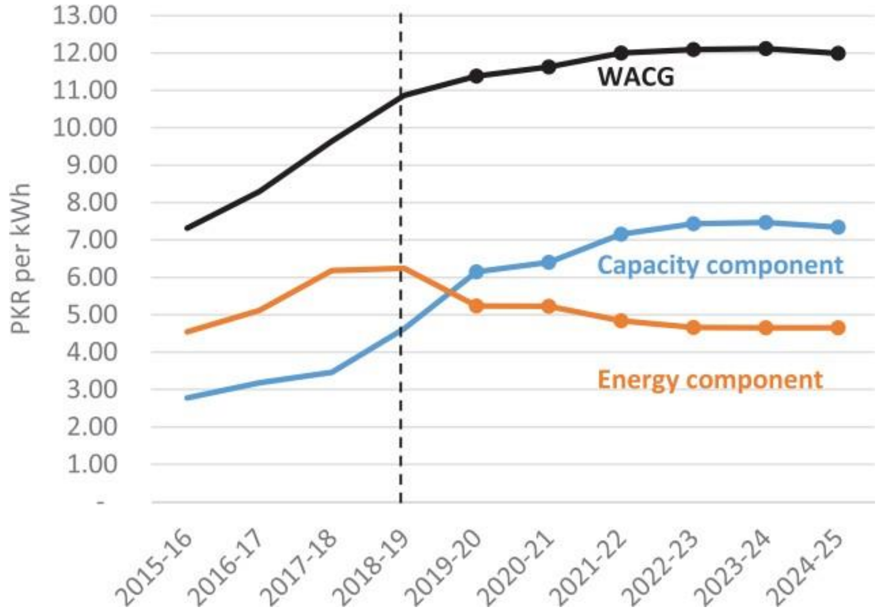
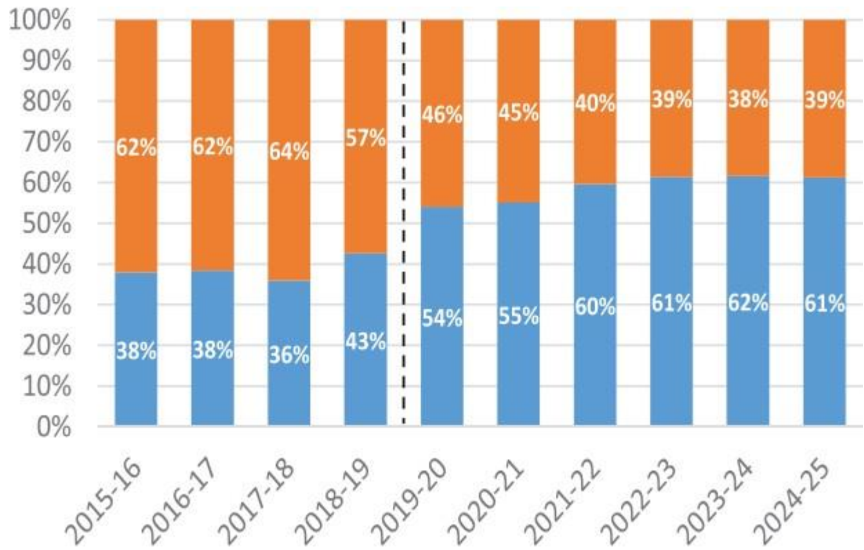
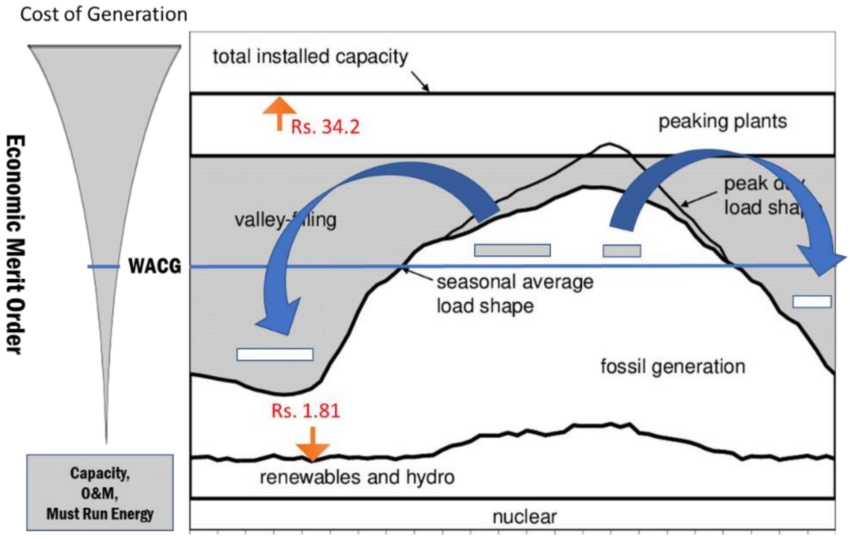


Figure 3: Percentage Shares of Capacity and Energy Components (Chaudhry, 2020)



It is critical to establish strategies to reduce the rise in WACG. To this end, the use of idle capacity during off-peak hours appears to be a viable option. It will result in a lower WACG because the energy requirements will be met using less expensive generation sources. To achieve this goal, there is a need to introduce a variety of non-seasonal loads that can be utilized during off-peak hoursto bridge the demand and generation capacity difference, as shown in figure 4. This is referred to as demand-side management (DSM). In order to encourage utilization of the idle generation capacity during off-peak hours, an incentive in the form of a mechanism of temporally variable tariff rates is needed. A flexible pricing approach like this generates a win-win situation for both users as well as electricity generation companies. The power sector increases its load factor by utilizing the surplus capacity during off-peak hours, while the consumers benefit from a lower price.

Figure 4: Valley Filling through Flexible Loads Using ToU Pricing



Pakistan does not have a framework in place to provide end-users with variable tariff rates. Therefore, this project builds a dynamic dashboard-based Time-of-Use (ToU) pricing tool for off-peak generation capacity utilization. It is worth noting that the project's goal is to provide a ToU pricing mechanism for various types of flexible load (Diaz, Ruiz, & Patino, 2017; Mullan, Harries, Bräunl, & Whitely, 2011; Swain, Lakhara, Khetan, Mishra, & De, 2021; Zhang, Liang, & Liu, 2017). We predict that by using the ToU pricing mechanism, lower tariff rates can be charged to end-users while at thesame time utility companies and other power sector entities maintain their revenue.

The United Nations established and endorsed the United Nations Sustainable Development Goals (UNSDGs) in 2015, which are a collection of 17 global goals aimed to be achieved by 2030. The illustration of all 17 goals is shown in Figure 5. These goals are an urgent call for action by all countries in a global partnership. The 13th goal is related to climate action, which calls for immediate action to prevent climate change and its consequences through emissions regulation and promotionof renewable energy development.

Figure 5: The United Nations Sustainable Development Goals

Pakistan is a signatory to the United Nations Framework Convention on Climate Change's (UNFCC) Paris Agreement. According to the agreement, the Government of Pakistan (GOP) is responsible for reducing its emissions and limiting global warming below 2 degrees Celsius, which experts and scientists consider to be a safe level. The Paris Agreement mandates all parties to do their best through National Determined Contributions (NDCs) and continue to strengthen their efforts in the coming years. The GOP has taken a lot of actions to reduce its emissions.

The UNFCC's 26th Conference of the Parties (COP-26) was held in Glasgow from October 31 to November 13, 2021. Many affluent countries failed to meet the prior climate financing target of USD 100 billion per year by 2020 to assist developing countries in transitioning to sustainable development at this summit. Several developing countries have made their climate obligations conditional on getting foreign support. The GOP has updated its NDC and proposes an aggressive goal of a 50 percent reduction in emissions by 2030 via conditional and voluntary contributions, with a 15 percent reduction in emissions from domestic resources and a further 35 percent reduction in emissions with foreign financial assistance.

The indicative generation capacity expansion plan (IGCEP) considers the influence of future electricity generation on carbon emissions. Carbon emissions from power generation in the countrytotal 0.353 kg-CO2/kWh in the fiscal year 2021 and are targeted to fall to 0.202 kg-CO2/kWh by theyear 2030, which is significantly lower than the average set by the Organization for Economic Co- operation & Development (OECD) (Planning, 2021).

The progress made towards the above-mentioned goals is detailed in this report. The literature review is discussed in section 2. The suggested ToU pricing mechanism is described in Section 3, and the result is illustrated in Section 4. Finally, policy implications for stakeholders, policymakers, and power sector professionals are presented.

LITERATURE REVIEW

The power sector's decarbonization poses many challenges (Davis et al., 2018). The energy transition involves expanding the use of RE and electrifying end-use sectors (industrial, commercial, or residential), both of which are necessary for long-term decarbonization and climate goals. Large proportions of RE and rapid electrification could jeopardize the system's reliability. In this environment, increased flexibility is required to alleviate potential supply and demand imbalances. DSM refers to harnessing flexibility not only on the supply side but also on the demand side (Carlos Fernández, 2019).

DSM can be described as the fraction of demand that can be reduced, increased, or shifted in a specific period of time to:

1. Encourage distributed generation (DG)
2. Reducing peak loads and seasonality
3. Reduction of power generation costs by transferring Load from high to low price periods

Inadequate planning for the electrification of end-use sectors can have a direct influence on the power system's reliability. This electrification may increase energy demand during peak hours, causing problems with peaking and ramping. To establish the feasibility of matching the growth of the demand profile with an increasingly variable generation mix, new demand forecasting methodologies and analyses will be required. The DSM can be utilized instead of expensive rapid ramping-up of energy to satisfy peak demand if an acceptable regulatory framework is in place.

Demand response (DR) can result in significant economic and environmental benefits (Chao, 2010; Hogan, 2009). Economic benefits are associated with reduced cost of generation during peak hours and decreased price volatility. According to a study (Bergaentzlé, Clastres, & Khalfallah, 2014), lowering the annual peak demand in the United States by 5% could result in annual savings between USD 5–10 billion. Typically, since peak demand is catered through fossil fuel-based generation sources, peak-load curtailment has environmental benefits through a reduction in emissions. Finally,reducing the peak load enables further integration of renewable sources in the energy mix that are often intermittent in nature (Hesser & Succar, 2012).

Numerous studies and experiments have been performed to gauge the efficacy of temporally variable tariff rates or ToU pricing for incentivizing electric vehicle (EV) charging during off-peak hours. The effect of EV charging during peak and off-peak hours has been analyzed in a study (Mullanet al., 2011) which shows the short and long-term benefits obtained through charging vehicles employing DSM or structured tariffs. In the short term, providing incentives for off-peak charging increases the utilization of idle transmission capacity and cheaper, more efficient base-load generation capacity. In the long-term, the hefty investment needed for generation capacity to cater to higher peak load can be avoided.

Domestic refrigerators have also been widely investigated as flexible load. In a study (Taneja,Lutz, & Culler, 2013), a flexible electrical load in the form of a domestic refrigerator, augmented witha thermal storage system, was developed. The results indicate that the prototype can respond to time-of-use tariffs to reduce summer refrigeration electricity costs by up to 13% on the consumer end while decreasing expenditure on the utility side by flattening out the peak.

Water Booster Pressure Systems (WBPS) are becoming popular as a flexible load (Diaz et al., 2017). A dynamic model for a WBPS was developed in order to evaluate it as a flexible load for DR applications. It is shown that the WBPS can operate as a flexible load by changing the pressure set point and has achieved 27% energy efficiency through DR without affecting the water flow in the building.

Water pumping and storage systems (WPSSs) are classified as flexible load (Lopes et al., 2020). A case study was conducted involving a real-world WPSS in which energy flexibility was employed to lower electricity prices. The collected data indicates that savings of around 16% can beachieved while lowering pumping cycles by 57%.

METHODOLOGY

WACG is determined by a thorough data collection process that culminates in a dashboard interface. The collected data is processed in a series of processes in order to extract meaningful information for WACG calculation. Each stage is described in detail below.

3.1 Data Collection

LUMS Energy Institute (LEI) has signed a memorandum of understanding (MoU) with Power Information Technology Company (PITC), granting LEI access to real-time generation and demand data from across the country at a one-hour granularity. The data consist of all the relevant information about the machine loading, active power supply, reactive power supply, peak power supply, load management (forced and scheduled outages), and daily log sheets at one-hour granularity. Similarly, LEI has access to real-time generation data and real-time generation capacity data through its MoUs with other entities in the power sector. The relevant data for merit order according to which various generation sources are utilized has been provided by NPCC and NTDC. The provided merit order contains the price of a generation of electricity from each source and its corresponding structure of capacity payments. The CPPA provides data on energy and capacity payments for the power plants. This study makes use of the above-mentioned data sets, which include but are not limited to hourly energy generation and demand, monthly energy generation costs, and monthly capacity payments for the fiscal year 2020-21. The raw data sets were provided in MS Excel (.xlsm) format. Furthermore, a report by NREL, and NVE was used to gather emission statistics for various power generation facilities. Based on the power generated by various power plants, the associated cost of carbon emissions has been determined.

3.2 Data Synthesis

Data analysis is a process of scrutinizing, cleaning, transforming, and modeling data to discover useful information, reach conclusions, and support decision-making. To this end, an automated tool for data cleaning has been developed using the R programming language. The tool extracts relevant data from the extensive data sets provided by the power sector entities and performs data cleaning. It yields hourly energy generation data in .csv format for further analysis andstudy. The detailed and rigorous process of data synthesis is outlined below

1. The foundation of data synthesis is laid by data preprocessing using a combination of Rprogramming language and MS Excel.

2. The raw data is then scrutinized for outlier anomaly detection and removal.

3. As a remedial measure, missing values are estimated through mathematical calculations.

4. Once the data sets are cleaned, and missing data is evaluated, unification of data from various formats is performed for the purpose of standardization.

5. A sanity check is performed to assess the justifiability of data so that irrational values can beremoved.

6. The exploratory data analysis is performed, which concerns tentative qualitative andquantitative visualization of data.

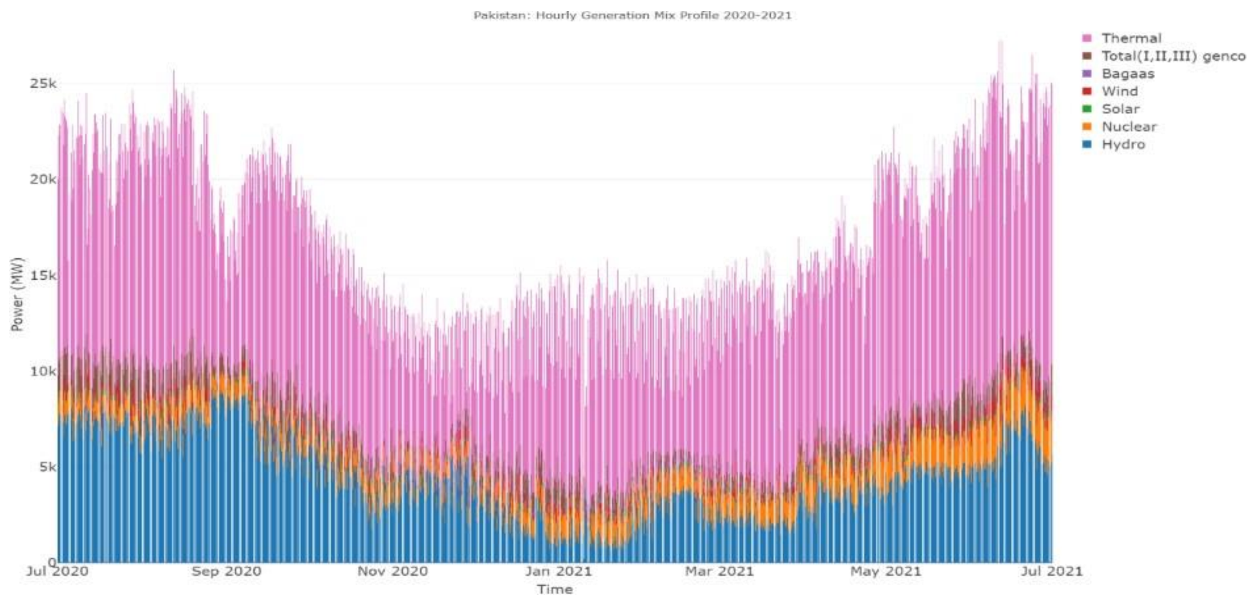
The processed data is in a single file, irrespective of the size of input data or the number of input files of raw data. It contains hourly generation data for each source of generation.

3.3 Load Data Analysis

The synthesized data of the fiscal year 2020-21 is used for load analysis. The generation profile for the year is provided in figure 6 below. The analysis of data yields insights regarding classifications of generation profiles based on seasons. This classification is based on generation usage and enables the development of recommendations for NEPRA for devising tariff models.

According to the analysis of the data, hydel power plants are one of the most cost-effective sources of generation, due to which they are utilized as 'must-run' sources to cater baseload. Additionally, these sources have a high ramping rate employing that are used as peaking sources of generation to cater peak load. Furthermore, the analysis reveals that Furnace Oil and Diesel-based power plants also contribute significantly in meeting peak demand, but their cost of generation is high compared to most other sources of generation.

Figure 6: Pakistan's Hourly Generation Profile FY 2020-21



3.4 Analysis on Flexible Load Growth

The identification of flexible loads is a key aspect of this study. Load flexibility is essentially about shifting the timing of energy consumption to reduce stress during peak demand periods. Many loads can be shifted to off-peak hours. These loads include water pumps, tube wells, refrigerators, heating, and cooling systems, EV charging, dishwashers, washing machines, and many other industrial processes. Our task for this part was to figure out all such possible loads, keeping in view that such loads do not increase the daily load peaks.

Annual load data of different sectors, including Domestic, Commercial, Agriculture, Industrial, Public Lighting, and Bulk consumers, was acquired through the above-mentioned liaison mechanisms of LEI. The data sets provide the annual sector-wise growth of load from the year 2003to 2021.

As per the data, the total energy consumed in the fiscal year 2020-2021 was 132,299 GWh. The share of energy consumption by agricultural tube wells was 10,115.32 GWh. Moreover, the share of industrial Load reached 24,664.95 GWh for the fiscal year 2020 2021(NEPRA, 2021). Figure 7-9 shows the current and forecasted generation mix for each category. These figures show that the share of renewable energy sources in the energy mix increases over time. Solar capacity is 569 GWh in 2021 and will be increased to 1,916 GWh in 2025. Similarly, as forecasted by the NTDC (Planning, 2021), the share of other RE sources will increase, as shown in table 2.

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Figure 7: Generation Mix in 2021 Category-wise

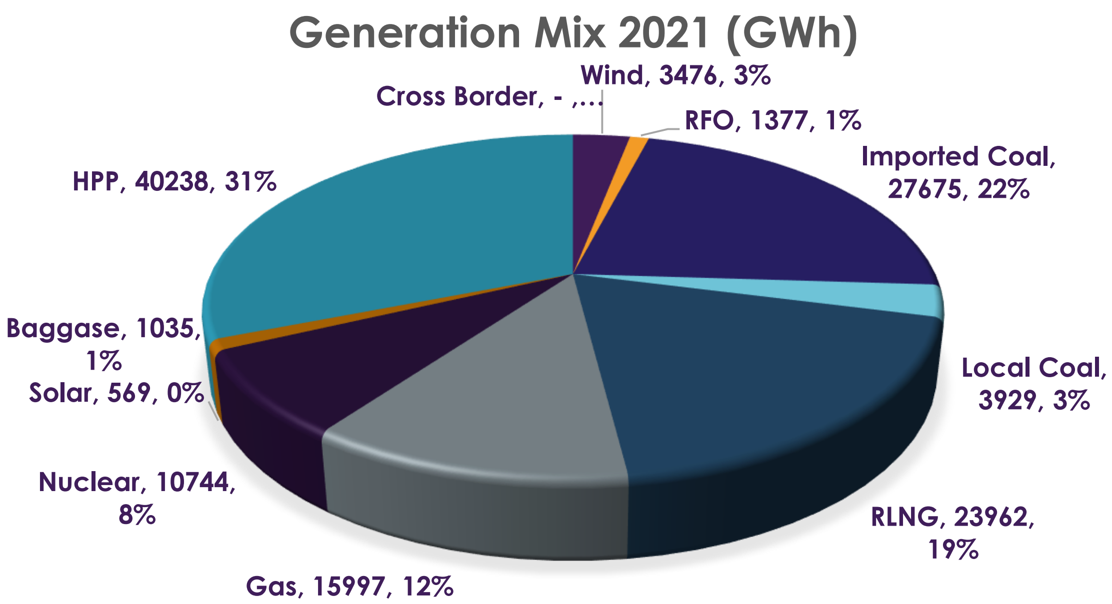


Figure 8: Forecasted Generation Mix by 2025 Category-wise

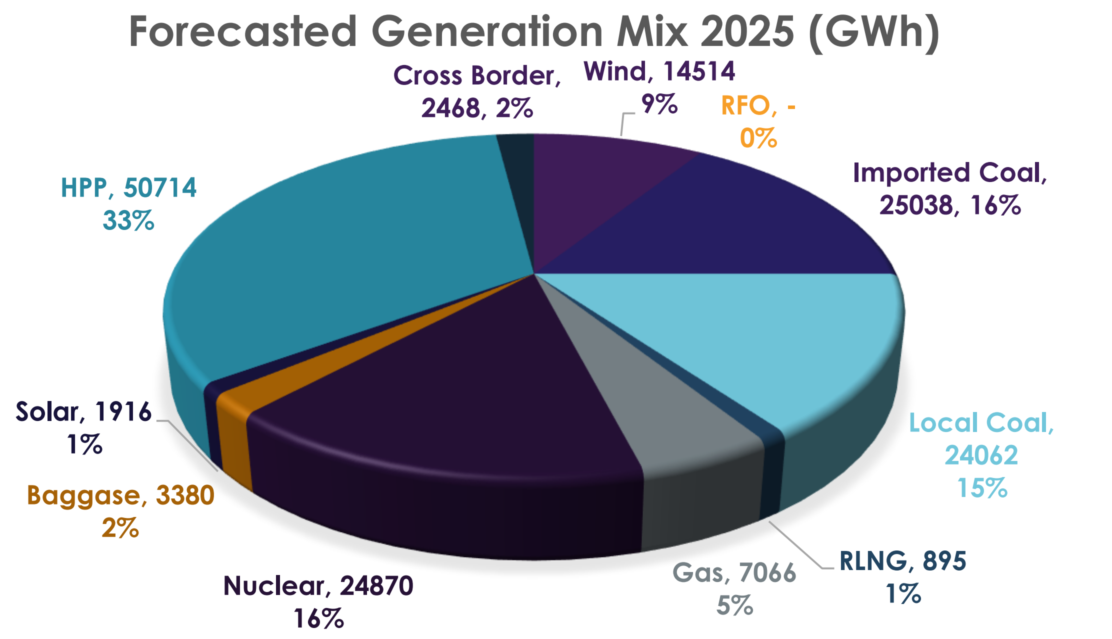


Figure 9: Forecasted Generation Mix by 2030 Category-wise

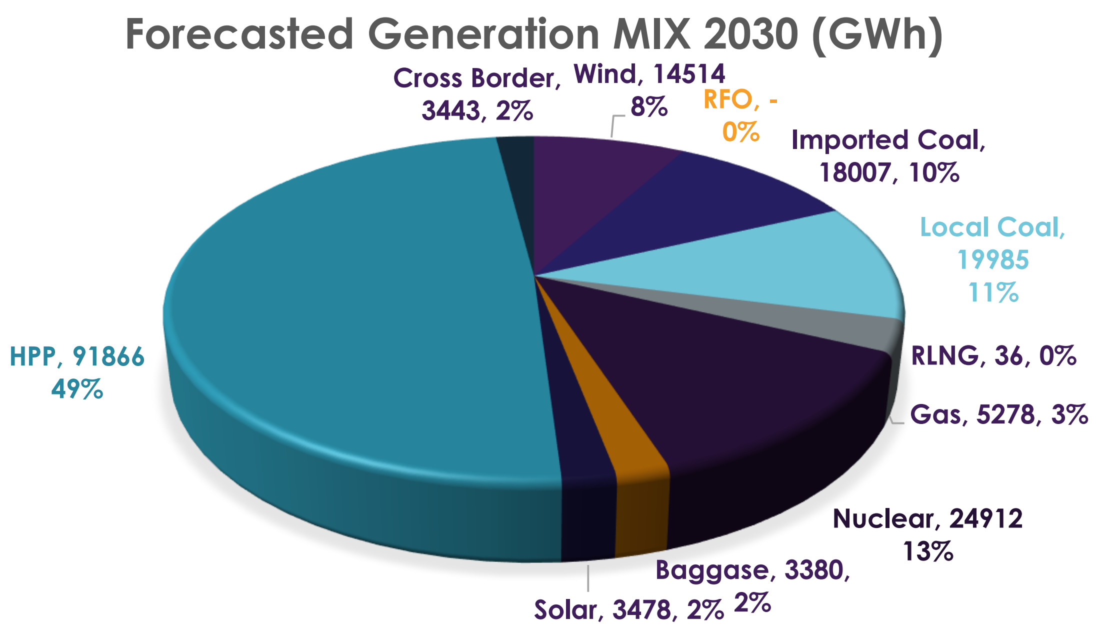


Figure 10 and figure 11 illustrated the forecasted category-wise sale for 2022-23 and 2027-28 in GWh, respectively (Planning, 2019). As seen, the share of commercial Load will be increased in 2027-28.

Figure 10: Forecasted Category-wise Sale 2022-23 (GWh)

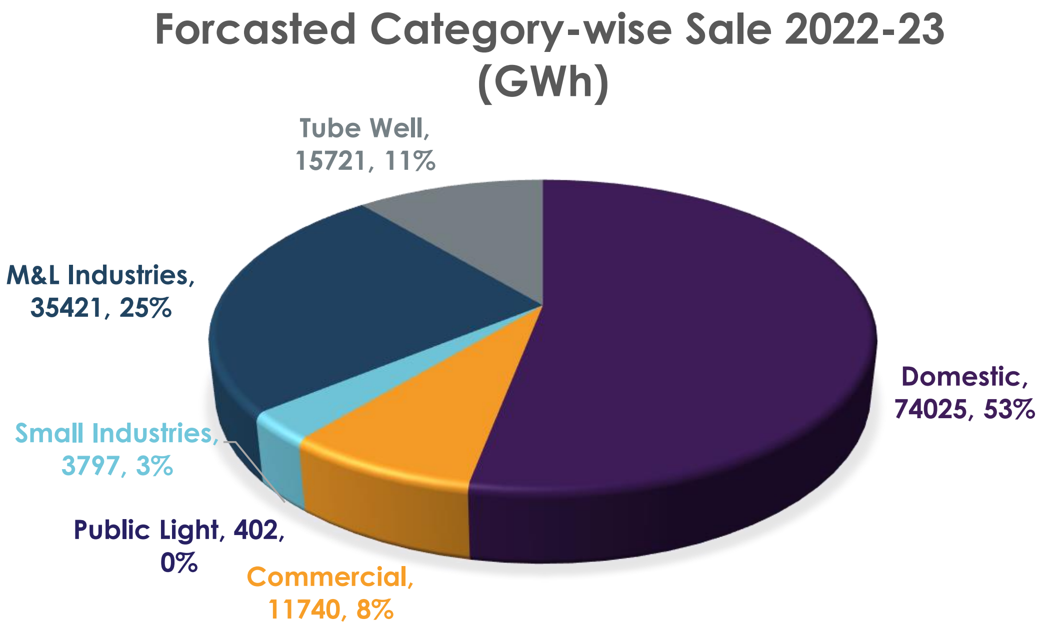


Figure 11: Forecasted Category-wise Sale 2027-28 (GWh)

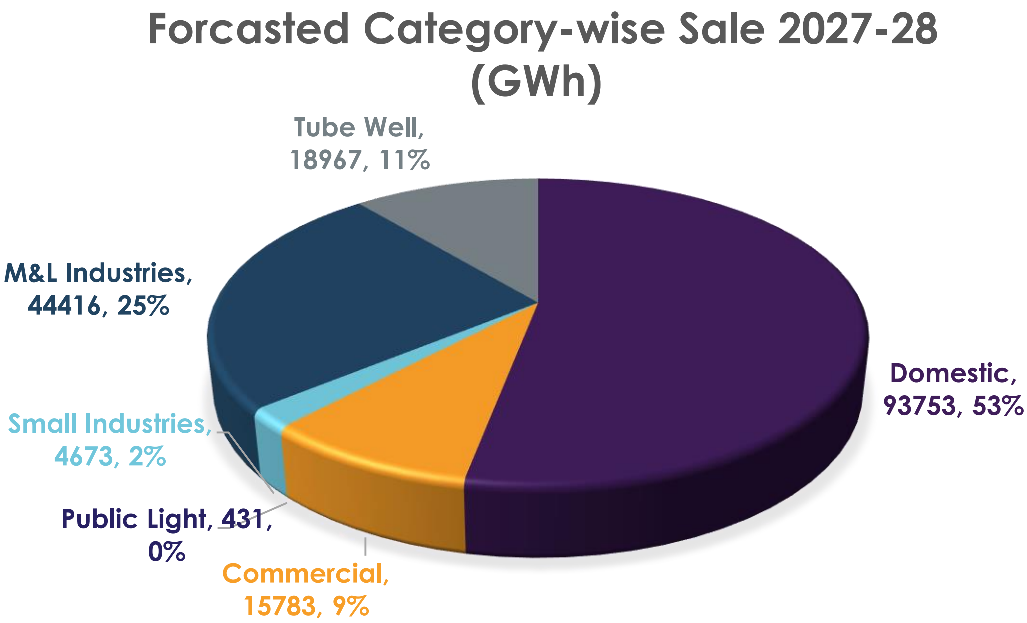


Table 2: Forecasted Category-wise Sale of Energy (GWh)

Year	Domestic		Commercial		Public Light		Small Industries		M&L Industries		Tube Well		Total	
	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R
2017-18	59258		8519		376		3012		24326		12639		108130	
2018-19	61626	4.0	9037	6.1	381	1.4	3160	4.9	26309	8.2	13534	7.1	114047	5.5
2019-20	64355	4.4	9676	7.1	386	1.4	3313	4.8	28832	9.6	14045	3.8	120607	5.8
2020-21	67293	4.6	10335	6.8	391	1.4	3470	4.7	31342	8.7	14583	3.8	127414	5.6
2021-22	70637	5.0	11026	6.7	396	1.4	3631	4.6	33311	6.3	15139	3.8	134140	5.3
2022-23	74025	4.8	11740	6.5	402	1.4	3797	4.6	35421	6.3	15721	3.8	141106	5.2
2023-24	77611	4.8	12557	7.0	407	1.4	3966	4.5	37324	5.4	16324	3.8	148189	5.0
2024-25	81337	4.8	13373	6.5	413	1.4	4139	4.4	39030	4.6	16949	3.8	155241	4.8
2025-26	85260	4.8	14144	5.8	419	1.4	4314	4.2	40814	4.6	17597	3.8	162548	4.7
2026-27	89434	4.9	14947	5.7	425	1.4	4492	4.1	42565	4.3	18269	3.8	170132	4.7
2027-28	93753	4.8	15783	5.6	431	1.4	4673	4	44416	4.4	18967	3.8	178023	4.6
Ave. Growth (2018-28)	4.7		6.4		1.4		4.5		6.2		4.1		4.7	

According to our analysis, the most flexible load in Pakistan is agricultural tube wells, followed by soft industrial load. Our analysis yields that the load of tube wells, which accounts for 10 percent of the total energy consumption, is the most suitable for transition to off-peak hours. It is important to mention that to support the agriculture sector; the government is already giving subsidies on tube wells' electricity tariffs. This subsidy will become redundant if the incentive for operating them in off-peak hours is provided. This will save cost in terms of subsidies for the government while offering lower tariffs for the farmers within off-peak hours. Furthermore, almost 5 percent of the total load is industrial load. According to our analysis, 5 percent of the industrial Load is estimated to be soft load, which can be shifted to off-peak hours.

3.7 Analysis of WACG Model

The Weighted Average Cost of Generation (WACG) has two components: the capacity component and the energy component. It is given by

$$WACG = \frac{Capacity\ Component + Energy\ Component}{Energy\ Utilization} \quad (1)$$

The WACG is represented in general by Equation 1. In the case of Pakistan, capacity payments must be paid regardless of energy payments. The modeled equation for calculating WACG is shown in Equation 2.

$$WACG = \frac{Capacity\ Payments + \sum_{P=1}^{n} Energy\ Payments_P}{\sum_{p=1}^{n} Energy\ Utilization_{\ p}} \qquad n \le z \quad (2)$$

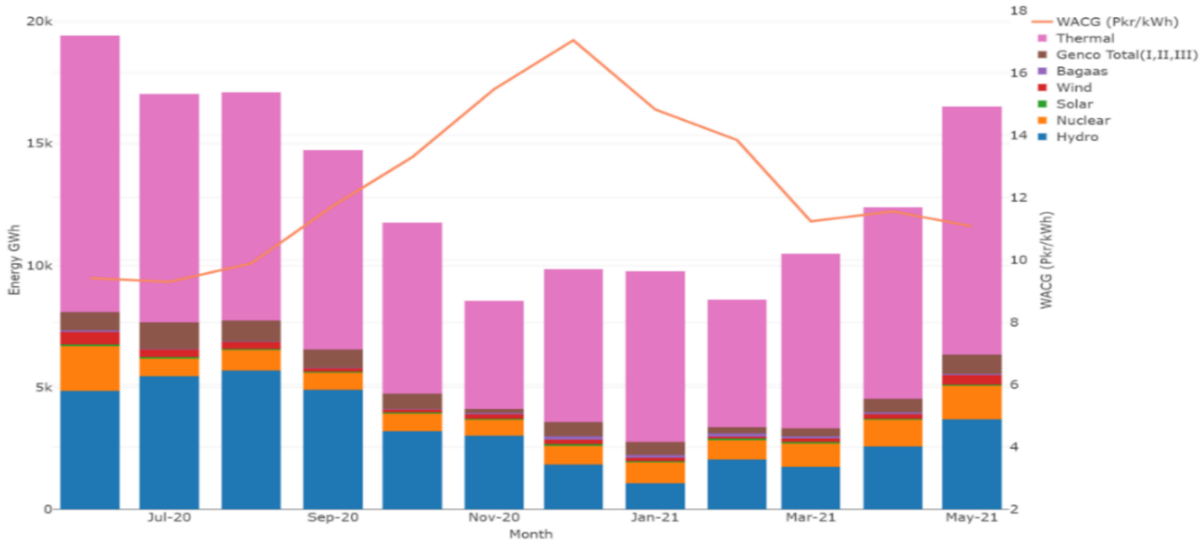
The number of power plants is represented by the value of n. z is the total number of power plants. P denotes plant number in terms of merit order for the given hours. Equation 3 represents the WACG for a month based on an hour-to-month calculation.

$$WACG = \sum_{h=1}^{720} \frac{Capacity\ Payments + \sum_{P=1}^{n} Energy\ Payments_P}{\sum_{p=1}^{n} Energy\ Utilization_{\ p}} \qquad n \le z \quad (3)$$

Where h represents the number of hours.

The available generation capacity component is fixed for each month. If the energy usage is increased, it will decrease the WACG. Therefore, it is advisable that Load is transferred to 'valleys' of load and generation profile, where the gap between available generation capacity and the load demand is maximum. The variation in WACG for the fiscal year 2020-21 is given in figure 12 below.

Figure 12: Variation in WACG for FY 2020-21



RESULT AND DISCUSSIONS

The WACG was estimated using the R programming language tool. The tool uses a defined data set to determine the ideal value of the WACG at a one-hour granularity. The cost of generation for each power plant is apparent in relation to its utilization at specific hours. Each power plant's associated emissions are also calculated.

4.1 Energy Analytics Visualization in Dashboard

The cost of generation is divided into two parts. One is the cost of energy, which is determined by the power plants that are available and ready to serve. The other part is the capacity cost, which is determined by the plant capacity that is available in that hours to serve the load. The energy and capacity components have hourly and monthly variations, respectively. Both components are included in the developed tool. These two components are used to calculate the WACG. The developed tool informs us of the generation's value on the generation bus. Figure 13 illustrates the designed dashboard of the developed tool. The tool has several tabs. The hourly generation cost on the generation bus is depicted in Figure 13. The computed cost for 11 a.m. on July 1, 2020, was 8.78 rupees per kilowatt-hour, with an energy cost of 4.56 rupees per kilowatt-hour and a capacity cost of 4.22 rupees per kilowatt-hour. The cost of energy generation is the total 20.86 GWh of energy sold by the DISCOs for 95.06 million rupees at that specific hour. The capacity payments are handled in a separate part. By hovering over the cursor, users can view all the power plants that are used to serve this Load and see how much energy each one provides and how much it costs. The dashboard's interface provides all similar and other details in a convenient manner to the users.

Figure 13: Designed Dashboard at Shinyapps.io

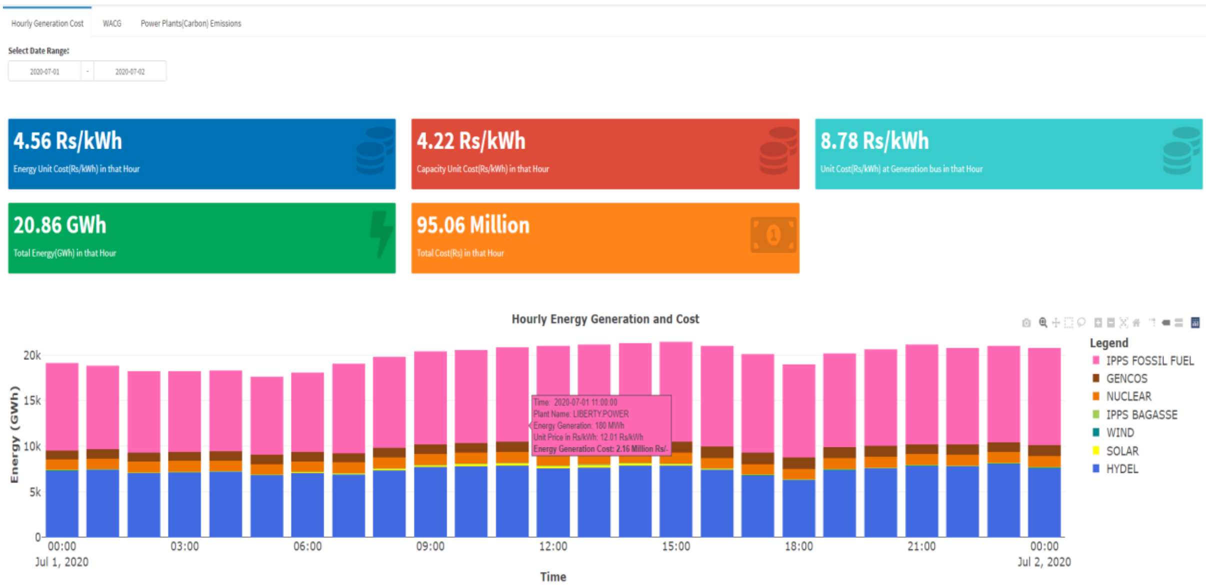


Figure 14 depicts a map of power generation sources, with the circle size indicating the relative power output of the power plants at 11 a.m. on July 1, 2020. The size of circle is variable according to the power output of the power plants at the specific time interval.

Figure 14: Map of the Power Plants that Utilized at the Particular Hour

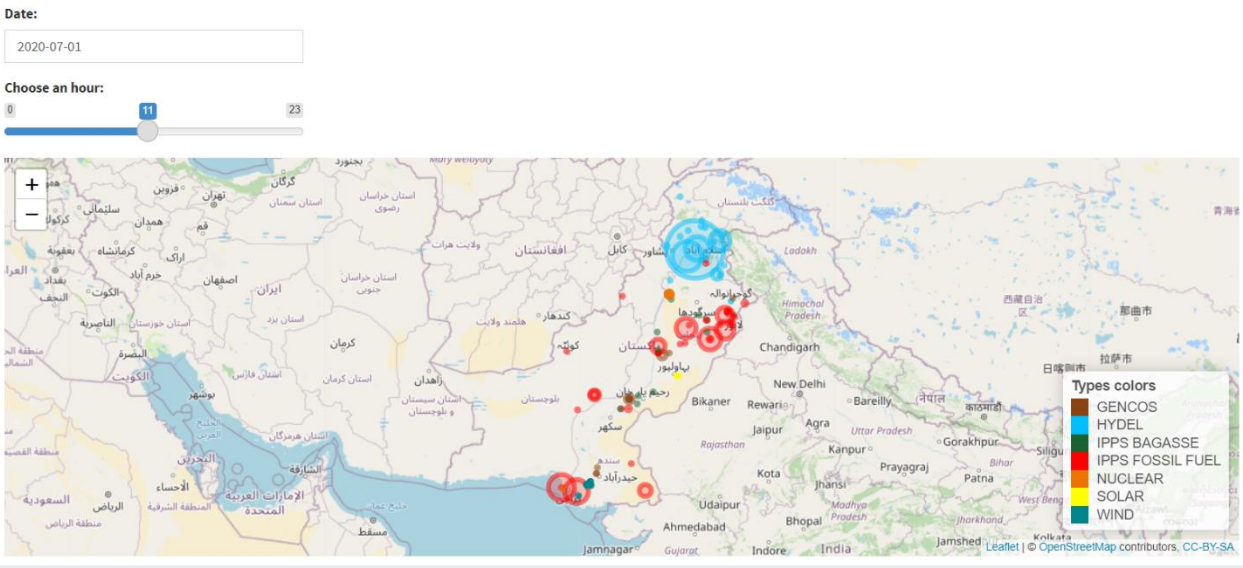


Figure 15: Total Hourly Energy Generation and Its Associated Cost

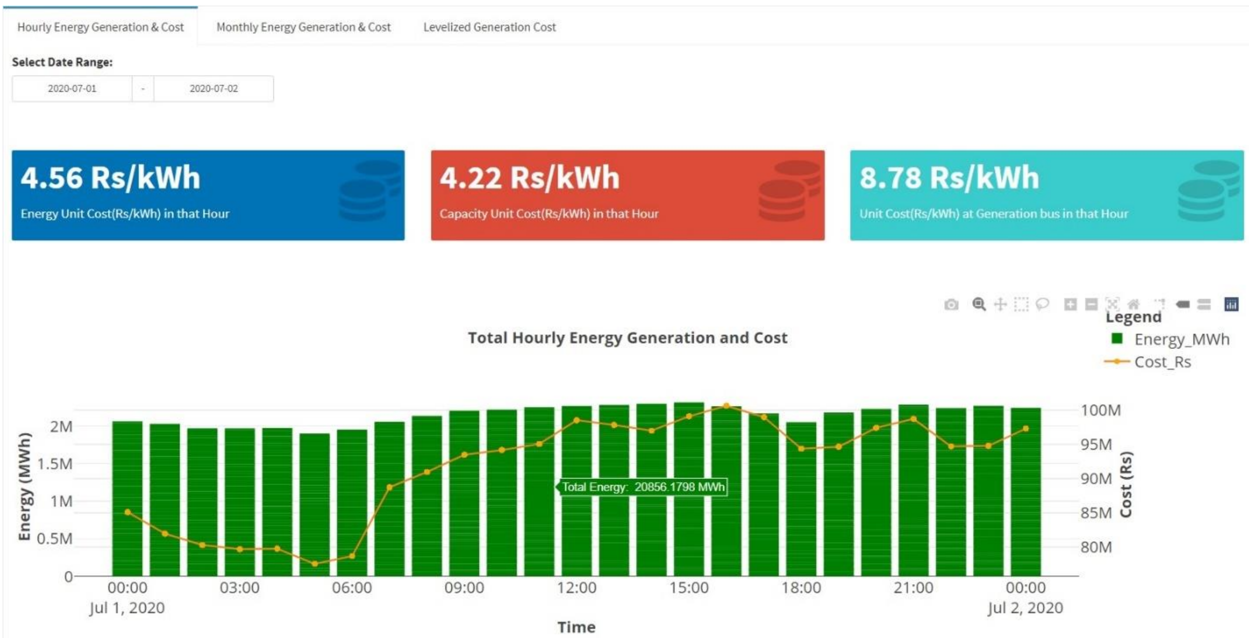


Figure 15 presents the total hourly generated energy and its cost over the following 24 hours. By scrolling the cursor, the value of energy generated in MWh and its generation cost can be computed. Energy cost, capacity cost, and the total cost of generation are represented by the values in the boxes. Through this approach, we can calculate the cost of energy and capacity on an hourly and daily basis. Figure 16 depicts a month's total energy generation. The graph represents the fiscal year 2020-21. The figure's upper green box shows energy generation for the month of July 2020. The percentage share of each type of generation source can be seen and located by using the cursor.

Figure 16: Category-wise Total Monthly Energy Generation

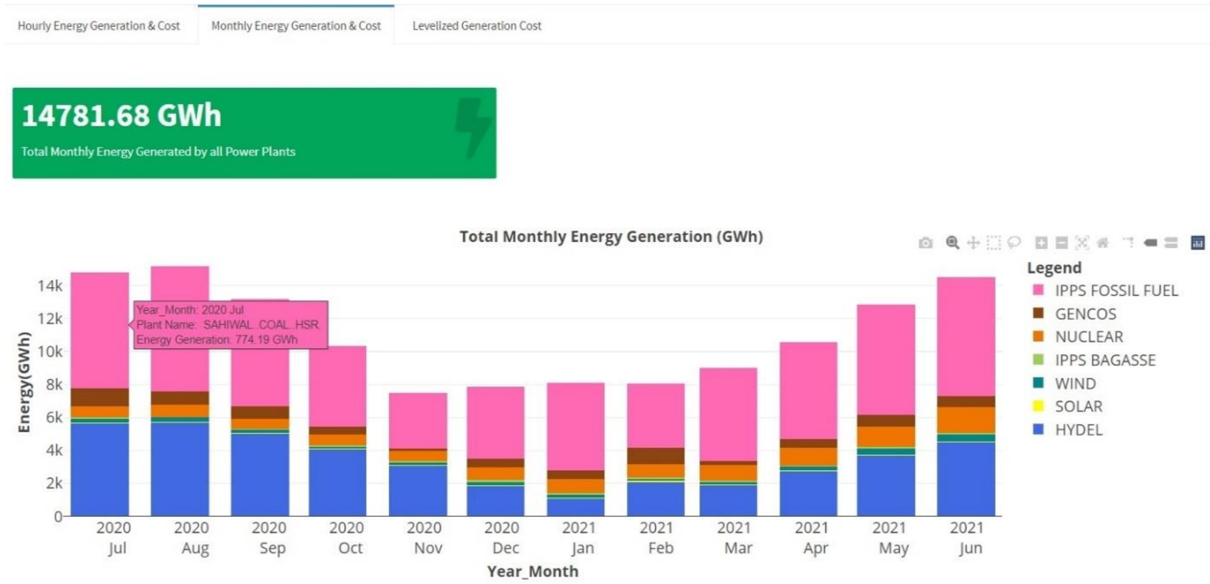


Figure 17: Category-wise Total Monthly Energy Cost

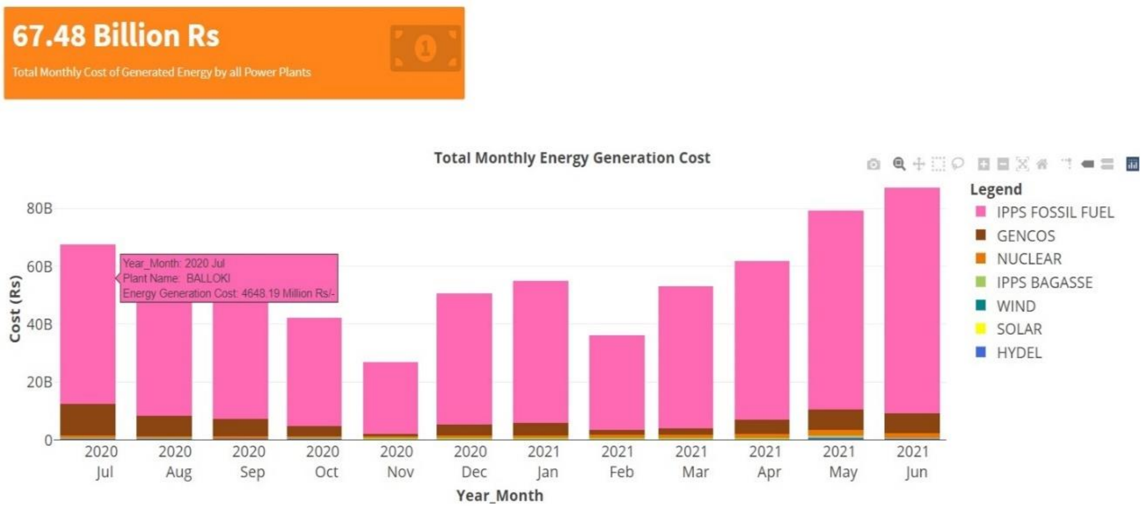
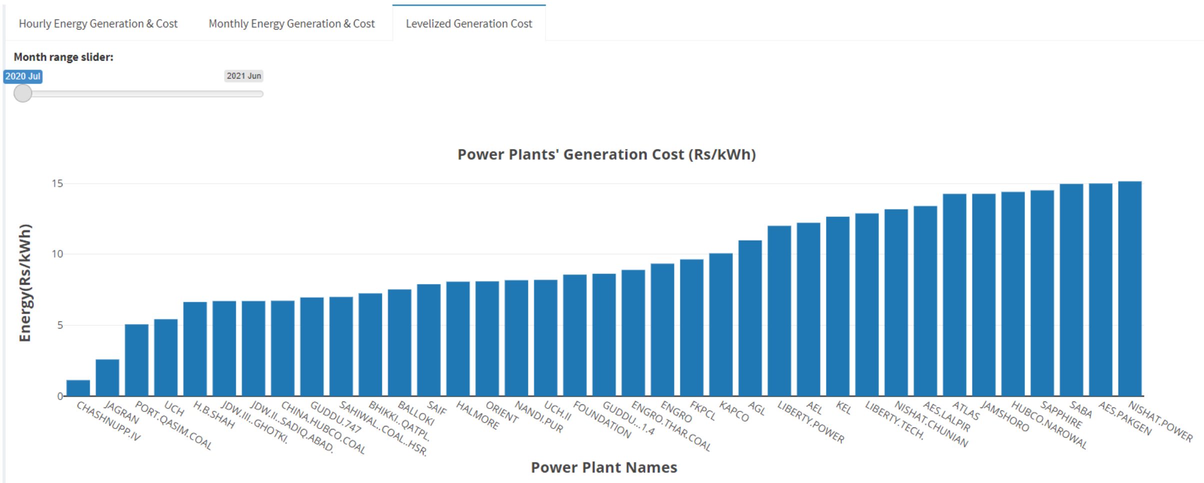


Figure 17 illustrates the cost of generation on a monthly basis. The statistics depict the cost from different generation sources. As the figure indicates, the cost of generation from IPPs is extremely expensive in comparison to Hydel. The orange box depicts the cost of generation of the electricity generated by the power plants during the month of July 2020. Figure 18 shows the levelized cost of generation for each power plant in the month of July 2020, expressed in rupees per kilowatt-hour. According to the figure, the cost of generation for each power plant ranges from a few 'paisa' up to around 35 rupees.

Figure 18: Generation Cost for each Power Plant (Rs/kWh)



The weighted average cost of generation is calculated based on the data sets. Many cases and scenarios can be developed; however, three cases will be highlighted in this report, with each case containing four scenarios based on the load pattern and shifting of peak demand to off-peak hours. For the purpose of simplification, the report computes and displays the hour shifting. However, the tool can shift a multi-hour input to a multi-hour output. The next subsection illustrates one case, while the other two cases are presented in the appendices of this report.

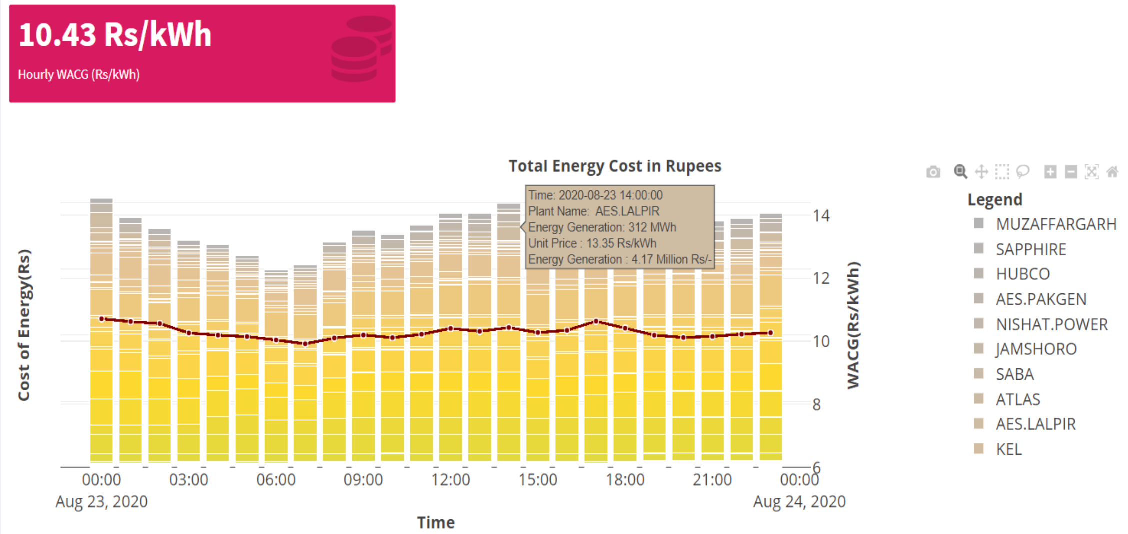
4.2 Case A: 5% Load Shifting from Peak-hours to off-Peak hours

Case A illustrates a 5% load shift from peak to off-peak hours. The cost savings and emission reductions associated with load shifting are discussed in detail below for four different scenarios. Each scenario has a unique load pattern and peak period. Each scenario is discussed in depth below.

Scenario 1- Annual Peak Month (Highest Load)

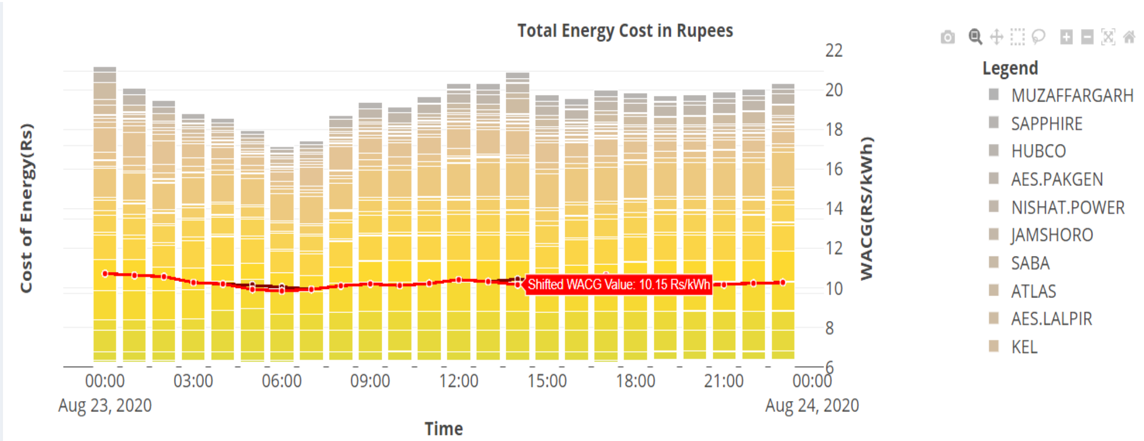
The annual peak in the fiscal year 2020-2021 occurred on 23 August 2020. The WACG at 2 pm on the peak day is 10.43 Rs/kWh. Figure 19 shows the total energy cost for all power plants that have been utilized on this day. The red line on the bar graph depicts the WACG values throughout the course of 24 hours.

Figure 19: The Generation Cost of each Power Plant and WACG for Each Hour



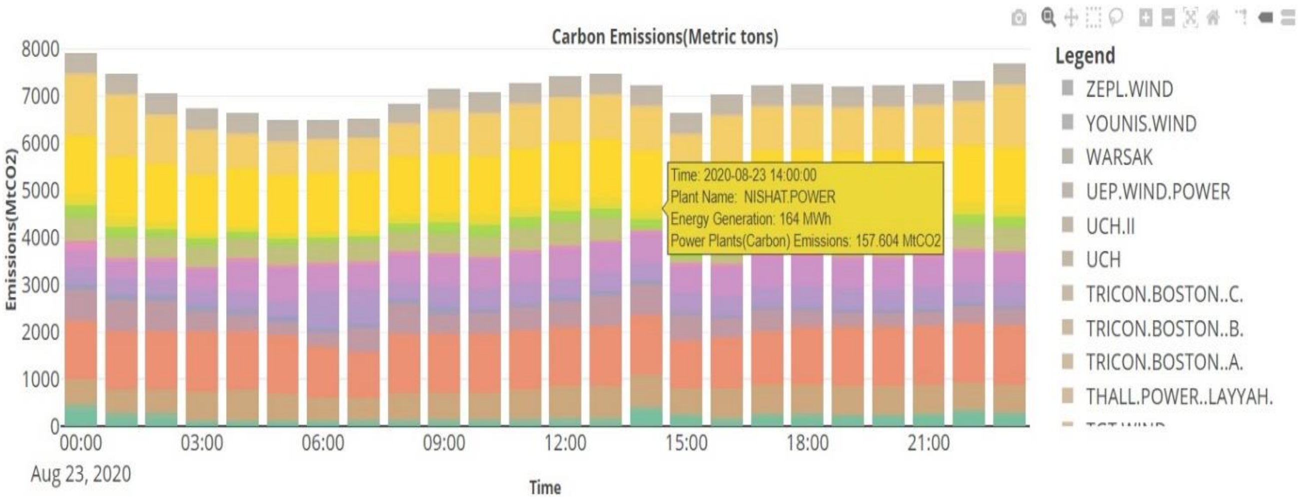
The Power sector may save 17.18 million rupees on a single occasion by moving the 5% load from peak to off-peak hours. If this load is moved for a month, the power sector can save 514.41 million rupees from the shifting, as shown in figure 20. The shifted WACG is 10.15 Rs/kWh, while it was 10.43 Rs/kWh prior to the shift.

Figure 20: Total Energy Cost and Shifted WACG Value



When power plants are switched from peak to off-peak hours, the power sector may lose or gain in terms of carbon credits. The power sector emits 7,679.17 metric tons of CO_2 during peak hours, but when the demand shifts by 5% to off-peak hours, CO_2 emissions decay to 7214.92 metric tons. Figure 21 shows the carbon emissions of all the power plants that are in use at that hour.

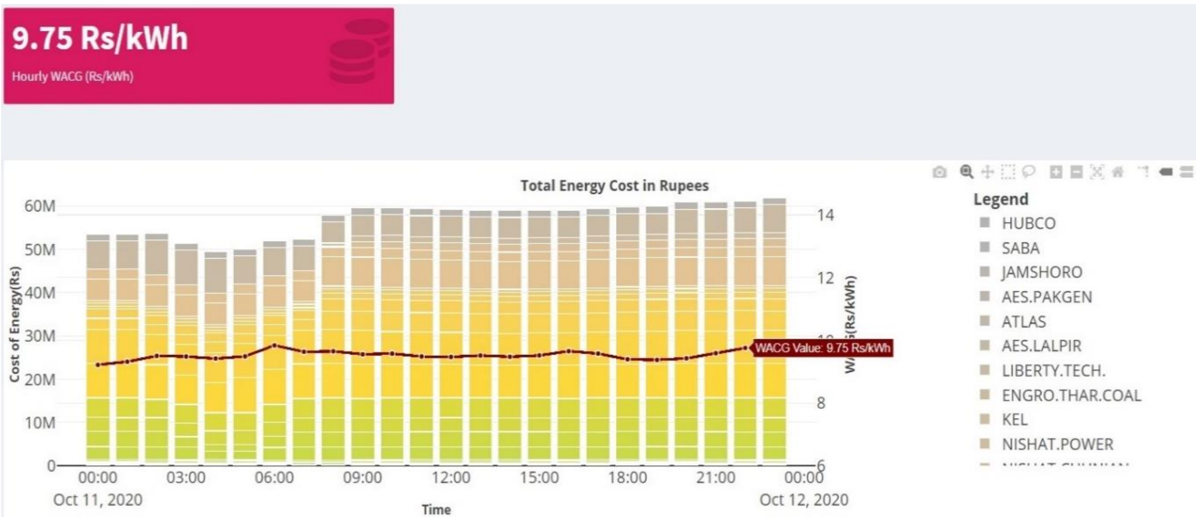
Figure 21: Emission Plot for Various Power Plants



Scenario 2- Shoulder Month (Average Load Month)

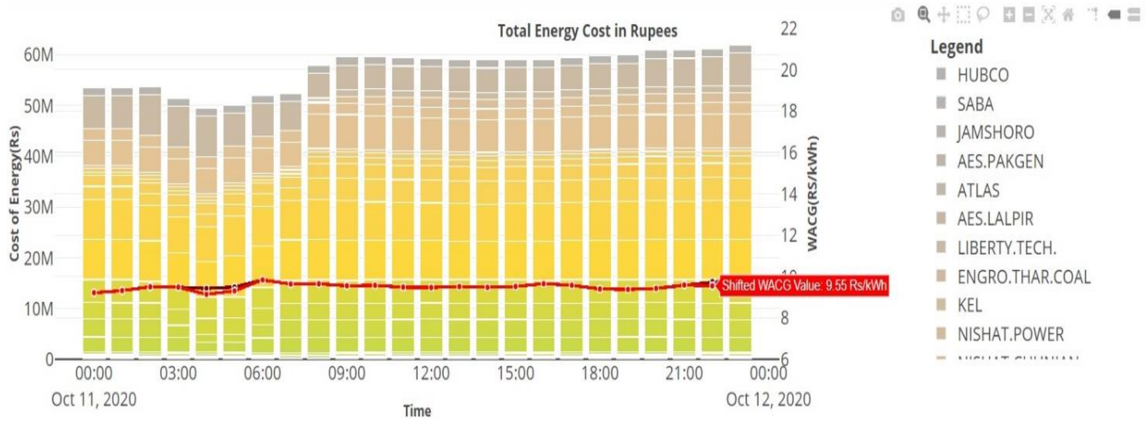
In the fiscal year 2020-2021, the average Load occurred on October 11, 2020. At 11 p.m. on this day, the WACG is 9.75 Rs/kWh. Figure 22 depicts the overall energy cost for all power plants in use on this particular day. The WACG values throughout the course of 24 hours are depicted by the red line on the bar graph.

Figure 22: The Generation Cost of Each Power Plant and WACG for Each Hour



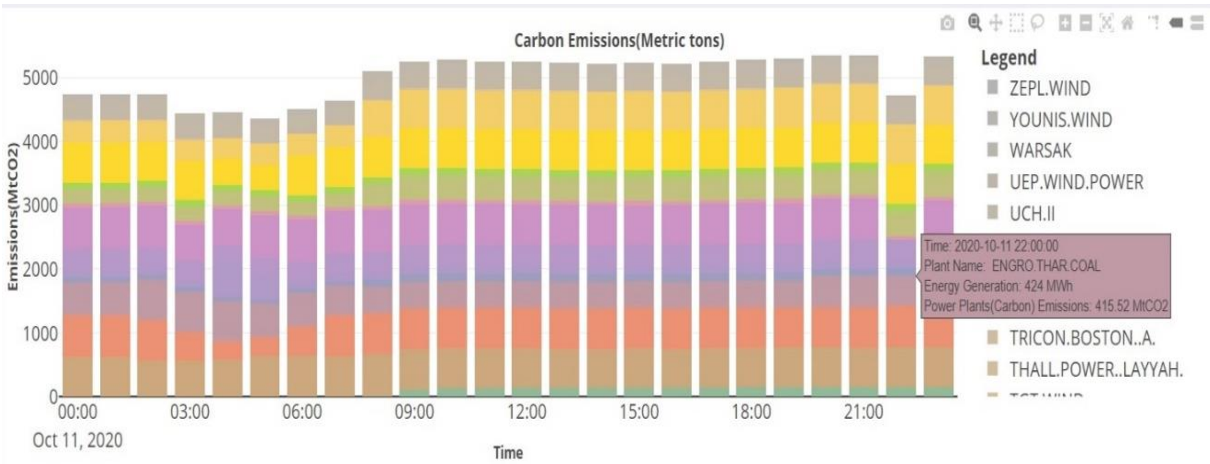
By shifting the 5% load from peak to off-peak hours, the power sector can save 8.89 million rupees on a single occasion. As indicated in figure 23, if this Load is shifted for a month, the power sector can save 266.68 million rupees. The repositioned WACG is 9.55 rupees per kWh, down from 9.75 rupees per kWh prior to the shift.

Figure 23: Total Energy Cost and Shifted WACG Value



When power plants are switched from peak to off-peak hours, the power sector may gain roughly 30.47 million rupees per month in carbon credits for the month of October. The power sector emits 5357.81 metric tons of CO_2 during peak hours, but when the demand shifts by 5% to off-peak hours, CO_2 emissions decrease to 4703.51 metric tons.

Figure 24: Emission Plot for Various Power Plants



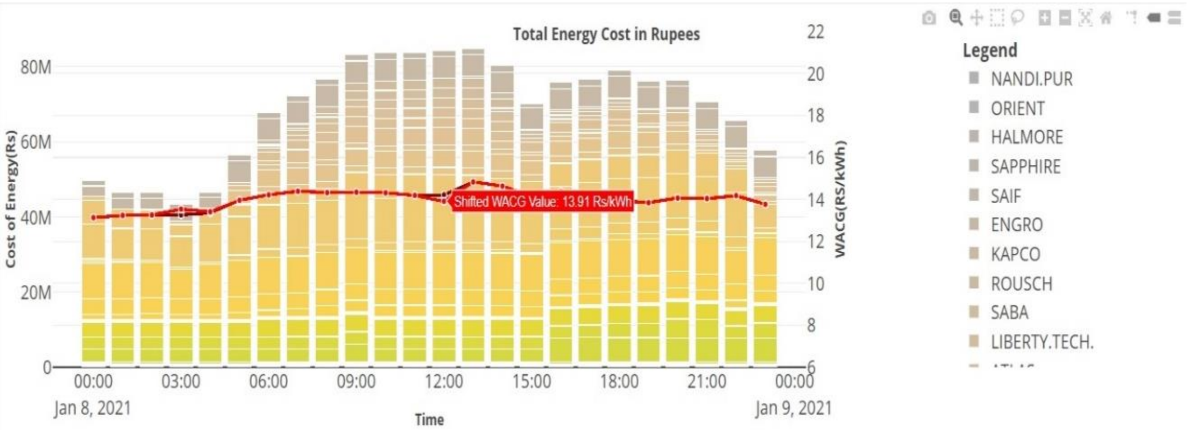
Scenario 3- Lowest Load Month

On January 8, 2021, the lowest Load for the fiscal year 2020-2021 was recorded. At 1 p.m. on that day, the WACG was 14.83 Rs/kWh. Figure 25 depicts the total energy cost for all power plants in use on this day. The WACG values throughout the course of 24 hours are depicted by the red line on the bar graph.

Figure 25: The Generation Cost of each Power Plant and WACG for each Hour

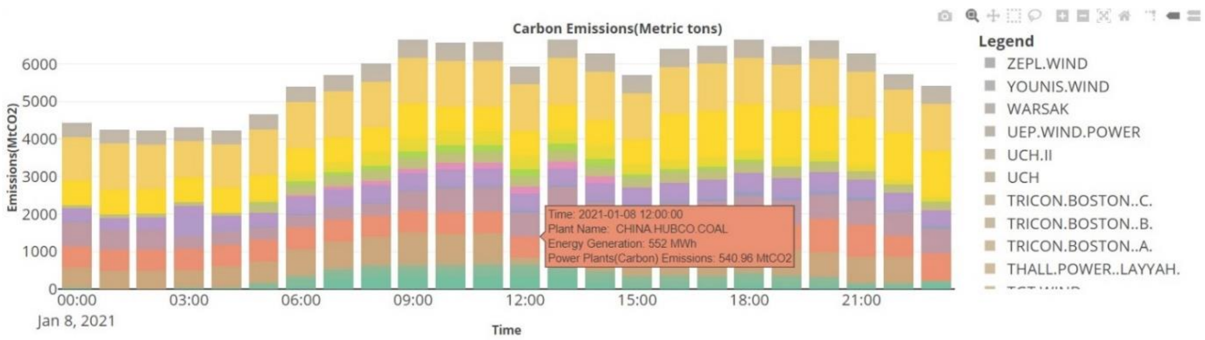
The power sector might save 1.78 million rupees on a single occasion by shifting the 5% load from peak to off-peak hours. If this Load is moved for a month, the power sector will save 53.48 million rupees, as shown in figure 23. The WACG now costs 13.91 rupees per kWh, compared to 14.83 rupees per kWh before the shift.

Figure 26: Total Energy Cost and Shifted WACG Value



The power sector might gain around 27.52 million rupees per month in emission trading value if power plants are shifted from peak to off-peak hours in January. During peak hours, the power sector releases 6586.73 metric tons of CO_2, but when demand changes by 5% to off-peak hours, CO_2 emissions drop to 5915.99 metric tons. Figure 27 depicts the emissions from each power plant used on this day.

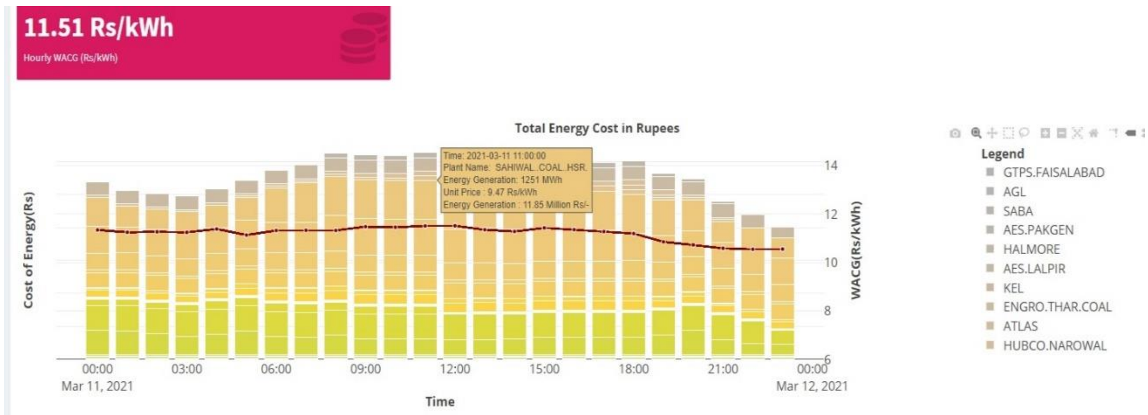
Figure 27: Emission Plot for various Power Plants



Scenario 4- Shoulder Month (Average Load Month)

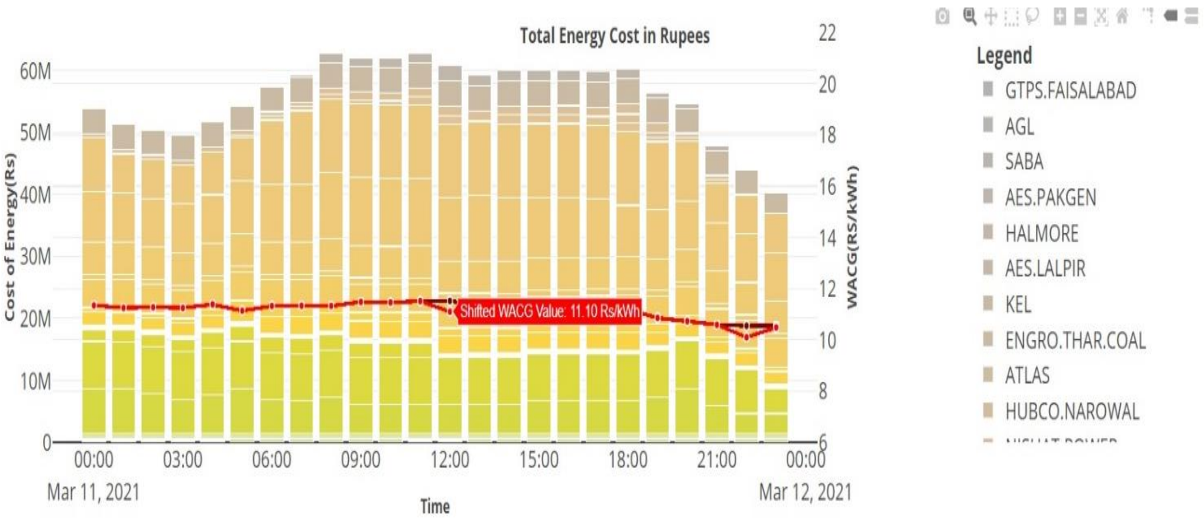
In the fiscal year 2020-2021, the average Load occurs on March 11, 2020, which is considered a shoulder month. At 11 a.m. on this day, the WACG is 11.51 Rs/kWh. The total energy cost for all power plants that were in use on this day is depicted in Figure 28. The WACG values throughout the course of 24 hours are presented by the red line on the bar graph.

Figure 28: The Generation Cost of each Power Plant and WACG for each Hour



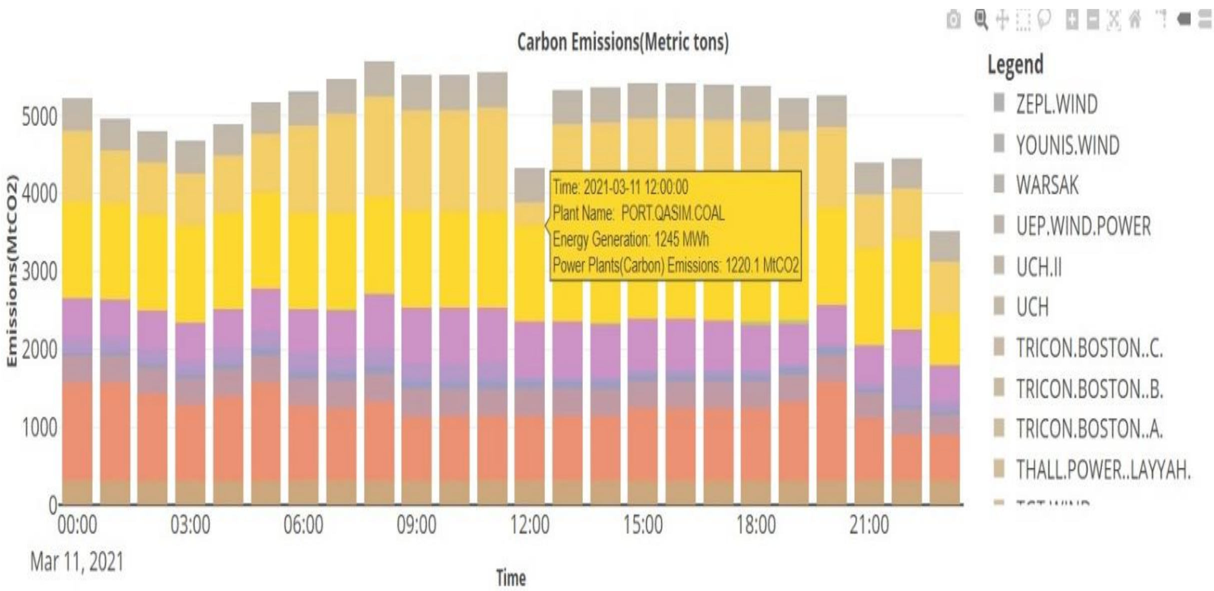
The power sector might save 10.52 million rupees on a single occasion by moving 5% load from peak to off-peak hours. If this Load is moved for a month, the power sector will save 304.53 million rupees, as shown in figur 29. The WACG now costs 11.10 rupees per kWh, compared to 11.51 rupees per kWh prior to the shift.

Figure 29: Total Energy Cost and Shifted WACG Value



When power plants are switched from peak to off-peak hours, the power sector may gain around 144.73 million rupees in carbon reduction value for the month of March. During peak hours, the power sector releases 5362.38 metric tons of CO_2, but when demand changes by 5% to off-peak hours, CO_2 emissions fall to 4311.74 metric tons. Figure 30 depicts the emissions released by each power plant during this day.

Figure 30: Emission Plot for various Power Plants



CONCLUSION AND POLICY IMPLICATION

5.1 Recommendations

Based on the findings of this study, literature review, and the collected data and analyses, the following recommendations should be considered in order to provide the foundation for shifting Load from peak to off-peak hours in Pakistan and achieving success in this approach.

Utilization of Installed Smart Meters

To regulate peak load, smart meters must be placed for demand side management and to monitor the Load at any given time interval. For agricultural purposes, a pilot project has been initiated under which smart meters are being deployed in Multan Electric Power Company (MEPCO) and Peshawar Electric Supply Company (PESCO) by USAid. Smart meters keep a near-real-time record of electricity consumption. The meters communicate the electricity usage trend to the distribution company automatically. During peak periods, customized tariffs may be offered to the consumers based on price signals. The DR will minimize electricity generation costs by lowering the peak demand at time intervals.

Incentivized Tariff Offering for Bulk and Industrial Consumer

Once the abovementioned pilot project has been successfully completed in the MEPCO and PESCO regions, the next target consumers should be Bulk and Industrial consumers. This strategy will involve the provisioning of dynamic tariffs via price signals to the industrial and bulk consumers. The consumers will be responsible for the cost of the smart meters. The variable tariff rates will be set by the generating unit's marginal cost. This cost should be less than the rate of the tariff previously offered. This will benefit both the participants and the utility. The success of this approach will be solely dependent on the DISCO's management of the participants' information. When industrial and bulk consumers are offered ToU tariff rates, the WACG can be significantly reduced.

Identification of New Flexible Loads

After incorporating industrial and bulk consumers, a range of newly identified flexible loads can be further added to the ToU pricing regime. This step will include the addition of flexible municipal loads such as tube wells, water pumps, etc. Smart meters need to be installed at these loads. Through the usage of smart meters, users will get dynamic tariff rates via communication protocols of smart meters and App development. To incentivize the users, beneficial tariff rates can be offered. This load shifting will have little impact on consumer convenience. The success of this DR will help both municipalities and DISCOs by lowering their peak demand and increasing their load factor.

Community Awareness and Inclusion

In this step, a broader range of loads can be added in order to increase flexibility. A wider range of consumers can be welcomed to take advantage of these ToU tariff rates. Smart meters will be used to monitor and signal the pricing. Smart meters will allow provisioning of real-time pricing and monitor electricity consumption at any point in time. The success of this DR is contingent upon the DISCO's administration. The initiative will benefit both the consumer and the utility by lowering the utility's peak demand and offering incentives to the consumers participating.

5.2 Conclusion

The energy and power sector in Pakistan faces multi-dimensional and multi-sectoral challenges. These challenges demand a multi-pronged approach for a complete solution which may not be possible in short to medium-term. However, some unconventional solutions to the conventional problems can prove to be highly efficacious in alleviating the burden on the energy sector. To this end, we have proposed and developed a mechanism for offering temporally variable tariff rates for partially shifting different flexible loads to off-peak hours. This shifting of Load to off-peak hours increases utilization of idle generation capacity, decreases reliance on expensive fossil fuel-based peaking plants, increase R.E utilization, and decreases the WACG. A combination of these factors collectively results in a reduction of circular debt of the energy sector in Pakistan which has now surpassed PKR 2.7 trillion. Our calculations show that just shifting 5% of the flexible load to off-peak hours can result in substantial savings to the national exchequer. We avidly believe that the work conducted during the course of this study can serve as a valuable guideline in implementing ToU pricing in Pakistan.

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APPENDIX

Case B: 10% Load Shifting

Scenario 1- Annual Peak Month (Highest Load)

WACG before shifting : **10.43 Rs/kWh**

WACG after shifting : **9.89 Rs/kWh**

Daily Savings :**13.13 million Rs**.

Monthly Savings : **393.92 million Rs.**

Emission before shifting : **7679.17 $MtCO_2$**

Emission after shifting : **5730.97 $MtCO_2$**

Monthly gain : **98.6 million Rs.**

Figure 31: Total Energy Cost and Shifted WACG Value

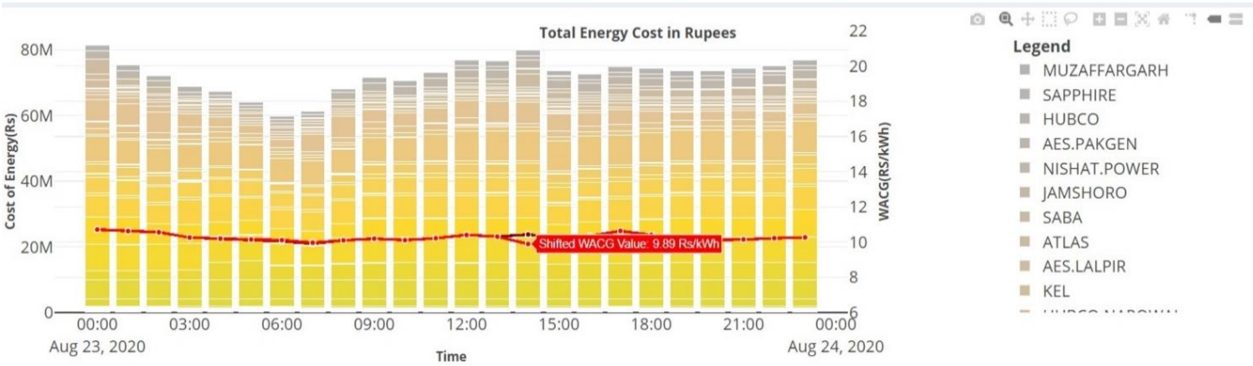
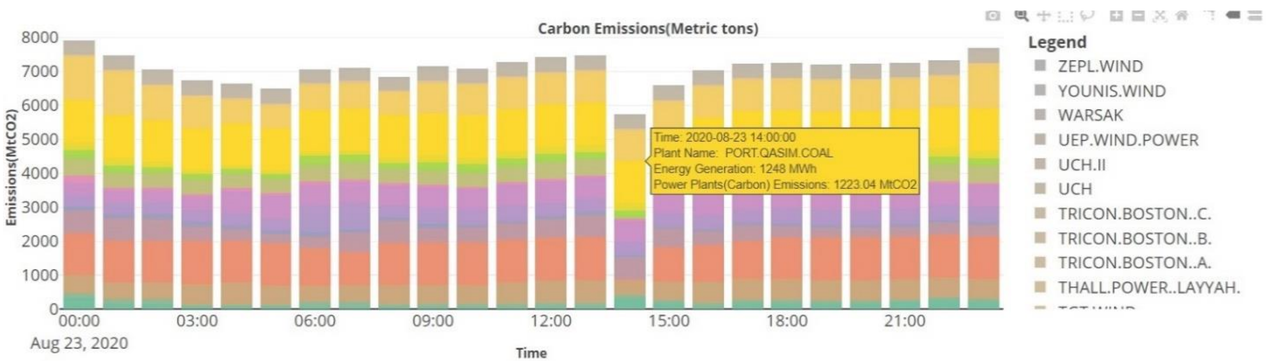


Figure 32: Emission Plot for various Power Plants



Scenario 2- Shoulder Month (Average Load Month)

WACG before shifting: **9.75 Rs/kWh**

WACG after shifting: **9.48 Rs/kWh**

Daily Savings: **9.86 million Rs.**

Monthly Savings: **295.91 million Rs.**

Emission before shifting : **5357.81 $MtCO_2$**

Emission after shifting : **4524.35 $MtCO_2$**

Monthly gain: **17.41 million Rs.**

Figure 33: Total Energy Cost and Shifted WACG Value

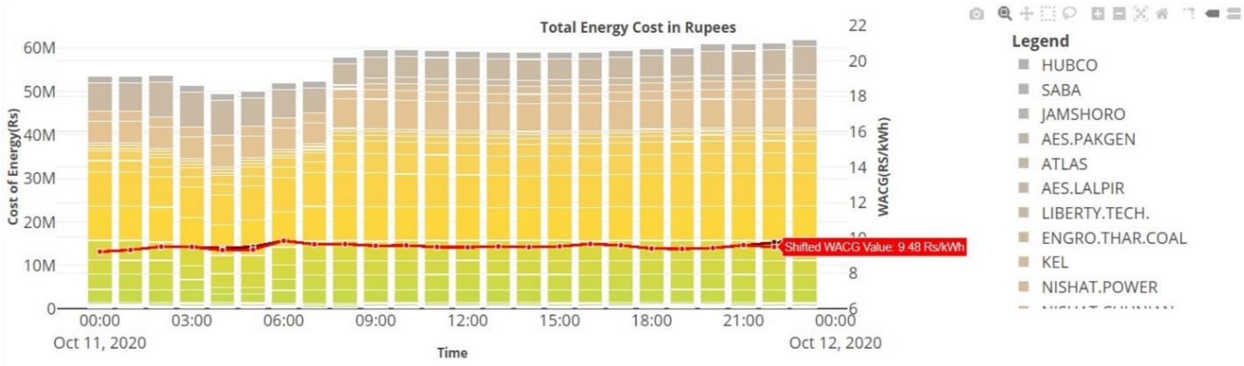
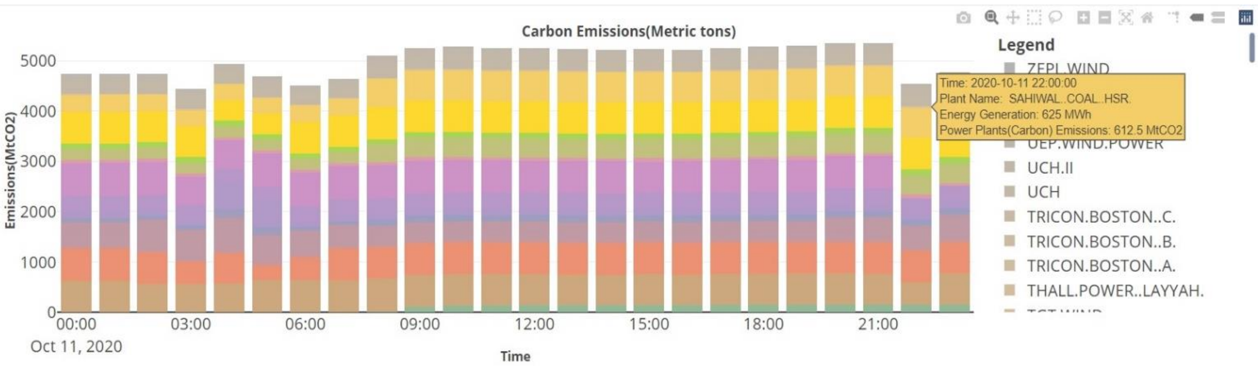


Figure 34: Emission Plot for various Power Plants



Scenario 3- Lowest Load Month

WACG before shifting: **14.83 Rs/kWh**

WACG after shifting: **14.57 Rs/kWh**

Daily Savings: **1.56 million Rs.**

Monthly Savings: **46.8 million Rs.**

Emission before shifting : **6586.73 $MtCO_2$**

Emission after shifting : **5903.00 $MtCO_2$**

Monthly gain: **55.03 million Rs**.

Figure 35: Total Energy Cost and Shifted WACG Value

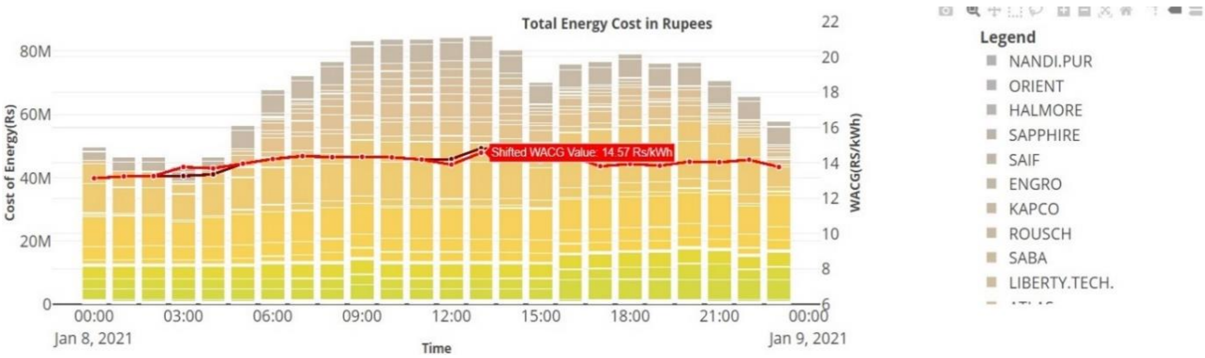
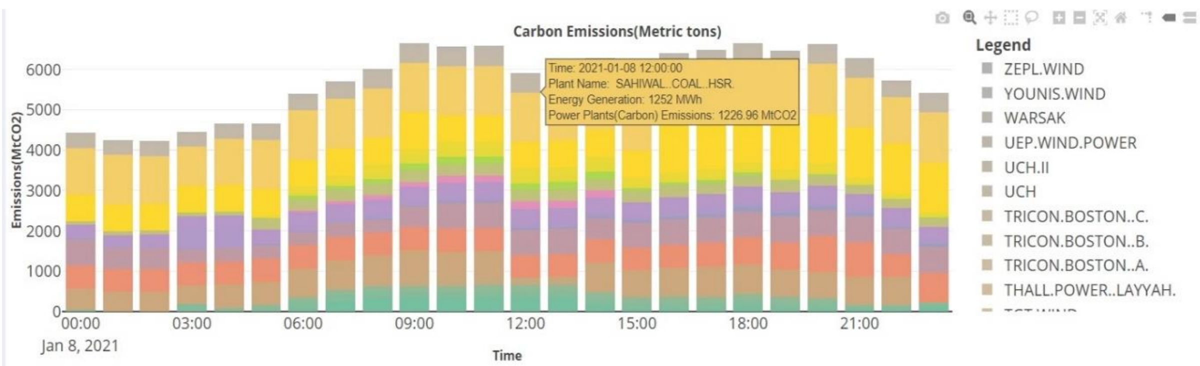


Figure 36: Emission Plot for various Power Plants



Scenario 4- Shoulder 4 (Average Month)

WACG before shifting: **11.52 Rs/kWh**

WACG after shifting: **11.02 Rs/kWh**

Daily Savings: **18.29 million Rs.**

Monthly Savings: **548.7 million Rs.**

Emission before shifting : **5362.38 $MtCO_2$**

Emission after shifting : **4134.44 $MtCO_2$**

Monthly gain: **289.46 Rs.**

Figure 37: Total Energy Cost and Shifted WACG Value

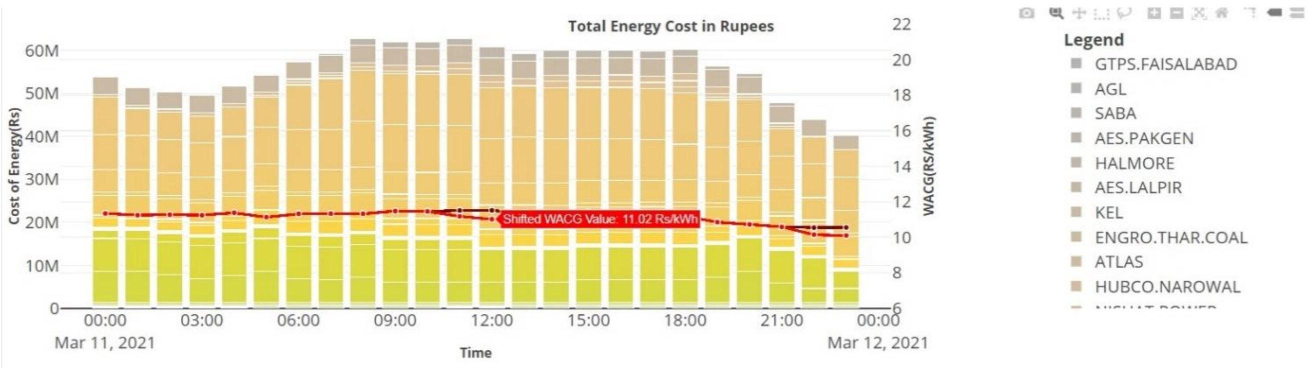
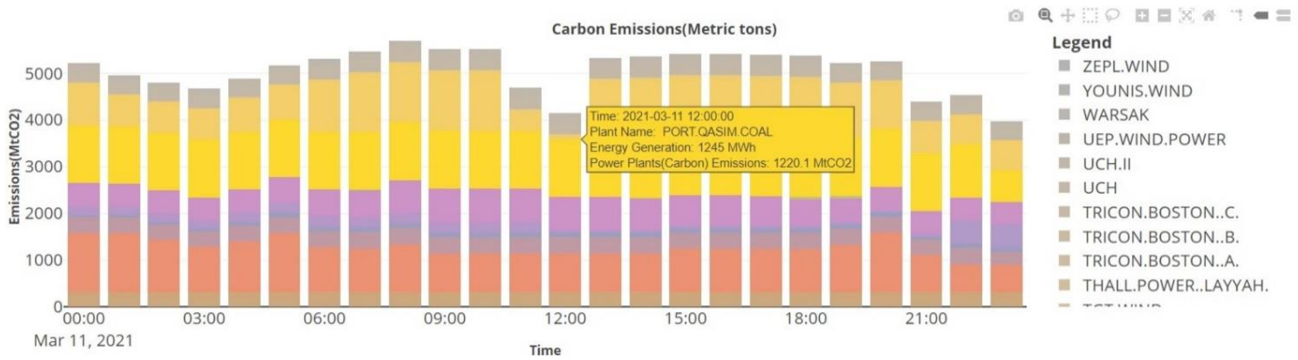


Figure 38: Emission Plot for various Power Plants



Case C: 15% Load Shifting

Scenario 1- Annual Peak Month (Highest Load)

WACG before shifting : **10.43 Rs/kWh**

WACG after shifting : **9.48 Rs/kWh**

Daily Savings : **2.23 million Rs.**

Monthly Savings : **66.91 million Rs.**

Emission before shifting : **7679.17 MtCO$_2$**

Emission after shifting : **4814.53 MtCO$_2$**

Monthly gain : **127.45 million Rs.**

Figure 39: Total Energy Cost and Shifted WACG Value

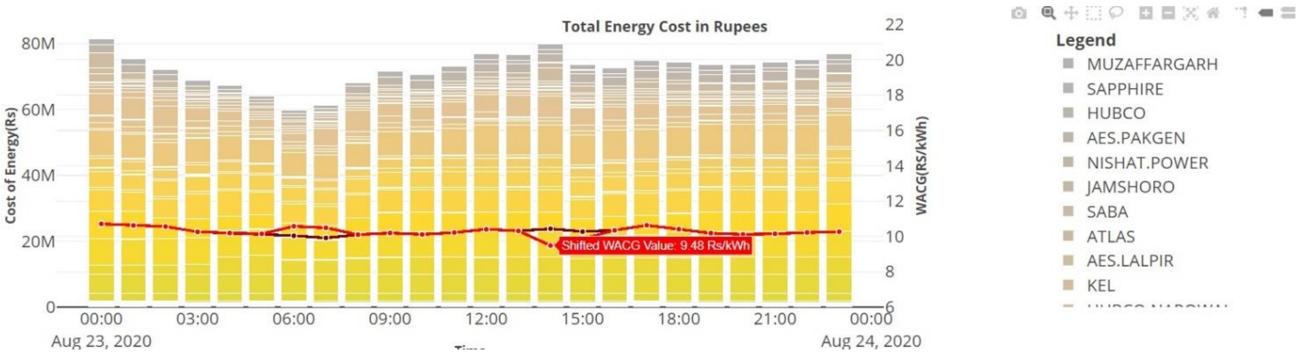
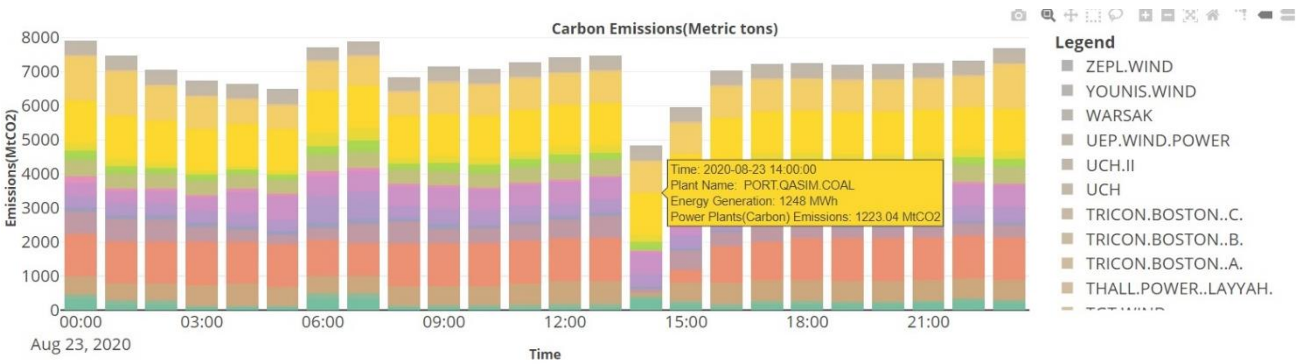


Figure 40: Emission Plot for various Power Plants



Scenario 2- Shoulder Month (Average Load Month)

WACG before shifting : **9.75 Rs/kWh**

WACG after shifting : **9.30 Rs/kWh**

Daily Savings : **11.57 million Rs.**

Monthly Savings : **347.14 million Rs.**

Emission before shifting : **5357.81 $MtCO_2$**

Emission after shifting : **4065.63 $MtCO_2$**

Monthly Loss : **129.27 million Rs.**

Figure 41: Total Energy Cost and Shifted WACG Value

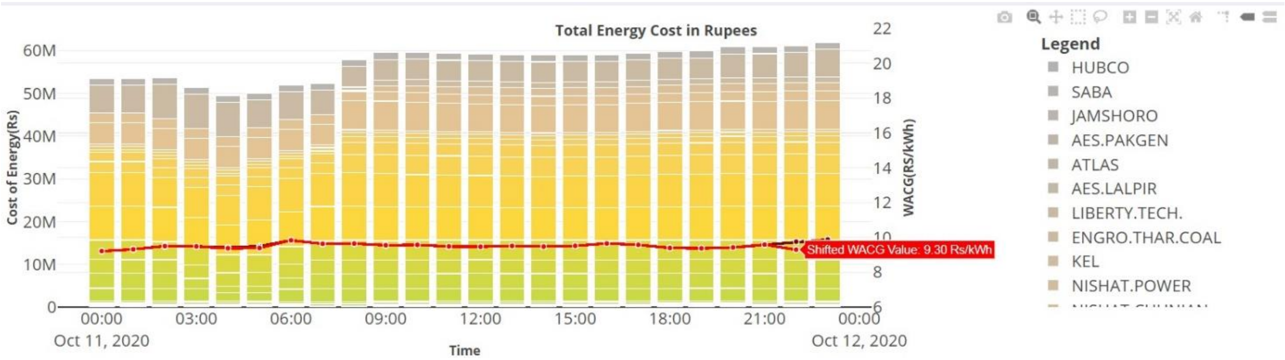
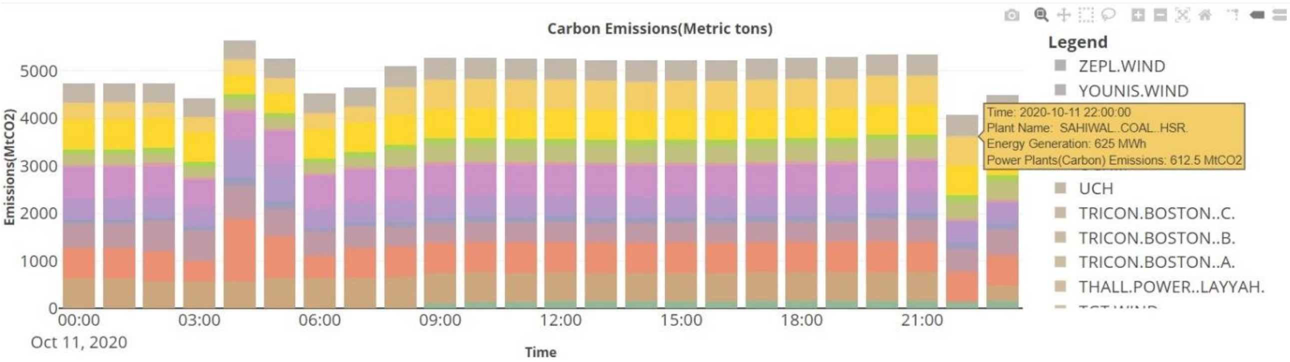


Figure 42: Emission Plot for various Power Plants



Scenario 3- Lowest Load Month

WACG before shifting : **14.83 Rs/kWh**

WACG after shifting : **14.48 Rs/kWh**

Daily loss : **3.84 million Rs.**

Monthly loss : **115.21 million Rs.**

Emission before shifting : **6586.73 $MtCO_2$**

Emission after shifting : **5903.00 $MtCO_2$**

Monthly gain: **210 million Rs.**

Figure 43: Total Energy Cost and Shifted WACG Value

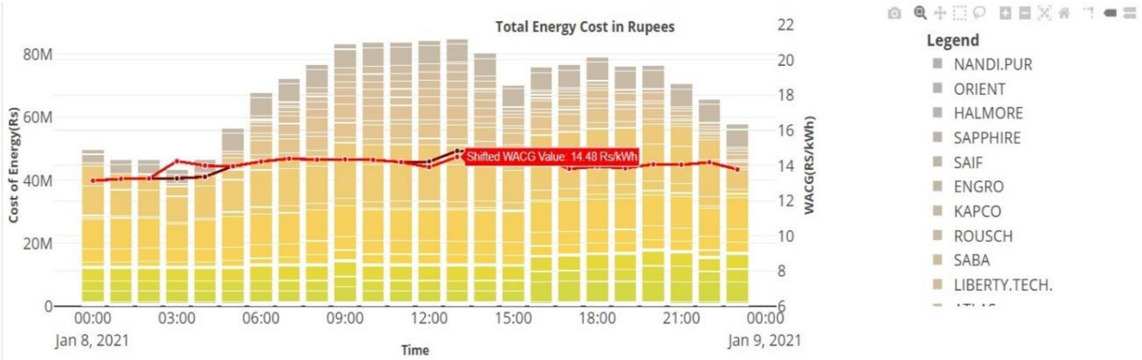
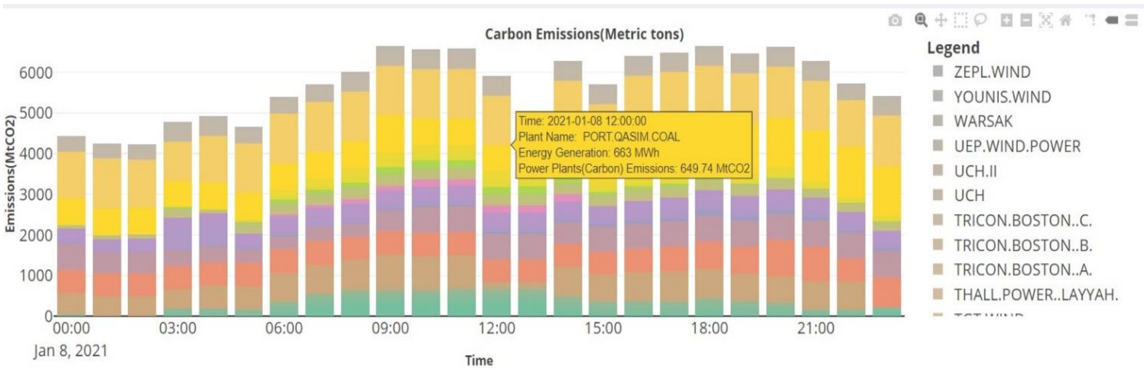


Figure 44: Emission Plot for various Power Plants



Scenario 4- Shoulder 4 (Average Month)

WACG before shifting : **11.52 Rs/kWh**

WACG after shifting : **11.02 Rs/kWh**

Daily Savings : **20.98 million Rs.**

Monthly Savings : **629.53 million Rs.**

Emission before shifting : **5540.67 $MtCO_2$**

Emission after shifting : **3911.56 $MtCO_2$**

Monthly gain : **272.11 million Rs.**

Figure 45: Total Energy Cost and Shifted WACG Value

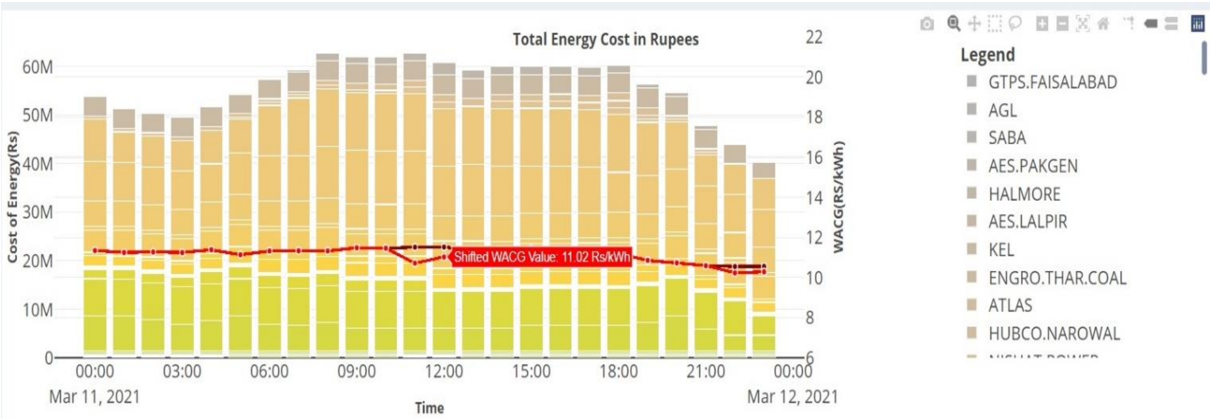


Figure 46. Emission Plot for various Power Plants