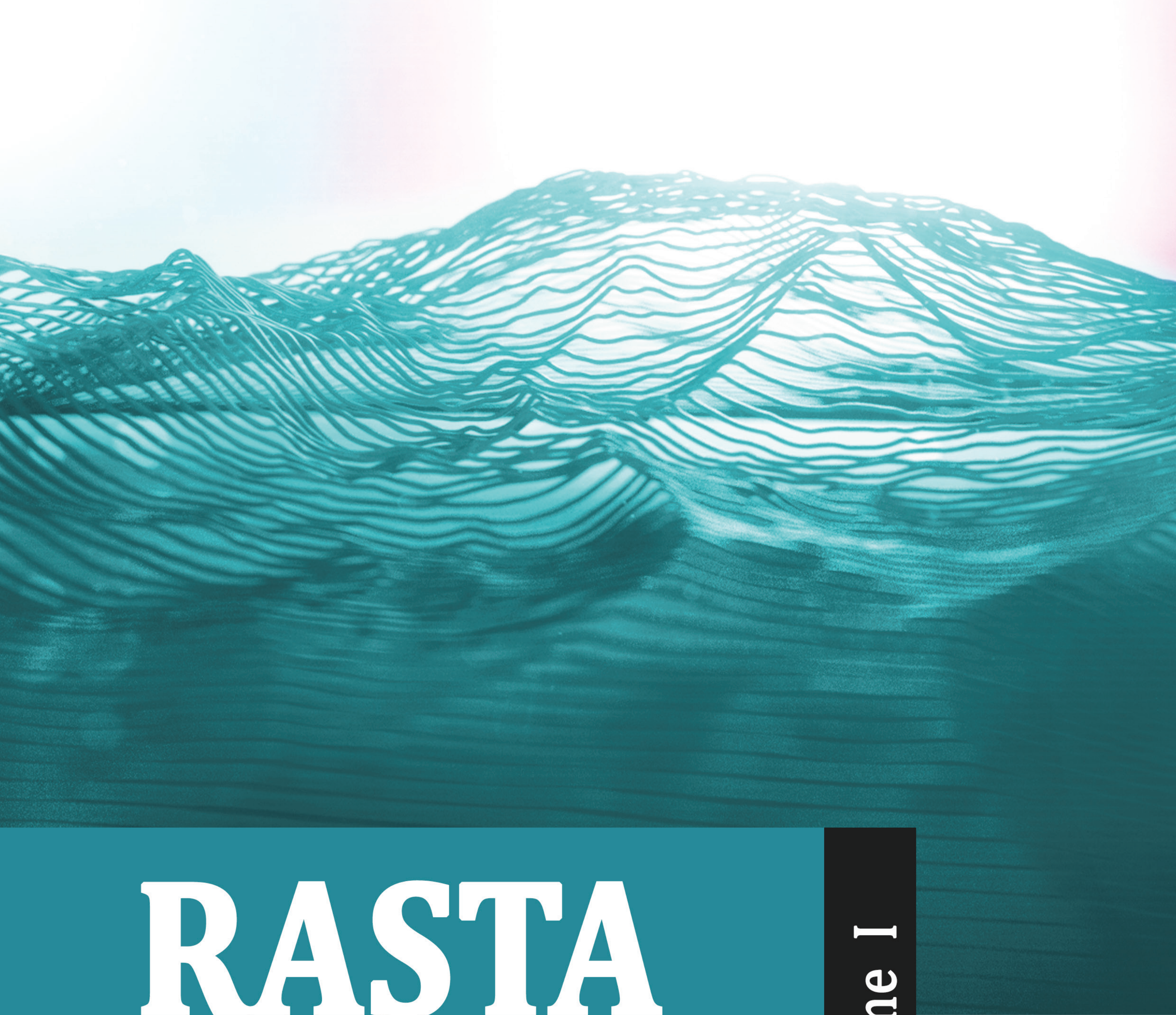

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Volume I

ENERGY ISSUES

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Edited by Nadeem Ul Haque and Faheem Jehangir Khan

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November 2022

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PART I

ENERGY ISSUES

Research Papers

A TECHNO-ECONOMIC ANALYSIS OF WIDESPREAD MICROGRID/MINIGRID DEPLOYMENT IN PAKISTAN'S ELECTRICAL POWER SECTOR

Danial Saleem and Salis Usman

ABSTRACT

In the recent past, the Government of Pakistan has undertaken certain appreciable initiatives in the electrical power sector, which is undergoing an extensive reform and restructuring process, particularly in the areas of decarbonisation and deregulation. Although Pakistan is blessed with abundant natural energy resources, a significant percentage of the population remains without electricity access since the expansion of the centralised grid is uneconomical due to certain reasons, including but not limited to limited financial resources and a scattered population. In this regard, micro/mini-grid (MG) deployment offers an excellent opportunity to address this problem, improve the life quality of the people of Pakistan, and help improve the economy. The study is predominately based on simulation and analysis-based research methods wherein the techno-economic analysis is performed keeping in view the technical and commercial aspects and also MG impacts on Pakistan's power grid and prospective customers of MGs.

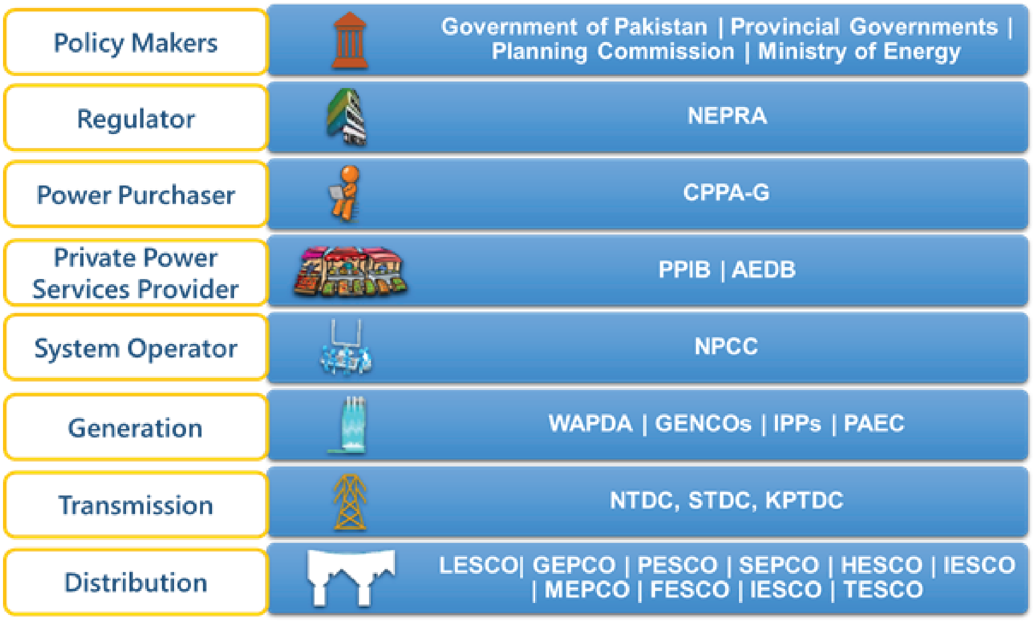
According to this study's findings, in comparison to fossil fuel-based MGs, renewable energy-dominated MGs offer a lucrative investment opportunity/financial viability and also contribute to reducing adverse effects on the environment. Even though MGs present a cost-effective solution for the remote unelectrified areas of Pakistan, they may suffer from technical issues if not properly designed. Direct current MGs and the application of MGs for irrigation purposes present interesting cases with respect to reducing the overall cost of energy. Some of the important factors to be considered to evaluate the feasibility of MGs are the electricity demand pattern, supply reliability requirement, discount rate, and project lifetime, among other things.

There is an urgent need for a comprehensive policy and regulatory framework since the existing one is insufficient to effectively upscale MGs deployment in Pakistan. While assessing electricity provision options for remote unelectrified areas of Pakistan, the electricity planners must consider and evaluate MGs before proposing huge investments in transmission and distribution infrastructure. One of the important considerations is to align the design of MGs with the affordability for the customers in each specific geographical area, to create a win-win situation for all the stakeholders.

1. INTRODUCTION TO THE POWER SECTOR OF PAKISTAN

The present power structure consists of the top-down regulated structure with the policy makers i.e., the Ministry of Energy, Power Division, at the top. However, because of its complexity and ramifications for other sectors of the economy as well, the decision-making process involves other ministries along with the highest forums of the government. The complete structure of the power sector is shown in Figure 1.

Figure 1: Existing Structure of the Power Sector



An independent regulator, National Electric Power Regulatory Authority (NEPRA), is functioning since the late nineties to ensure that the rights of investors, public companies, and consumers are protected.

The existing power sector operates on a single buyer model, i.e., electric power is procured from the generation companies for the distribution companies through a single entity, which is the Central Power Purchase Agency (CPPA-G). Before the procurement of electric power from generation companies, there is a comprehensive process for entry into the electricity market of Pakistan along with the development of a power project. This requires support to private companies who are prospective participants in the regulated market. These services are provided by the Private Power Infrastructure Board (PPIB) for conventional thermal and hydro projects and the Alternative Energy Development Board (AEDB) for renewable projects.

Electric power is generated from the generation facilities of WAPDA, thermal Generation Companies (GENCOs), Pakistan Atomic Energy Commission (PAEC), and Independent Power Producers (IPPs). This power is transmitted through the high voltage transmission network of the National Transmission and Despatch Company (NTDC) and it is distributed to the consumers through the distribution network of distribution companies (DISCOs). The system operations of the power sector are managed at the National Power Control Center (NPCC) by NTDC.

Among the power sector stakeholders, K-Electric is a vertically integrated utility, which performs the functions of generation, transmission, distribution, regional system operation, and private power services provision in the Karachi region.

Future Electricity Market

The regulated structure is coming to an end since NEPRA has recently approved the Competitive Trading Bilateral Contract Market (CTBCM) model and plans to deregulate the power sector. The CTBCM is set to introduce a deregulated framework in Pakistan's power sector enabling wholesale purchases of electricity through bilateral contracts.

Electricity is a commodity capable of being bought, sold, and traded. In a mature electricity market, bids and offers use supply and demand principles to set the price. Additionally, there may exist long-term contracts similar to power purchase agreements as well as bilateral transactions between generators and bulk power consumers.

The first phase of the CTBCM is envisaged to begin the wholesale trade of electricity through bilateral contracts between generators and wholesale electricity consumers either directly or through traders.

With such a radical transition set to place in a couple of months, the purpose of a competitive market of electricity in Pakistan is to achieve the following:

- Optimize the basket price of electricity
- Create the conditions to attract investments
- Introduce competition to enhance efficiency in the power system
- Ensure accountability, transparency, and open access to information
- Maximize the economic benefits of available resources and promote efficiency

Implementation of the action items as per the approved CTBCM model and plan is in full swing. The Commercial operation date of CTBCM is 1st May 2022.

The New Age

In pursuit of energy access and low-cost sustainable energy, there is a need to move away from the integrated grid due to its inefficient and unsustainable nature, which results in a high cost of electricity to the consumers. In this regard, the CTBCM is the beginning of the decentralisation of the power sector in Pakistan. However, microgrids/mini-grids (MGs) fit into the jigsaw of the decentralised power sector as they can provide sustainable and low-cost energy to the consumers of electricity promising more value for money. MGs are gradually taking the center stage in the future outlook of the power sector both in Pakistan and globally.

Rationale for MG Development

MG is a small network of electricity generators and storage that use local energy resources (mostly renewables or hybrid) to generate electricity that can function independently as well as in connection with the grid. Globally, the size of MGs ranges from 1 kW to 10 MW.

A significant area of Pakistan is yet to be electrified even though the country is bestowed with huge natural energy resources geographically spread throughout the land. Due to various reasons, such as limited financial resources and scattered population/electricity demand (particularly in Balochistan), the expansion of the national/DISCO grid to most of the unelectrified locations is not economically viable. Therefore, MGs have a huge potential to improve the quality of life quality of the people of Pakistan and complement the economy. Fortunately, unstructured efforts have already started in the country. Globally, MGs have become a mainstream solution for providing energy access to everyone. It is, therefore, inevitable to upscale the setting up of MGs wherever required and, of course, potentially possible. Following are some of the important factors that necessitate the upscaling of MGs for providing energy access at a low cost to the people of Pakistan:

- Sharp and sustained increasing trend of end-consumer tariff
- A large number of unelectrified areas in Pakistan are not expected to be electrified soon
- Decreasing cost trend of MGs deployment due to significant reduction in the individual component costs of MGs, such as converters, solar PV panels, wind turbines, etc.
- The availability of huge potential for renewable energy resources, such as solar, wind, hydro, etc.
- A substantial number of areas in Pakistan have difficult terrain making grid access difficult
- Detrimental environmental impacts being faced by Pakistan in recent years due to a significant share of conventional fuels in electricity generation and the usage of other inefficient fuels due to a lack of

generation adequacy
- Hampering economic development due to lack of electricity access in remote areas
- Prevailing supply unreliability to remote areas

The Government of Pakistan (GOP) promulgated the National Electricity Policy in 2021 which stresses the sustainability of the electrical power sector in Pakistan. It means that the GOP has decided to pass electricity prices in full to end-consumers by withdrawing subsidies, contrary to other developing nations of the world. The policy direction for sustainability in Pakistan's electricity sector will have considerable implications for the people of Pakistan who are already paying a very high per unit tariff for electricity.

Considering the internal report of one of the credible institutions of Pakistan's power sector (it is an internal working report and is expected to be publicised soon), the existing average tariff, i.e., Rs.14.85/kWh is forecasted to be Rs.24.28/kWh in the year 2030 excluding taxes. This forecast is based on certain optimistic assumptions of factors listed below. Any variation in these factors may significantly increase the forecasted end-user tariff.

- A rising trend of inefficiencies in the integrated electrical grid
- A continuing trend of incurring the sunk cost of committed power projects
- Introduction of the CTBCM and a high probability of an increase in end-user tariff due to market power, inexperience, an increase in stranded costs, etc.
- Sharp currency devaluation
- Increase in fuel prices

Considering the above-mentioned factors and the GOP's target of sustainability in the electricity sector, the people of Pakistan, who can afford the substantial investment, have already started opting for stand-alone roof-top solar PV with and without net-metering provision. A major drawback of stand-alone PV is the unavailability of solar power during the late evening/night time as well as the supply during rain or bad weather. MGs, thus, provide a more complete solution for the issues of higher costs and supply reliability.

Off-grid MG deployment for remote rural areas is a globally accepted solution. The feasibility of MG deployment for various scenarios is analyzed in detail in this study. However, it is important to mention here that there are certain challenges in MG design, development, and implementation that need to be addressed for the successful implementation of MG in Pakistan. These challenges are discussed in this study along with the proposed remedial measures.

After the 18th amendment to the Constitution of Pakistan, the provincial governments can take decisions regarding the generation, transmission, and distribution of electricity in their respective territories. Instead of following a strenuous and long process, which includes project approval at a centralised level and building extensive generation, transmission, and distribution infrastructure, MG deployment is a sustainable solution for the provincial governments in Pakistan.

The far-flung areas of Pakistan are without electricity for approximately 16 hours a day due to multiple reasons, including theft and distribution system unreliability. The reliability of supply through MGs development is another important aspect which is explored in this study.

It is important to mention here that this study does not recommend the deployment of MGs everywhere in Pakistan; rather it highlights certain favourable factors, scenarios, and applications where the MG deployment stands far more promising as compared to other potential options. A few of the possible scenarios are:

- Remote rural areas
- Difficult terrain areas where grid access is difficult
- Communities having rich mini/micro hydro potential
- Areas having flexible load demand profiles (or can be easily adjusted)
- Hospitals and military installations, which cannot afford unreliable supply
- Housing societies/commercial centres having net metering provision
- Communities/areas where provincial/territorial governments want a viable alternative for the provision of electricity other than the nationally integrated grid

Since the study was mandated to analyse unconventional solutions for electricity-related issues in Pakistan, it required simulation-based techno-economic evaluation. Techno-economic evaluation is the key to finding the most feasible solution to electrical energy-related issues. For this purpose, HOMER (Hybrid Optimisation of Multiple Energy Resources) Pro software was used to present reliable results and findings. The study benchmarked and standardised the analysis procedures to evaluate MG deployment.

One of the key motives to perform this analysis was to present the case for the democratisation of the power sector in Pakistan. Every citizen of Pakistan has the right to receive electrical energy from the seller or opt for electrical energy-related services of his choice, i.e., a utility, service provider, independent MG system, own means, etc. The study explored initiatives to start the journey, as a nation, towards the democratisation of the power sector. It may be highlighted that the recent decision to incentivise ordinary customers by allowing net metering of up to 25 kW without any formal license is an initial step towards the democratisation of the power sector in Pakistan. One of the benefits of providing consumers with a choice for opting for MG solution will be the promotion of competition in the electricity market in Pakistan.

Research Questions

The following research questions were derived for this study:

- Can MG be a possible solution to resolve the issues of unelectrified areas and expensive electricity rates? What are the possible application scenarios for MG development in Pakistan?
- How to evaluate the feasibility of MG development in a particular area in Pakistan? What are the general technicalities involved in MG development in Pakistan?
- What are the possible advantages/disadvantages of MGs in the context of Pakistan's electrical power sector? How can the policy and regulatory framework be utilised for the successful widespread deployment of MGs in Pakistan?
- What are the possible business models, in broader terms, for MGs deployment in Pakistan? What are the recommendations to decision-makers to promote MGs in Pakistan?

Objectives of the Studies

The objective of the study was to present a comprehensive analysis of the widespread deployment of MG systems in Pakistan. The study was carried out keeping in view the techno-economic and policy perspectives; its results will facilitate the policy makers in taking necessary initiatives for MGs development in Pakistan. Identification of business attractive models for MGs were also a part of this research work which will encourage various stakeholders in utilizing this cutting-edge technology to overcome the current challenges of Pakistan's power sector, i.e., sustainability, affordability, and reliability.

The power sector of Pakistan is already following the path of major restructuring in line with the globally well-established 3D reforms, i.e., decarbonize, decentralise, and democratise. The current reforms related to 'decarbonize' and 'decentralize' include the important steps of the electric vehicle policy, the implementation of the CTBCM, and the Alternative and Renewable Energy (ARE) Policy 2019. This research work will pave the way for the very next step, which is the 'democratisation' of the power sector through the deployment of MGs in the electrical power network of Pakistan.

For this purpose, potential application scenarios and locations were identified across Pakistan and their technical, economic, and policy implications were analyzed. The significance, as well as potential benefits, of MGs in Pakistan's future energy policies, were investigated. In addition to policy recommendations, technical solutions for issues associated with the interconnection/operation of on-grid and off-grid MGs, such as frequency control, voltage control, harmonics, stability issues, etc., are proposed specifically in the context of a weak electrical power network in rural/remote areas. Moreover, possible business models for MG deployment in Pakistan were chalked out. The scope and findings of the study make it can prove to be useful for the federal as well as provincial/territorial governments because the adoption of MGs can offset the demand on the national grid and trigger the development of widespread MGs in the provinces of Pakistan.

2. RESEARCH METHODOLOGY

The study was carried out in a linear sequential way, answering each research question and then moving forward to the next one. While answering each research question different research methodologies were employed. A literature review and textual/content analysis were conducted to understand how MG has made a significant impact, especially in the regions of South Asia and Africa. Based on these qualitative analyses, three possible scenarios were developed to understand the technical and commercial interactions of the MG with the power grid of Pakistan and prospective customers of MGs.

Data was collected to simulate three scenarios to evaluate the feasibility of MG deployment and was validated using multiple sources. Data collection was conducted through questionnaires, interviews, and site visits. In order to determine the feasibility and business viability of MGs for particular scenarios, techno-economic analysis was carried out on HOMER Pro, a dedicated optimisation tool for MG analysis.

The study is predominately based on simulation and analysis-based research methods. It means that the answers to the research problems were found through a mathematical model that represented the structure and dynamics of technical and economic processes of the subject under study, which is MG in this case. The HOMER Pro mathematical model was designed to handle the complexities of building cost-effective and reliable MG systems that may include elements like conventional generators, renewable energy resources, storage, and load management, among other things. Similarly, wide-ranging data were analyzed to draw conclusions.

Textual and content analyses of ARE Policy 2019, National Electricity Policy 2021, and tNEPRA (Microgrid) Regulations 2021 (draft) were carried out. Moreover, existing business models, being implemented in Pakistan were also considered. Interviews were conducted with concerned personnel from the PEDO and the PPDB, the executing agencies for MG in Khyber Pakhtunkhwa (KPK) and Punjab, respectively, and with the authors of the draft MG regulation from NEPRA. Based on results from the techno-economic analyses of three scenarios and interviews performed with the officers of the regulator and public-sector executing agencies, business models were proposed in this study.

The research processes, tools and techniques used during the study are briefly described below:

Data Collection

Numeric data were collected for the analysis, i.e., techno-economic analysis for this study. Depending upon the nature and necessity, various sources were selected for data collection, i.e., relevant international /national publications, journals, and reports. In addition to numeric data, qualitative data was used.

Literature Review

To carry out the techno-economic analysis, research papers on techno-economic analysis, energy modelling, renewable energy resources, grid resiliency, system stability and protection issues, etc. were studied. In addition to research papers, important policy documents were also studied, i.e., ARE Policy 2019, National Electricity Policy 2021, IGCEP 2021 and NEPRA (Microgrid) Regulations 2021.

Survey

Data were collected through a survey and site visits (the site visit report is attached as Annexure-III). The questionnaire was distributed to the concerned provincial entities to obtain data, particularly for our study (the questionnaire is presented in Annexure-I of this report).

Interviews

One-to-one correspondence was carried out with concerned persons/experts in relevant offices of PEDO, the PPDB, and NEPRA.

Techno-Economic Analysis

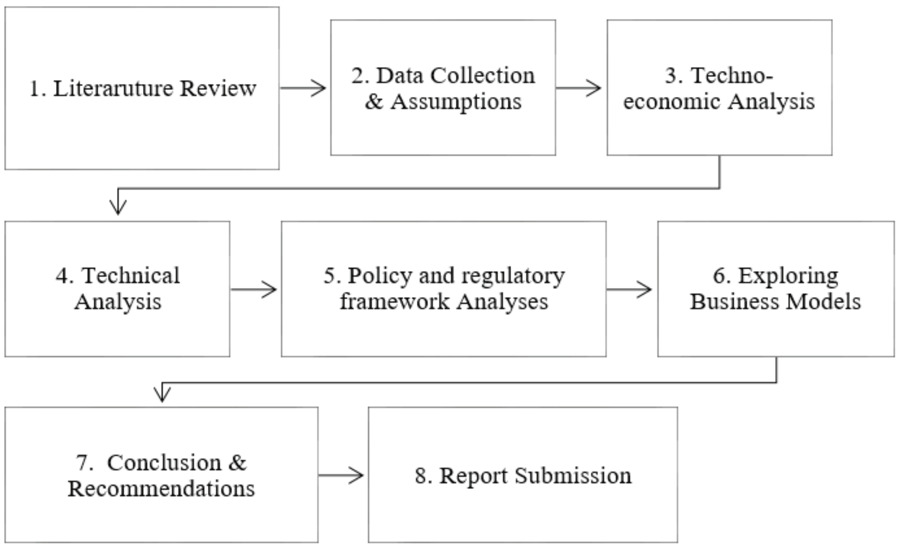
The techno-economic analysis was performed on the HOMER Pro hybrid optimisation model. The three scenarios were analyzed on HOMER Pro to find out the techno-commercial feasibility of the scenarios.

Textual Analysis

The case studies, policy instruments, and regulatory documents were analyzed to find coherence in their objectives, identify gaps, and point out missing links while comparing them with international best practices.

The flowchart shown in Figure 2 describes in totality the research methodology followed during the study.

Figure 2: Research Methodology for the Study



3. MODELLING ANALYSIS, SIMULATION, AND RESULTS

This section explains the modelling of MG, analysis, and the findings of the simulations carried out for this study. Techno-economic feasibility was performed for both off-grid and on-grid applications of MGs. HOMER Pro modelling and simulation tool was used to draw out the findings pertaining to the objectives of this study. An advanced study comprising sensitivity analysis was performed to further deliberate the discussed scenarios of applications. Special applications of MGs, such as Deferrable Load and Direct Current (DC) MGs were also analysed.

TECHNO-ECONOMIC ANALYSIS

In this section, techno-economic modelling and simulations are discussed. We discuss how to evaluate the feasibility of MG deployment in a particular area.

HOMER Pro

The HOMER Pro is software used for optimizing MG design in various applications, from remote far-flung villages to on-grid communities and campuses. It simplifies the task of evaluating designs for both off-grid and on-grid power systems from both feasibility and design perspectives. For designing an MG power system, the following critical decision parameters about the configuration of the system arise:

- Choosing the best combination of components/elements for the system

- Selecting the required optimal number of each component/element along with the most feasible size/rating.

A large number of technology options, variation in costs, and the availability of energy resources make these decisions quite complex. HOMER's optimisation and sensitivity analysis algorithms make it easier to evaluate many possible system configurations and select the best option for a particular application/scenario/site (Homer Energy, 2021).

Considered Application Scenarios

Out of various possible options for widespread MGs deployment in Pakistan, the following three most probable and feasible scenarios were design ed for the pre-feasibility analysis:

- Off-grid MGs application for rural villages/areas having solar PV and wind potential
- Off-grid MGs application for rural villages/areas having solar PV and micro-hydro potential
- Grid-connected MGs application for housing societies or commercial centres in urban areas having utility electricity access

Each scenario is discussed in the following section along with results/findings.

Basic assumptions for the whole study are tabulated in Table 1 and Table 2.

Table 1: Basic Assumptions for Analysis

S. #	Parameters	Units	Values
1	Project Lifetime	Years	30
2	Discount rate	%	10
3	Inflation rate for project life	%	8
4	Fuel Price for Generator	$/litre	0.8
5	Operating reserve as a percentage of hourly load	%	5
6	Operating reserve as a percentage of peak load	%	0
7	Operating reserve as a percentage of solar power output	%	10
8	Operating reserve as a percentage of wind power output	%	10
9	Grid sale tariff	$/kWh	0.15

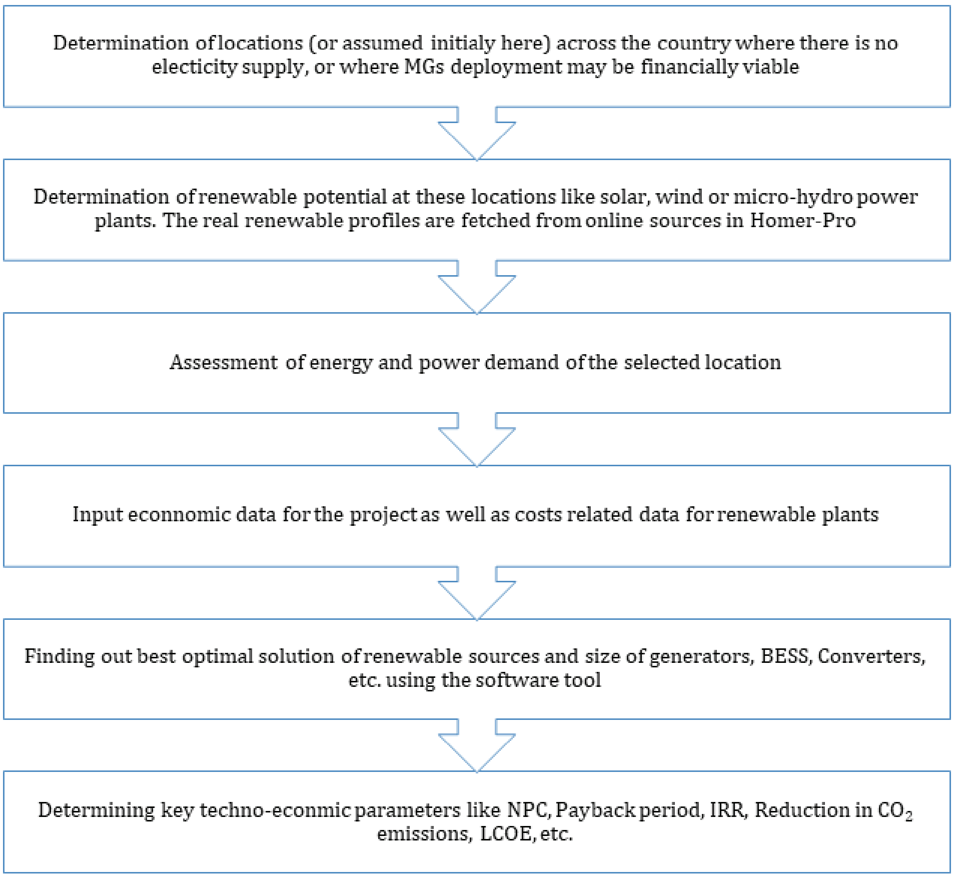
Table 2: Cost Assumptions for Analysis

S.#	Component	Initial Capital Cost ($/kW)	Replacement Cost ($/kW)	O&M Cost ($/kW)	Lifetime (Years)
1	Solar PV	496	496	18.3	30
2	Wind Turbine	1,473	1,178	44.5	35
3	Battery Storage	350	280	20	10
4	Converter	600	300	3	15
5	Diesel Generator	500	500	0.03 ($/operating hour)	15,000 operating hours
6	Micro-Hydro	2000	1000	80 ($/year)	40

It is important to mention here that considerations like the cost of distribution infrastructure, cost of land, profit margins, etc. were not considered for this study, which need to be taken care of while evaluating the feasibility of a particular project, as it may vary significantly from one case to another.

The following approach was for the study:

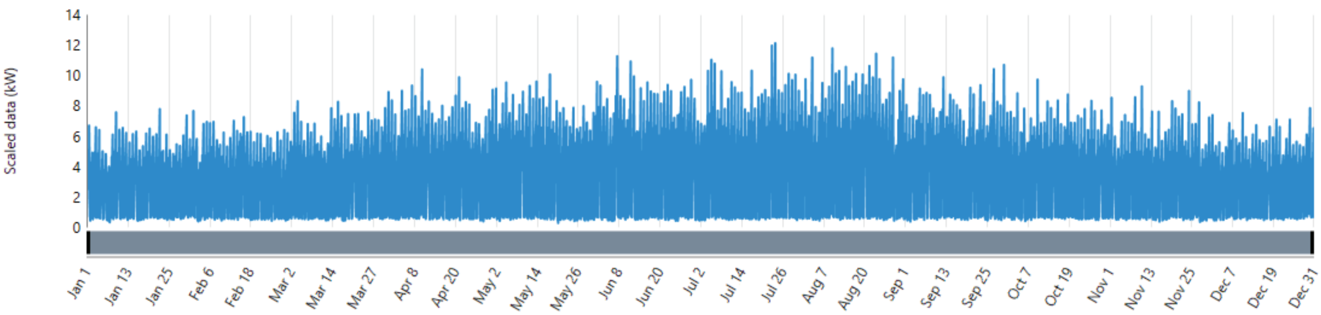
Figure 3: Approach Used for Techno-Economic Analysis



Scenario 1: Off-Grid MGs Application for Rural Villages/Areas Having Solar PV and Wind Potential

This scenario is particularly important to analyse the feasibility for remote rural populations having a significant distance from the utility grid connection. This situation is quite relevant in the scenario for Baluchistan, where a large number of areas are still unelectrified and providing grid access to those areas is difficult and does not hold financial viability. A village near Panjgur with geographical coordinates of 26°58.2'N, 64°5.3'E was considered. The following load profile was considered with a peak load of 12.13 kW and annual average energy of 72 kWh/day.

Figure 4: Load Profile for Scenario 1



In order to meet this demand profile of electricity, the schematic as shown in Figure 5 was modelled in the software with the option to optimize the selection and size of the most feasible option considering the real solar and wind profiles from the NASA database.

Figure 5: Schematic Diagram for Scenario 1

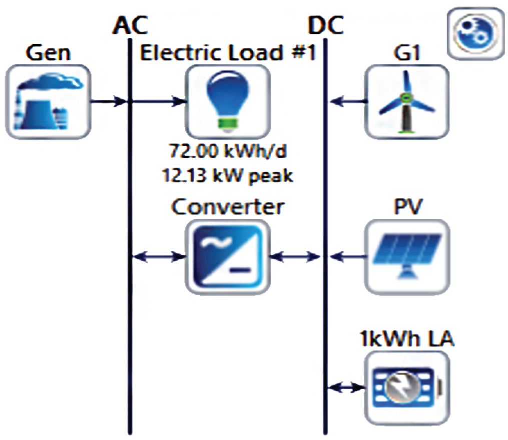


Figure 6: Wind Speed Data for Scenario 1

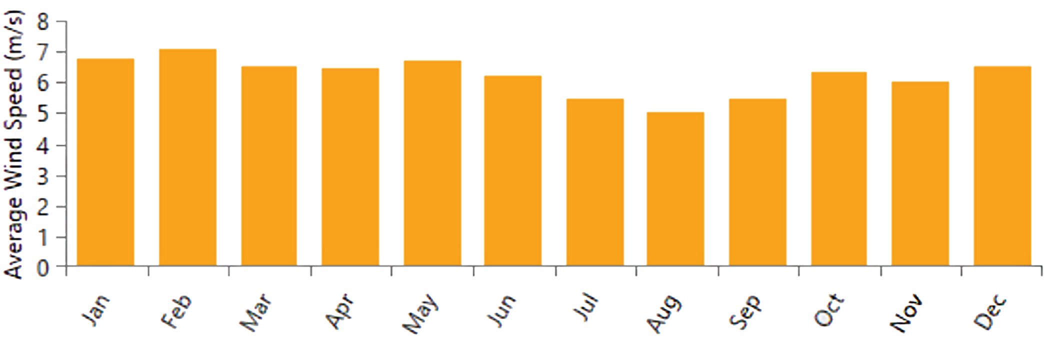
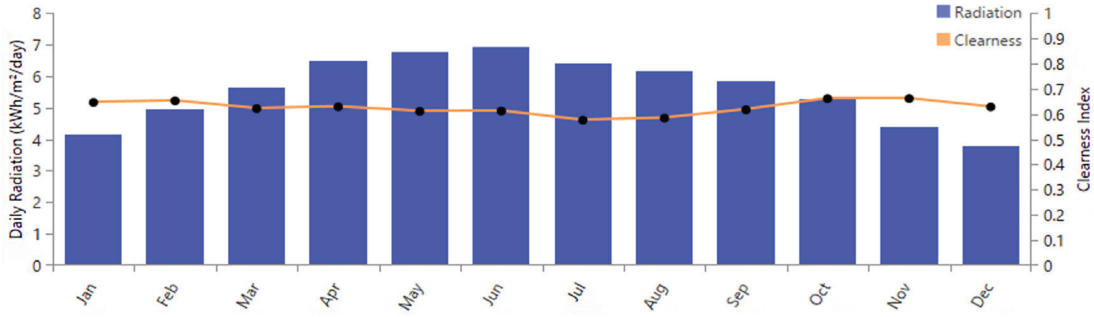


Figure 7: Wind Speed Data for Scenario 1



Different technology options were considered to determine the most feasible one for MG, as listed in Table 3 below.

Table 3: Considered Combinations for Scenario 1

Option No.	Combination
1	Diesel Generator Only
2	Solar PV Only
3	Wind Only
4	PV + Wind
5	PV + Storage
6	Wind + Storage
7	PV + Wind + Storage
8	PV + Wind + Storage + Diesel Generator
9	PV + Diesel Generator
10	Wind + Diesel Generator
11	PV + Storage + Diesel Generator
12	Wind + Storage + Diesel Generator

From the above different combinations, option 7 was determined to be the most feasible one. The optimised size/rating for each component is provided in Table 4:

Table 4: Optimised System Size for Scenario 1

Component	Type	Size	Unit
PV	Generic flat plate PV	21.1	kW
Storage	Generic 1kWh Lead Acid	19	Strings
Wind turbine	Generic 1 kW	4	kW

System converter	System Converter	8.04	kW

Net present costs for each category of the selected components are summarised in Table 5 below:

Table 5: NPC for Scenario 1

Component	Net Present Cost (US$)				
	Capital	Operating	Replacement	Salvage	Total
Generic 1 kW Wind Turbine	$5,892	$4,069	$0.00	-$388.19	$9,573
Generic 1kWh Lead Acid Battery	$6,650	$8,687	$15,407	-$2,703	$28,041
Generic flat plate solar PV	$10,469	$8,830	$0.00	$0.00	$19,299
System Converter	$4,824	$551.40	$1,832	$0.00	$7,207
Total System	$27,836	$22,137	$17,238	-$3,091	$64,120

Technical results related to load, storage, and generation from various resources are summarised in Table 6:

Table 6: Technical Results for Scenario 1

Parameter	Value	Unit
AC Primary Load	25,233	kWh/year
Solar PV Production	46,840	kWh/year
• Hours of Operation	4,388	Hours/year
• Level ised Cost	0.0180	$/kWh
Wind Production	9,857	kWh/year
• Hours of Operation	7,460	Hours/year
• Level ised Cost	0.0425	$/kWh

Energy Input to the Battery Storage	4,660	kWh/year
• Annual Throughput	4,174	kWh/year
• Autonomy	5.07	Hour
Energy Input to the Converter	25,488	kWh/year
• Hours of Operation	8,715	Hours/year

Comparing the base system (option 1) with the proposed optimised system, the IRR of the proposed system was found to be 79.5%, while discounted payback periods and simple payback periods were found to be 1.34 years and 1.32 years, respectively. A brief comparison of the base system and the proposed system is given in Table 7:

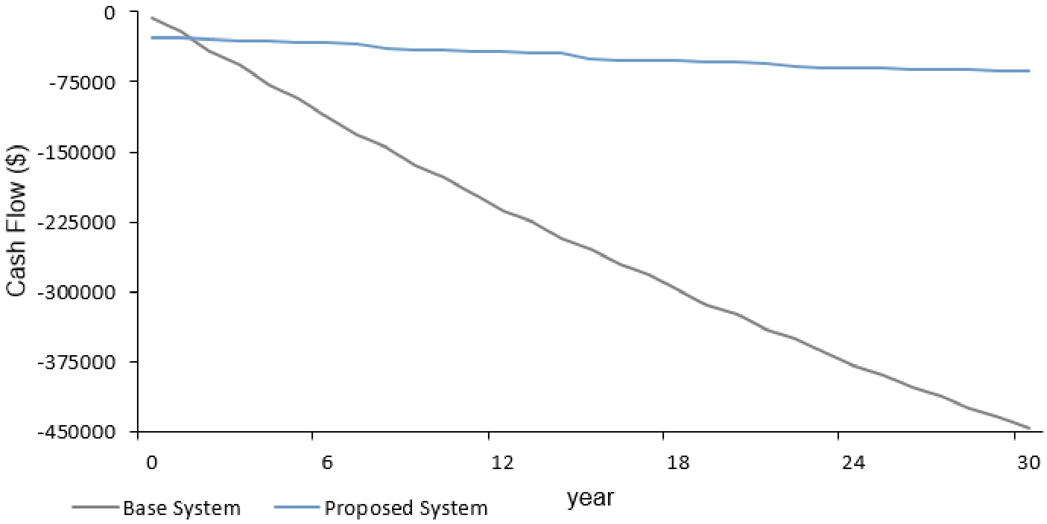
Table 7: Comparison with Diesel Generator Option for Scenario 1

Parameter	Base System	Proposed System
Net Present Cost	$445,342	$64,120
CAPEX	$6,500	$27,836
OPEX	$19,197	$1,587
LCOE (per kWh)	$0.741	$0.111
CO_2 Emitted (kg/year)	39,831	0
Fuel Consumption (Litre/year)	15,216	0

The Levelised Cost of energy (LCOE) came out to be $0.111/kWh, which is quite reasonable.

A graphical comparison of the base and the proposed system in terms of cash flows for the project lifetime is shown in Figure 8:

Figure 8: Cash Flows Comparison for Scenario 1

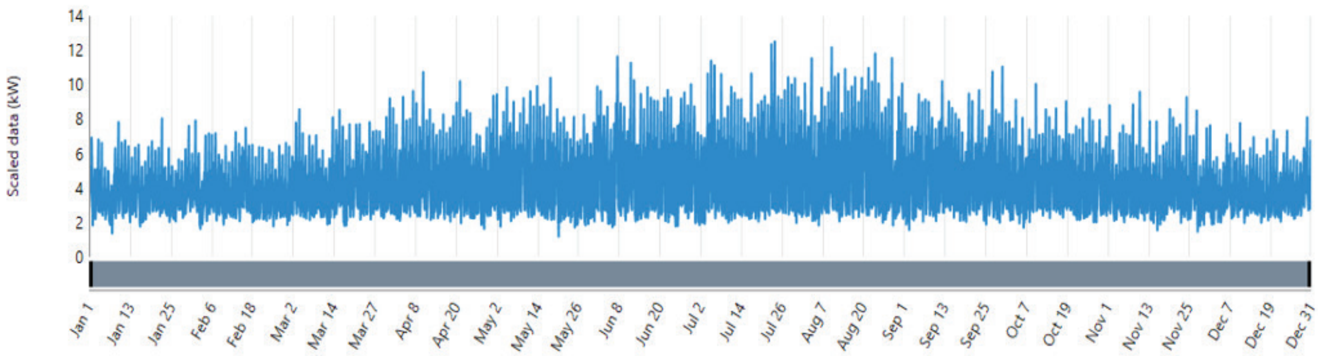


Scenario 2: Off-Grid MGs Application for Rural Villages/Areas Having Solar PV and Micro-Hydro Potential

This scenario is particularly important to analyse the feasibility for remote rural populations having a significant distance from the utility grid connection. This situation is especially relevant for Gilgit Baltistan, AJK, and the northern areas of KPK where a large number of areas are unelectrified and providing grid access to those areas is difficult and is not financially viable. These areas possess large hydropower potential and most of them are blessed with natural scenic beauty, rendering them attractive to tourists. Pakistan was declared as one of the top 10 tourist destinations in the world, while recently the GOP, with the collaboration of provincial governments, has announced initiatives to promote the tourism industry in Pakistan. However, the lack of reliable electricity access especially for clean heating in these areas is a problem. Moreover, burning wood to meet the heating demand in these areas not only affects the environment but also affects the GoP target of promoting tourism in these areas. Hence, off-grid MGs deployment in these areas is a feasible option. The sample feasibility of off-grid MG deployment is discussed in the following section.

A village near Chitral, named Kiyar was considered with geographical coordinates of 36°5.9'N, 71°51.0'E. The following load profile is considered with a peak load of 12.51 kW and annual average energy of 100 kWh/day.

Figure 9: Load Profile for Scenario 2



In order to meet this demand profile of electricity, the schematic as shown in Figure 10 was modelled in the software with the option to optimize the selection and size of the most feasible option considering the real solar and wind profiles from the NASA database.

Figure 10: Schematic Diagram for Scenario 2

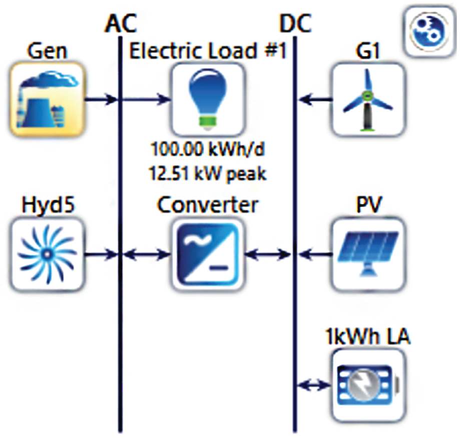


Figure 11: Wind Speed Data for Scenario 2

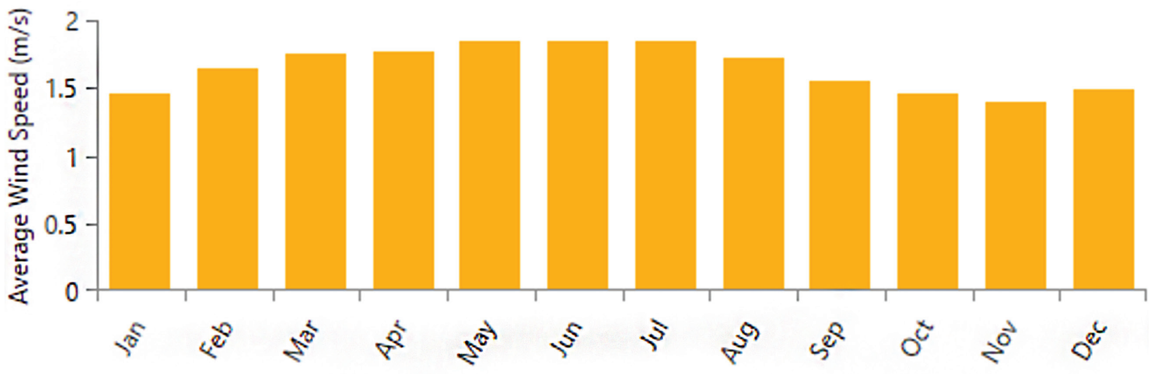
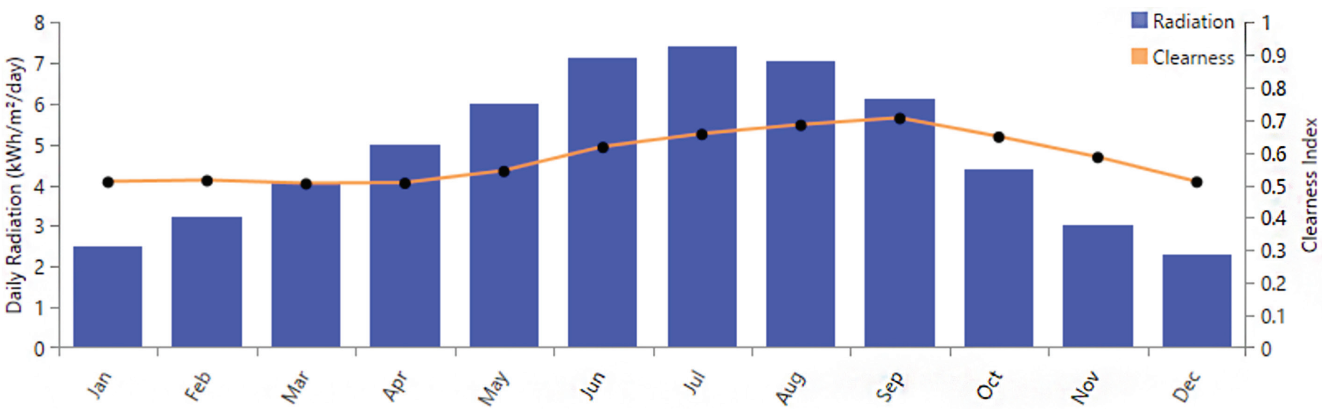
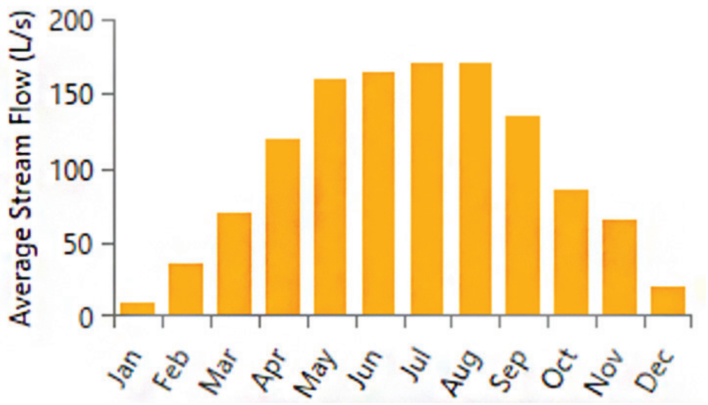


Figure 12: Solar Irradiance Data for Scenario 2



The stream flows assumed for the micro-hydro plant are shown in Figure 13. Available head of 7 m and pipe head loss of 10% are also assumed.

Figure 13: Hydro Flow Data for Scenario 2



Different options were considered to determine the most feasible one for the MG, summarised in Table 8 below.

Table 8: Considered Combinations for Scenario 2

Option No.	Combination
1	Diesel Generator Only
2	Solar PV Only
3	Wind Only
4	PV + Wind
5	PV + Storage
6	Wind + Storage
7	PV + Wind + Storage
8	PV + Wind + Storage + Diesel Generator
9	PV + Diesel Generator
10	Wind + Diesel Generator
11	PV + Storage + Diesel Generator
12	Wind + Storage + Diesel Generator
13	Micro-hydro Only
14	PV + Wind + Storage + Micro-Hydro + Diesel Generator
15	PV + Wind + Storage + Micro-Hydro
16	PV + Micro-Hydro
17	Wind + Micro-Hydro
18	Storage + Micro-Hydro
19	Micro-Hydro + Diesel Generator
20	Storage + Micro-Hydro

21	PV + Wind + Micro-Hydro
22	PV + Storage + Micro -Hydro
23	Wind + Storage + Micro-Hydro
24	Storage + Micro-Hydro + Diesel Generator
25	PV + Micro-Hydro + Diesel Generator
26	Wind + Micro-Hydro + Diesel Generator

From the above combinations, option 22 was determined to be the most feasible one. The optimised size/rating of each component is given in Table 9 below.

Table 9: Optimised System Size for Scenario 2

Component	Type	Size	Unit
PV	Generic flat plate PV	30	kW
Storage	Generic 1kWh Lead Acid	32	Strings
Micro-Hydro	5kW Generic	5.84	kW
System converter	System Converter	5.26	kW

Net present costs of each category of the selected components are summarised in Table 10.

Table 10: NPC for Scenario 2

Component	Net Present Cost ($)				
	Capital	Operating	Replacement	Salvage	Total
5kW Generic Micro - Hydro	$5,000	$1,829	$0.00	$360.42	$6,468
Generic 1kWh Lead Acid Battery	$11,200	$14,630	$13,666	$0.00	$39,496
Generic flat plate solar PV	$14,860	$12,533	$0.00	$0.00	$27,393
System Converter	$3,153	$360.40	$1,197	$0.00	$4,711
Total System	$34,213	$29,352	$14,863	$360.42	$78,068

Technical results related to load, storage, and generation from various resources are summarised in Table 11.

Table 11: Technical Results of Scenario 2

Component	Value	Unit
AC Primary Load	34,808	kWh/Year
Solar PV Production	59,750	kWh/Year
• Hours of Operation	4,383	Hours/year
• Levelised Cost	0.0201	$/kWh
Hydro Production	38,174	kWh/Year
• Hours of Operation	8,016	Hours/Year
• Levelised Cost	0.00741	$/kWh
Energy Input to the Battery Storage	2,846	kWh/Year
• Annual Throughput	2,572	kWh/Year
• Autonomy	6.15	Hour
Energy Input to the Converter	6,595	kWh/Year
• Hours of Operation	3,851	Hours/Year

It is important to mention here that although per unit cost for micro-hydro was far less than PV and wind sources, the software guided us to choose only 5kW (39%) from the hydro source. This is because the hydro flow is almost negligible during winter months, therefore, other sources, such as solar PV, would be needed to meet the load demand ensuring supply reliability to the consumers.

Another important aspect to consider is excess electricity generation as compared to load demand. Here again, the reason is intrinsic intermittency and uncontrollability of electricity generation from renewable energy sources. However, it must be highlighted that this excess electricity is the minimum excess electricity generated keeping in view the factors of load variability, renewables intermittency, and supply reliability. If not properly sised or designed, the excess electricity can increase which will result in increasing the LCOE. The issues related to unwanted power flows and voltage control can be managed by a system controller of the MG system.

Now, comparing Base System (option 1) with the proposed optimised system, the IRR of the proposed system came out to be 66.1%, while discounted payback period and simple payback periods were found to be 1.57 years and 1.53 years, respectively. A brief comparison of the base system and the proposed system is given in Table 12.

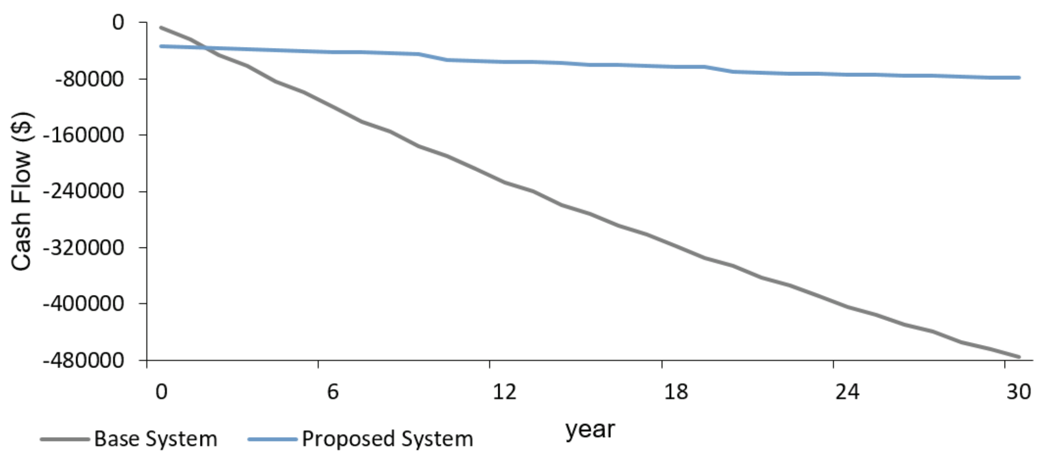
Table 12: Comparison with Diesel Generator Option for Scenario 2

Component	Base System	Proposed System
Net Present Cost	$475,276	$78,068
CAPEX	$7,000	$34,213
OPEX	$20,485	$1,918
LCOE (per kWh)	$0.570	$0.0981
CO_2 Emitted (kg/year)	42,276	0
Fuel Consumption (Liter/year)	16,151	0

The Levelised Cost of energy (LCOE) turned out to be $0.0981/kWh, which is quite reasonable.

A graphical comparison of the Base and the proposed system in terms of cash flows for the project's lifetime is shown in Figure 14.

Figure 14: Cash Flows Comparison for Scenario 2

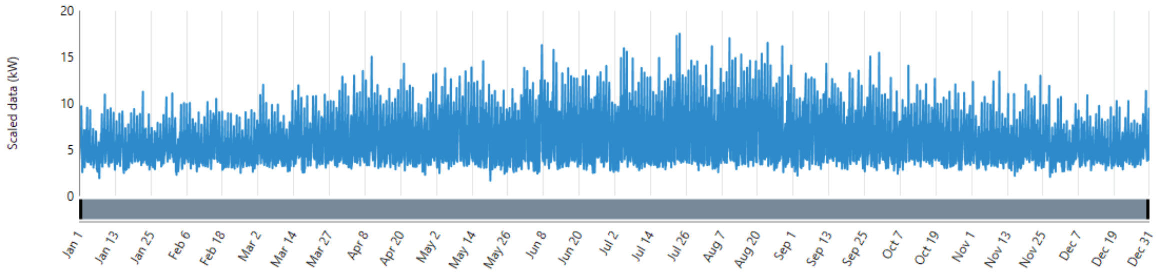


Scenario 3: Grid-Connected MGs Application for Housing Societies or Commercial Centres in Urban Areas having Utility Electricity Access

This scenario is particularly important to analyse the feasibility of housing societies or commercial centres situated in urban areas having utility electricity connections. This situation is relevant for large cities in Punjab, KPK, and Sindh, where a lot of private housing societies and large commercial centres already exist or will be developed in the near future. The rationale for considering this MG feasibility here is its ability to create a win-win situation for both the government as well as the private sector. This aspect is discussed later in this section.

A small housing society in Lahore near Sunder Raiwind was considered with geographical coordinates of 31°14.7'N, 74°12.8'E. The following load profile was considered with a peak load of 17.51 kW and annual average energy of 140 kWh/day.

Figure 15: Load Profile for Scenario 3



In order to meet this demand profile of electricity, the schematic as shown in Figure 16 was modelled in the software with the option to optimize the selection and size of the most feasible option considering the real solar and wind profiles from the NASA database.

Figure 16: Schematic Diagram for Scenario 3

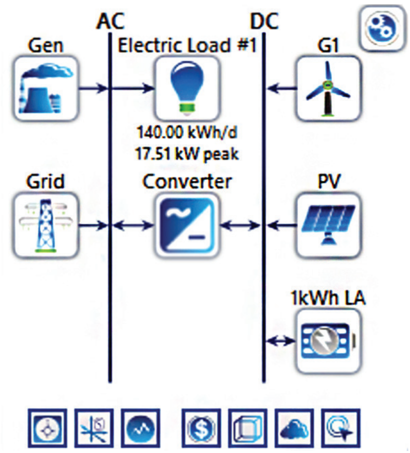


Figure 17: Wind Speed Data for Scenario 3

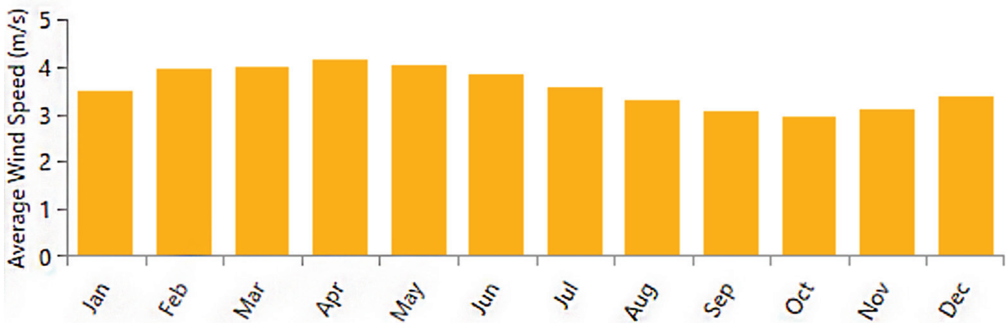
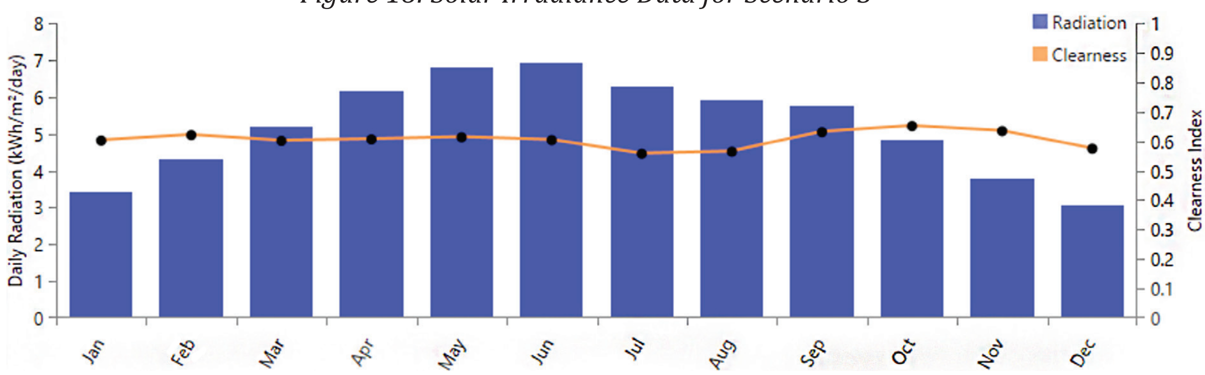


Figure 18: Solar Irradiance Data for Scenario 3



Different options were considered to determine the most feasible one for the MG, summarised in Table 13.

Table 13: Considered Combinations for Scenario 3

Option No.	Combination
1	Diesel Generator Only
2	Solar PV Only
3	Wind Only
4	PV + Wind
5	PV + Storage
6	Wind + Storage
7	PV + Wind + Storage
8	PV + Wind + Storage + Diesel Generator
9	PV + Diesel Generator
10	Wind + Diesel Generator
11	PV + Storage + Diesel Generator
12	Wind + Storage + Diesel Generator
13	Grid Only
14	PV + Wind + Storage + Grid + Diesel Generator
15	PV + Wind + Storage + Grid
16	PV + Grid
17	Wind + Grid
18	Storage + Grid
19	Grid + Diesel Generator
20	Storage + Grid
21	PV + Wind + Grid
22	PV + Storage + Grid
23	Wind + Storage + Grid
24	Storage + Grid + Diesel Generator
25	PV + Grid + Diesel Generator
26	Wind + Grid + Diesel Generator

From the above different combinations, option 16 was determined to be the most feasible one and the optimised size/rating of each component is given in Table 14.

Table 14: Optimised System Size for Scenario 3

Component	Type	Size	Unit
PV	Generic flat plate PV	21.3	kW
Grid	Grid	-	kW
System converter	System Converter	9.14	kW

Net present costs for each category of the selected components are summarised in Table 15.

Table 15: NPC for Scenario 3

Name	Net Present Cost ($)				
	Capital	Operating	Replacement	Salvage	Total
Generic flat plate PV	$10,563	$8,909	$0.00	$0.00	$19,472
Grid	$0.00	$91,237	$0.00	$0.00	$91,237
System Converter	$5,484	$626.85	$2,082	$0.00	$8,194
Total System	$16,048	$100,773	$2,082	$0.00	$118,903

Technical results related to load, conversion, and generation from various sources are summarised in Table 16.

Table 16: Optimised System Size for Scenario 3

Component	Value	Unit
AC Primary Load	51,100	kWh/Year
Solar PV Production	45,205	kWh/Year
• Hours of Operation	4,383	Hours/Year
• Levelised Cost	0.0188	$/kWh
Grid Purchase	26,608	kWh/Year
• Levelised Cost	0.15	$/kWh
Energy Input to the Converter	29,680	kWh/Year
• Hours of Operation	4,383	Hours/Year

Now, comparing the Base System (option 1) with the proposed optimised system, the IRR of the proposed system turned out to be 20%, while discounted payback period and simple payback period were found to be 5.22 years and 4.93 years, respectively. A brief comparison of the Base System and the proposed system is given in Table 17.

Table 17: NPC for Scenario

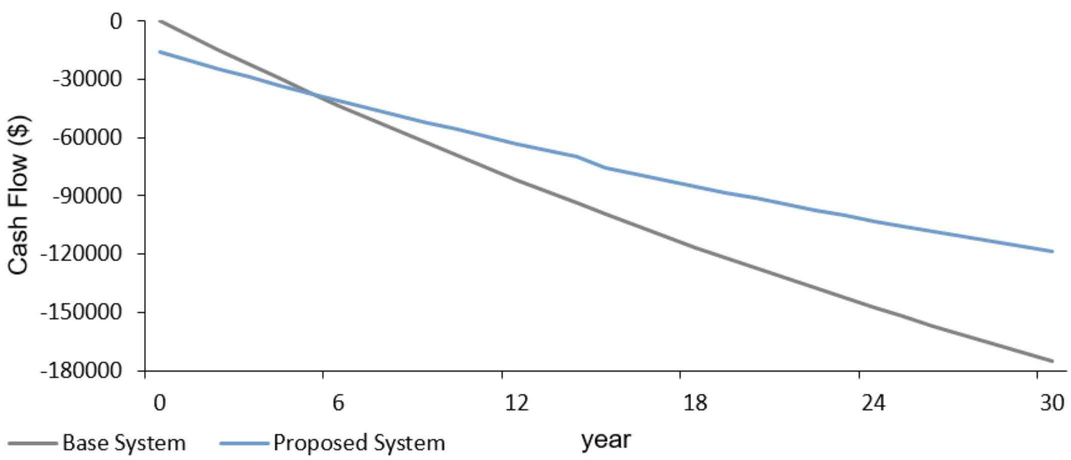
Component	Base System	Proposed System
Net Present Cost	$175,218	$118,903
CAPEX	$0.00	$16,048
OPEX	$7,665	$4,499
LCOE (per kWh)	$0.150	$0.0929
CO_2 Emitted (kg/Year)	32,295	16,816
Fuel Consumption (Liter/year)	0	0

The Levelised Cost of energy (LCOE) came out to be $0.0929/kWh, which is significantly lower than the existing grid-provided electricity tariff rate.

It is evident from the above analysis that the LCOE, which the end-consumer has to bear for only grid connection (0.15/kWh), would drop to $ 0.0929 $/kWh. Therefore, it holds substantial financial viability for end-consumers living in urban centres/housing societies.

Now, considering it from the perspective of the government, the need for investment planning for lesser energy/power, environment-friendly electricity generation, improving energy efficiency targets, and job creation in the private sector are some of its advantages. It also supports the democratisation objective of the electricity/energy sector aligned with globally accepted 3D targets of decarbonise, decentralise, and democratise. A graphical comparison of the base and proposed systems in terms of cash flows for the project lifetime is given in Figure 19.

Figure 19: Cash Flows Comparison for Scenario 3



FURTHER INSIGHTS INTO MODELLING, ANALYSIS, SIMULATION, AND RESULTS

In this section, further insights into the scenarios presented above are discussed. An advanced study comprising sensitivity analysis and multiyear analysis was performed to further validate and deliberate upon the discussed scenarios. A special application of MGs, namely, Deferrable Load Analysis, in Pakistan's rural areas for irrigation is discussed. Moreover, considering the rapid advancement in technology, the application of direct current (DC) MGs is also analysed as compared to conventional alternating current (AC) MGs.

It is important to highlight that the main purpose of the above-mentioned analyses was to present further insights and methodologies, which is why it was performed only for a few of the selected cases and applications. The need of performing these analyses or even more advanced ones depends upon the exact application and model of a specific project, therefore, results may vary from one project to another.

Sensitivity Analysis

Sensitivity analysis, also known as 'what-if analysis,' is required to assess the impacts of changes in various input parameters on the results of the analysis. The most important input parameters for performing sensitivity analysis are:

- Permitted capacity shortage (%)
- Project lifetime (Years)
- Discount rate (%)

These parameters were allowed to vary over a range of values and the resulting impact on LCOE was observed.

Table 18: Sensitivity Range for the Input Parameters

S.#.	Permitted Capacity Shortage (%)	Project lifetime (Years)	Discount rate (%)
1	0	5	1
2	0.5	10	2
3	1	15	3
4	1.5	20	4
5	2	25	5
6	2.5	30	6
7	3		7
8	3.5		8
9	4		9
10	4.5		10
11	5		
12	10		
Total	12	6	10

Based on the range of input parameters as highlighted in Table 1, a total number of 720 (12*6*10) scenarios/sensitivities were simulated through HOMER Pro for Case 1. Out of these 720 sensitivities, two are compared below as an example.

- Sensitivity A (Discount rate = 10, Project lifetime = 5 years, Capacity Shortage = 0%)
- Sensitivity B (Discount rate = 5, Project lifetime = 30 years, Capacity Shortage = 10%)

Table 19: Sensitivity A vs Sensitivity B

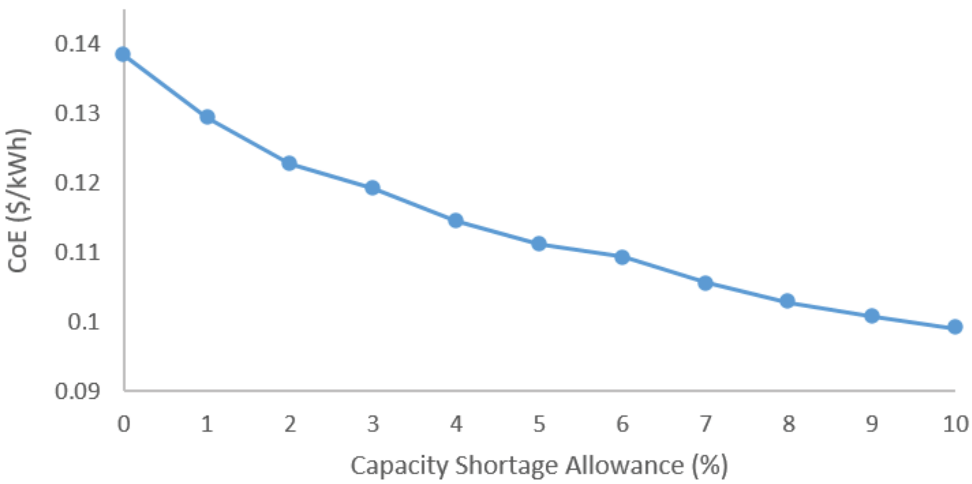
Component	Sensitivity A	Sensitivity B
Net Present Cost	$22,079	$83,957
CAPEX	$33,984	$25,841
LCOE (per kWh)	$0.177	$0.0729

It can be observed that the LCOE decreased either by increasing the project lifetime and the allowed capacity shortage or by decreasing the discount rate.

These sensitivities, along with other similar sensitivities, may be simulated for a specific project to identify the optimal solution as per the requirements. It is interesting to note that MGs' feasibility analysis is a multi-dimensional optimisation task where the project owner has to decide which energy mix will be installed to meet the electricity requirements of the consumers.

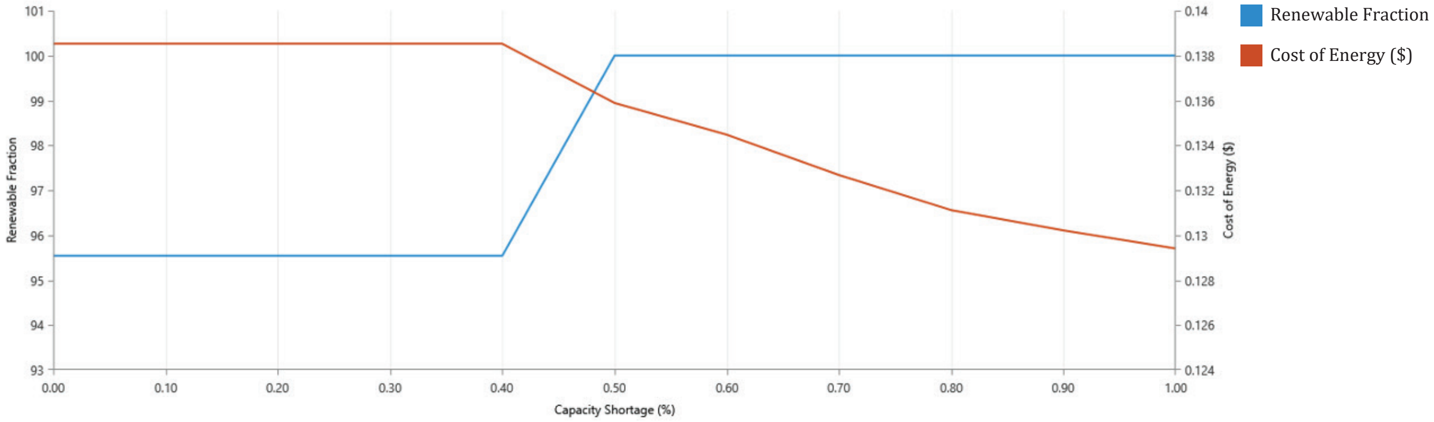
For example, let us consider the sensitivity of the cost of energy (CoE) with the capacity shortage allowance as shown in Figure 20. It is evident that the CoE decreased exponentially with the increase in the allowed capacity shortage.

Figure 20: CoE vs Capacity Shortage Allowance



An interesting behaviour was observed concerning the renewable fraction in the energy mix for the MG. For a capacity shortage allowance of up to 0.4 %, it is essential to include a conventional generator to determine the optimal resources for the MG, as shown in Figure 21. The corresponding graph for the CoE is also plotted below.

Figure 21: CoE and Renewable Fraction vs Capacity Shortage Allowance



Similarly, the relationship of CoE with discount rate and project lifetime can be easily observed as increasing linear and decreasing exponential respectively, as shown in Figure 22 and Figure 23.

Figure 22: CoE Vs Discount Rate

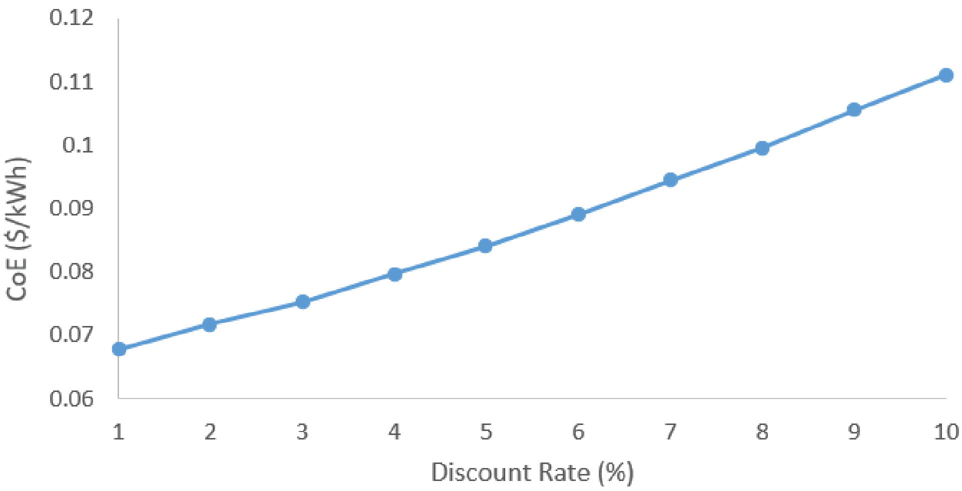
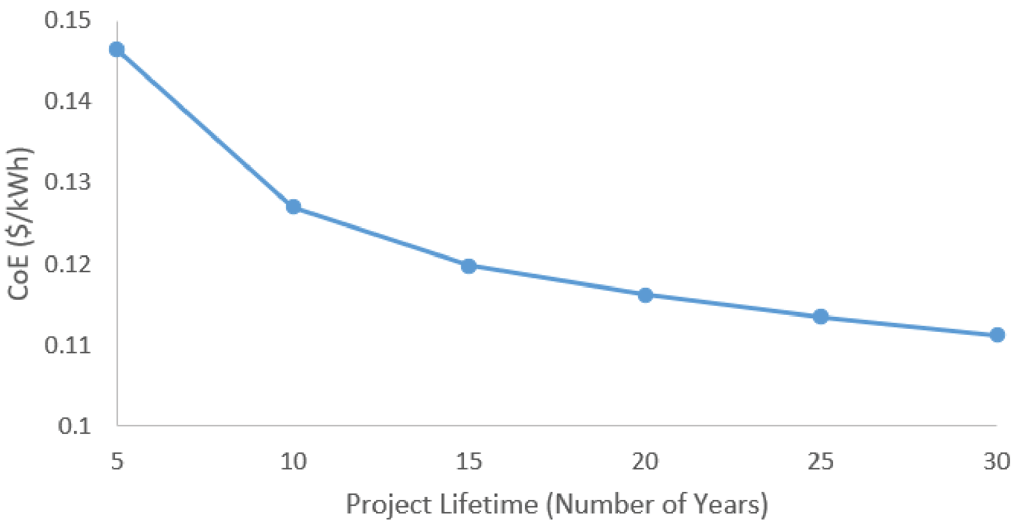


Figure 23: CoE Vs Project Lifetime



The impact of these critical factors is an important insight for policymakers. For example, if the customers want the provision of supply 100% of the time, the price of per-unit electricity may increase by 200% as compared to the customers who want 95% of the time. Again, this must be correlated with the consumer affordability index which varies significantly across the country. In line with the regulator's intent of deregulating this sector completely, it can be anticipated that it is the project owner who will conduct this sort of preliminary analysis to safeguard the investment, which would be depicted in the bilateral contracts between the project owner and the customers.

Multiyear Analysis

A multiyear analysis was performed by inputting future cost projections of solar PV and wind to provide a more realistic insight for the future. Following are the cost projections for solar PV and wind energy in $/kW taken from IGCEP 2021.

Table 20: Sensitivity A vs Sensitivity B

Year	Solar PV Cost ($/kW)	Wind Cost ($/kW)
2021	511	1274
2022	494	1261
2023	476	1249
2024	460	1236
2025	444	1224
2026	428	1212
2027	413	1200
2028	399	1188
2029	385	1176
2030	371	1164

Due to HOMER Pro's license restrictions, the multiyear analysis could not be performed for this study. It is important to highlight here that the results summarised in the previous modelling section will improve, i.e., LCOE will further decrease if a multiyear analysis is incorporated.

Deferrable Load Analysis

Deferrable load analysis was performed to analyse a very practical application of irrigation in Pakistan's rural areas. Without going into details about the irrigation system, we analysed the application of MGs in the agriculture sector of Pakistan, aligning the terminologies used in our analysis with those in agriculture.

Deferrable load is the load for which the exact timing of the electricity provision does not matter. However, it requires a certain amount of energy in a specific period. Loads are normally categorised as deferrable when they are linked with the availability of storage. Water pumping is a common example of deferrable load in rural areas of Pakistan. Thus, this special case was analysed here with respect to MGs' widespread deployment in the country.

An example of an agricultural area was considered in which the water requirement of 50 m^3 for irrigation was assumed. We supposed that there was a water storage provision of 175 m^3. The rated capacity of the water pump was assumed to be 5 kW and it was assumed that it pumped approximately 25 m3 per hour. The following parameters were used in the model to analyse the situation:

- Peak load = 5 kW
- Storage capacity = (175/25) hours x 5 kW = 35 kWh
- Average deferrable load = (50/25) hours per day x 5 kW = 10 kWh/day

Since deferrable load provides extra flexibility for the modelling of the MGs, it was anticipated that the LCOE for this case (considering deferrable loads of the agricultural sector) would be lesser than that of normal rural loads. The simulations' comparison of both cases is provided in Table 25.

Table 21: Comparison: Normal Load vs Deferrable Load

Cost	Deferrable Load	Normal Load
Net Present Cost	$64,059	$78,095
CAPEX	$28,999	$33,289
OPEX	$1,534	$1,960
LCOE (per kWh)	$0.0976	$0.119

It is evident from the above comparison that MGs application to irrigation is a feasible case and has more economic viability.

DC MG Analysis

DC MGs have become a reality in recent years. We compare the already presented Scenario 1 with another scenario in which we replaced AC with DC MG. Here the AC Load was converted to DC load, which resulted in avoiding the requirement of the AC bus and the converter. The main parameters and results of the two scenarios are tabulated below for comparison:

The optimised size/rating for each component for the two scenarios is shown in Table 26.

Table 22: Comparison: Optimised System Size for Scenario 1 vs DC MG

Component	Type	Unit	Scenario 1	Scenario 1 (DC MG)
PV	Generic flat plate PV	kW	21.1	17.3
Storage	Generic 1kWh Lead Acid	Strings	19	20
Wind turbine	Generic 1 kW	kW	4	5
System Converter	System Converter	kW	8.04	0

Net present costs for each category of the selected components are summarised in Table 27:

Table 23: Comparison: NPC for Scenario 1 vs DC MG

Component	Net Present Cost ($)	
	Scenario 1	Scenario 1 (DC MG)
Generic 1 kW Wind Turbine	$9,573	$11,966
Generic 1kWh Lead Acid Battery	$28,041	$28,788
Generic flat plate solar PV	$19,299	$15,824
System Converter	$7,207	$0
Total System	$64,120	$56,579

Technical results related to load, storage and generation from various resources are summarised in Table 28.

Table 24: Comparison: Technical Results for Scenario 1 vs DC MG

Component	Unit	Scenario 1	Scenario 1 (DC MG)
Primary Load	kWh/Year	25,233	25,233
Solar PV Production	kWh/Year	46,840	38,407
• Hours of Operation	Hours/Year	4,388	4,388
• Levelised Cost	$/kWh	0.0180	0.018
Wind Production	kWh/Year	9,857	12,321
• Hours of Operation	Hours/Year	7,460	7,460
• Levelised Cost	$/kWh	0.0425	0.0425
Energy Input to the Battery Storage	kWh/Year	4,660	4,708
• Annual Throughput	kWh/Year	4,174	4,216
• Autonomy	Hour	5.07	5.34
Energy Input to the Converter	kWh/Year	25,488	0
• Hours of Operation	Hours/Year	8,715	0

A brief comparison of the two is given in Table 29.

Table 25: Comparison: Scenario 1 vs DC MG

Cost	Scenario 1	Scenario 1 (DC MG)
Net Present Cost	$64,120	$56,579
CAPEX	$27,836	$22,949
OPEX	$1,587	$1,471
LCOE (per kWh)	$0.111	$0.098

The Levelised Cost of energy (LCOE) turned out to be $0.098/kWh in the case of DC MGs as compared to $0.111/kWh.

MGs with Day-Only Load

The load profile significantly affected the LCOE. For example, when the load profile was changed to a day-only load, LCOE turned out to be $0.0677/kWh as compared to $0.111/kWh (in Scenario 1).

4. TECHNICAL CHALLENGES AND SOLUTIONS

MGs are predominantly composed of distributed energy resources (DERs), which refer to a variety of small-scale electricity generation units and storage devices that are generally connected to an islanded electricity grid. In this chapter, the most relevant technical issues of MGs deployment in Pakistan and their possible solutions are discussed. It is important to highlight that the issues and their solutions are elaborated qualitatively since they may vary significantly from one case to another.

STABILITY OF MGs

To analyse the stability phenomenon in MGs, it is important to understand the fundamental modes of operations of various types of MGs described as follows.

Utility MG

A utility MG is connected to the main grid at one or more points, known as the point of common coupling (PCC). It can be operated in either a grid-connected mode or islanded mode, based on its application. In the grid-connected mode, the voltage and frequency of the MG are synchronised with the main grid, while in islanded mode, the MG is not connected to the grid.

Facility MG

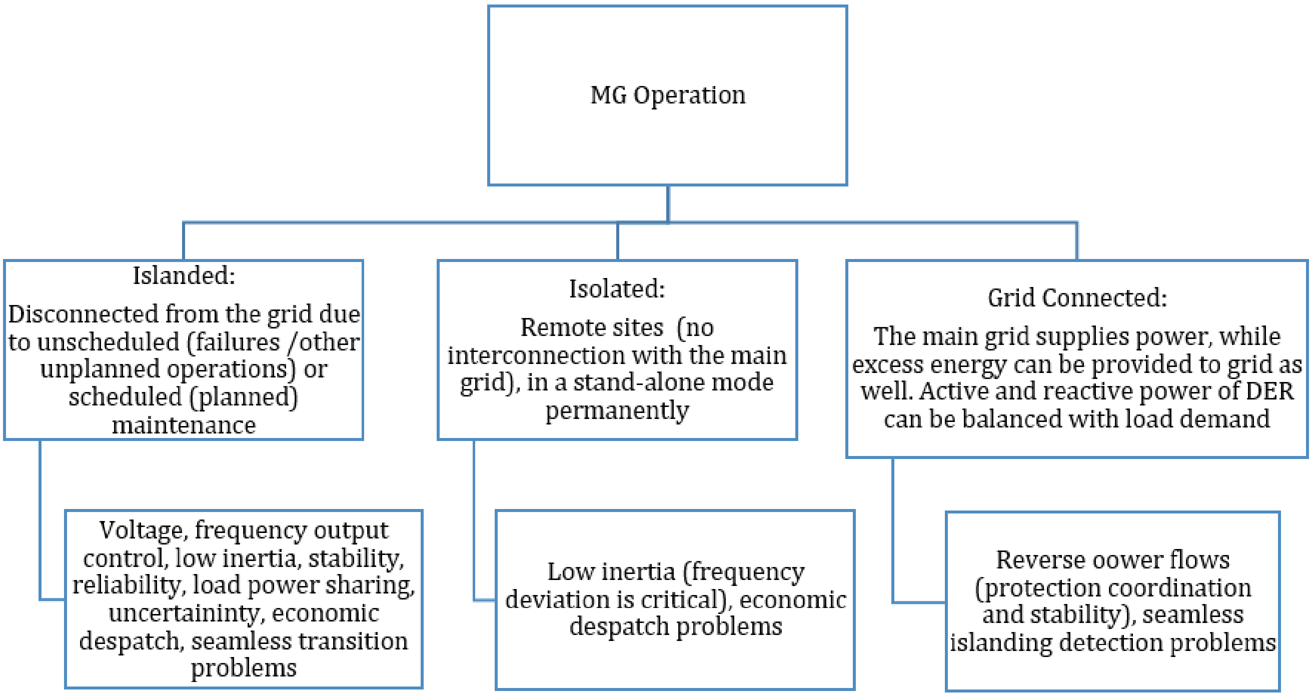
An MG can also be designed to provide a dedicated power supply to a single business entity, i.e., an institutional or industrial facility. This type of grid is known as facility MG and it can also be operated either in a grid-connected or islanded mode.

Isolated or Remote MG

There is also another type of MG which is classified as isolated or remote MG. It is not linked with the main grid or a utility, and decentralised control techniques are used for its operation.

Major issues associated with different modes of operation of MGs are summarised in Figure 24.

Figure 24: Major Issues in Various MG Operational Modes



Stability Challenges

In a conventional power system, synchronous generators are usually high in number and the inertia of these rotating generators helps them withstand transitions. However, typically MG systems do not have such a large number of synchronous generators and, therefore, the rotating mass and inertia of the system are low. Consequently, MGs cannot handle transients in the same way as conventional power systems can. Low inertia is an important concern for MGs. In addition to that, the existence of power electronics devices makes MGs unique and different in comparison to the conventional power system, which necessitates effective and efficient control techniques for MGs. It is important to recall that there exists an inverse relationship between frequency deviation and inertia of the system. Moreover, Voltage Source Converters (VSC), used for renewable energy generators, do not provide inertia, and also have limitations on switches' current ratings and droop control characteristics. Therefore, MGs intrinsically have instability problems in terms of frequency and voltage regulation. In literature, control techniques based on virtual inertia have been been shown to enhance the ability of the system to withstand large deviations in frequency during major faults and disturbances (Abdel & Oboskalov, 2020). Undesired load shedding can also be reduced in isolated MGs using these techniques.

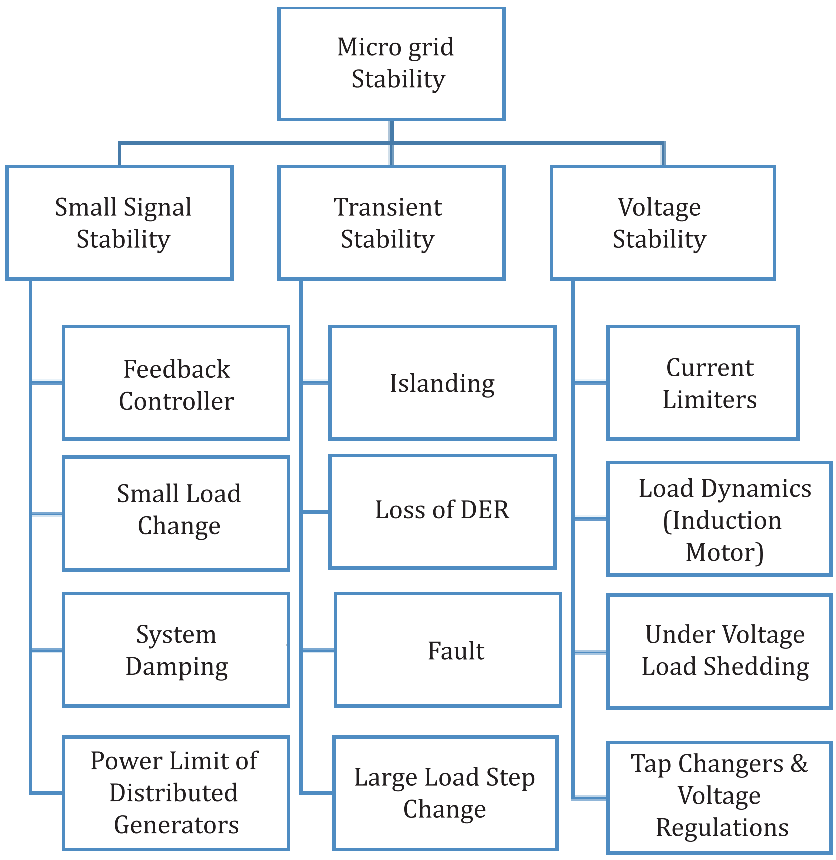
In the case of the grid-connected MGs, bidirectional flow (to and from MG – to and from the main grid) of active and reactive power is possible and excess energy produced by generators of MGs can be sold to the main grid. One of the advantages is that the main grid also provides voltage and frequency references. The load can be served by power from the main grid as well as from the generators of MGs. In the case of disconnection from the grid, the transition from the grid-connected mode to islanded mode should be smooth and seamless. In this scenario, either demand may be reduced or generation increased to tackle the supply-demand gap. This transition can bring instability to the MG if not properly handled through adequate frequency/voltage control techniques, accurate and fast islanding detection schemes, or the provision of enough supply of power through backup generation sources.

In the isolated mode, the MG is installed at a remote location and it is not connected to the grid. The issues with isolated mode are similar to that of islanded mode MGs. In the islanded mode of operation, if the output of solar power is reduced due to clouds, the power from other sources cannot be added to the system promptly to overcome the supply-demand gap at the same rate at which generation is reduced. Therefore, an energy storage system shall be an integral part of the islanded and isolated MGs so that the energy balance may be achieved without endangering system reliability.

The stability issues are divided into three groups here, i.e., small signal stability, transient stability, and voltage stability. Figure 25 shows the main reasons behind each class of issue.

It is pertinent to mention that DER feedback controllers with decentralised control techniques and current limiters are the reasons for small signal stability problem in a remote MG and utility MG, respectively. Numerous load-switching events within a relatively small area often produce small signal stability issues in a facility MG (Micallef, 2019). Islanding as a result of fault is the most common reason behind stability issues in utility or facility MGs. The occurrence of fault and isolation of a faulty section produce transient stability problems in remote MGs too. As far as voltage stability issues in MGs are concerned, the lack of reactive power compensation is the main cause.

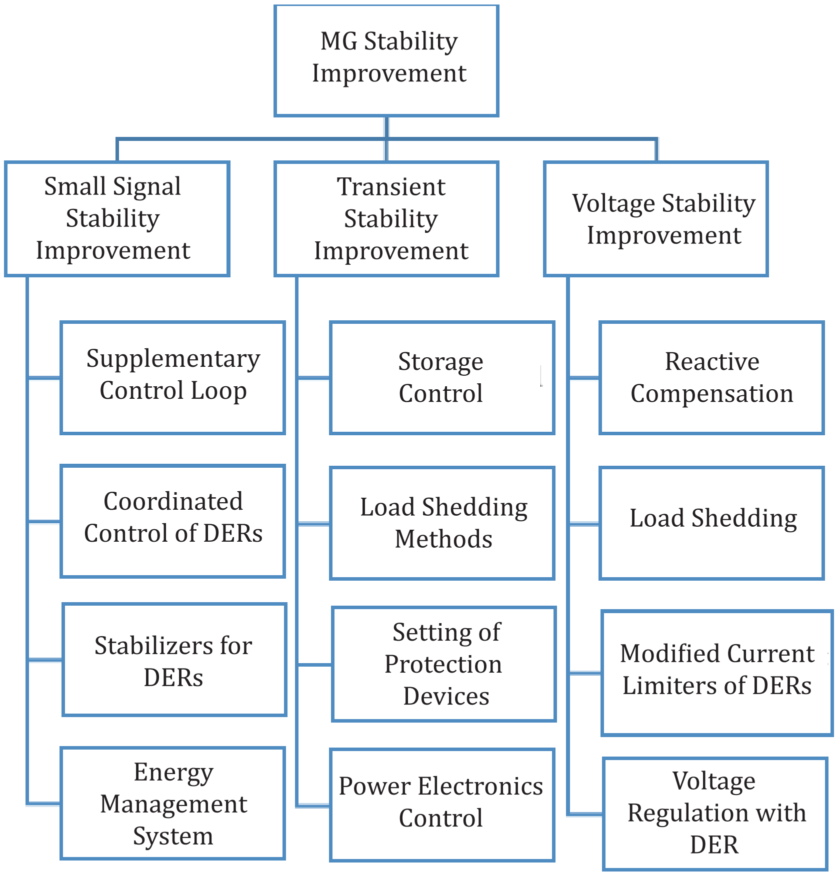
Figure 25: Main Reasons for Stability issues in MGs



Stability Improvement Methods in Microgrids

Figure 26 shows various methods of stability improvements, a few of these are discussed below.

Figure 26: Methods of Stability Improvement



Stabilizer

In order to improve small signal stability, stabilisers may be used with the VSC of DERs. The stabiliser can be introduced in any of the control loops. Here, the energy output, frequency, and voltage magnitude are inputs to the control system of stabilizers.

Reactive Power Compensation with DSTATCOM

In order to keep the voltage within prescribed limits, reactive power compensation in an MG is essential. Remote and utility MGs face most of the voltage regulation, issues which can be of the following two types:

- Voltage regulation issue occurring at the load side of the feeder in the grid-connected mode.
- Deviation of voltages below the prescribed limit anywhere in the islanded mode.

The distribution static compensator (DSTATCOM) is connected near the critical load to make sure the desired power quality. DSTATCOM injects reactive power whenever required by the system.

Energy Storage System: Flywheel

Stability improvement is provided by Energy Storage System in MG by injecting active power (sometimes also reactive power) during a power outage, tripping, islanding, DER dynamics, and fault ride through until the backup diesel generators come online. There are many energy storage devices but the flywheel is the most effective one, particularly for MG applications. With a fly-wheel system, power within the value range of MW can be injected within one-fourth of a cycle. The flywheel system is connected with MG with back-to-back power converters. The first converter works as a fly-wheel drive and keeps the DC side voltage at the desired level. The second converter is on the grid side and injects reactive and real power based on the measured voltage and frequency.

Load Shedding for Stability Improvement

The role of load shedding becomes critical in MG stability during islanding. The power imbalance is created due to a sudden disconnection of the grid. The load shedding can be carried out with various techniques mentioned below:

- Breaker interlock
- Under Frequency Relay
- PLC-Based Load Shed
- Advanced Methods of load shedding using the optimisation process.

PROTECTION SYSTEM OF MGs

To ensure the safe and reliable operation of the power system, adequate protective equipment with fast operation, better selectivity, simplicity, and versatile setting arrangements has to be selected. The conventional protection schemes in the distribution network cannot operate well in an MG because of variations in fault current, intermittent nature, dynamic characteristics of the DERs, and bidirectional power flows from MGs. In this section, potential challenges and solutions thereof are discussed from the perspective of the MG protection system.

Challenges in MG protection systems

Major challenges encountered in MG protection are:

- Dynamics in fault current magnitude
- Loss of connection from the utility
- Blinding of protection

Variation in Fault Current Magnitude

The fault current levels vary significantly for MGs. In the grid-connected mode, the fault current is very high due to the presence of both the utility connection and the MG system.

The value of fault current is lower during the islanded mode since the only source in the MG is the low-capacity DERs. In addition to having low capacity, the maximum fault current contribution is also very low for DERs, i.e., 1.5 times and 5 times the rated current for DER and synchronous generators, respectively.

Since the values of fault current have a wide range of variability and depend on the operational modes, the number and type of DER and output generated by DERs, prediction or estimation of fault current remains challenging in the MG system.

Loss of Connection from Utility

The loss of connection from the utility refers to the partial or complete disconnection of an MG from the main grid. The reasons are as follows:

- The problem in the circuit breaker connecting the MG with the grid
- Fault in the grid

In the case of partial disconnection, unintentional islanding is dangerous for the personnel attending the fault because a section of the network is still energised where the islanding has not been detected. Generators in an islanded system may face uncontrolled frequency and voltage as well as unsynchronised reclosures of circuit breakers, which can damage measuring devices and customer equipment.

Blinding of protection

When a fault occurs in the MG at the far end of the feeder, the contribution of fault current is from both the utility and the DERs. Additional impedance is introduced due to the presence of DERs in comparison to a traditional grid, which increases the value of Thevenin's impedance at the fault point. Consequently, there is a probability that the short circuit current may become lower than the pick-up current of the relay. Therefore, the fault may remain undetected resulting in the failure of the protection system.

Solution to Protection Challenges

To isolate the least portion of the network after the occurrence of a fault and to ensure reliable operation, there is a need to design an adequate protection scheme for the MG. This can be accomplished by combining backup and primary protections. The induction of DERs increases the complexity of the system. Certain standard solutions are briefly discussed below:

Current limiter

The Fault Current Limiters (FCL) are installed near the PCC to limit the fault current contributed by DER in MG to the grid and to reduce the fault current contribution by the grid to MG.

Protection based on variables

MG protection can also be carried out based on several parameters, i.e., voltage and current sampling, angles, Total Harmonic Distortion (THD), Wavelet Packet Transform (WPT), and travelling wave (Micallef, 2019).

Directional relaying

Whenever there is a bidirectional power flow or reverse power flow, the malfunctioning of main relays of feeders can occur, which are being fed from the grid. This problem can be solved by the use of directional over current relays.

5. POLICY OVERVIEW AND REGULATORY FRAMEWORK

Setting up and upscaling MGs in different geographical and administrative areas of Pakistan would certainly contribute to improving the life quality of the common man, especially of the marginalised class through electricity access. The widespread deployment of MGs entails a well-deliberated and prudent policy framework. For this study, prevailing policies, i.e., the ARE Policy 2019 and National Electricity Policy 2021 were studied and analysed. The case studies of other regions/countries were also studied where the economic and social conditions, scenarios and issues are similar to that of Pakistan. This chapter also describes the challenges, barriers, prerequisites and other implications that may be faced while deploying MG in Pakistan from the policy perspective. The best practices followed by other regions for the resolution of various issues along with their outcomes were also analysed. Based on the existing policies, gap analysis carried out and lessons learnt from the international experience of MGs deployment, certain policy insights are presented. Finally, recent developments in MG regulatory framework are discussed and suggestions for improvement in the framework are also presented.

ANALYSIS OF EXISTING RELEVANT POLICIES

ARE Policy 2019

As per the ARE Policy 2019, MGs are included in the targets, i.e., at least 20% on-grid RE generation by capacity by 2025 and at least 30% by 2030. However, all MG projects, under the ARE Policy 2019, developed with public sector funding will be undertaken through competitive bidding. However, this condition will not be applied to private sector projects. The ARE Policy 2019 mandates the AEDB to be the focal entity for developing and operating MGs in Pakistan. The AEDB is responsible for the following:

- Monitor the MG projects to ensure adherence to appropriate safety standards for all the MG projects.
- Maintain enhanced coordination, information creation and sharing, regulatory intervention and contracting support functions.
- Initiate the process for a simpler licensing and regulatory framework to be approved by NEPRA within six months.

National Electricity Policy 2021

The policy, approved in June 2021, is aimed to reform the power sector. However, its aim is also to promote electricity access in areas where grid expansion is financially unviable, through exploring off-grid and micro-grid solutions. The policy further includes the provision of integrated planning for rural electrification and the provision of electricity to unserved areas of the country.

GAP ANALYSIS

The ARE Policy 2019 is aimed to create a conducive environment for the sustainable growth of the ARE sector in Pakistan and is not exclusively meant to focus on encouraging and pushing MG development in Pakistan. In order to target substantial upscaling of MG, Pakistan certainly requires dedicated policy intervention due to its distinctive nature and associated benefits as well as challenges.

On the other hand, according to the ARE Policy 2019, the AEDB needs to accelerate its efforts for the implementation of three major responsibilities, namely the monitoring of safety standards, support and coordination of the MG developers and other stakeholders, and initiating licensing and regulatory framework (which is currently under approval by NEPRA).

In order to promote and secure the upscaling of MGs in the country, the Government of Pakistan (GoP) is certainly required to address the policy gaps described in this section. Furthermore, the AEDB is required to proactively pursue its mandate in this regard.

The inclusion of exploring MG solutions in the National Electricity Policy 2021 in a highly broad manner does not reflect the strong commitment and serious undertaking on the part of the GoP for MGs development in Pakistan. It is, therefore, expected that the GoP will manage a comprehensive and realistic coverage of MGs in the National Electricity Plan, which is expected to be launched for the implementation of the National Electricity Policy 2021, covering the aspects, which are not limited to the following:

- What will be the roles and responsibilities of different stakeholders? For example, who will build, operate, and maintain the distribution infrastructure? What will be the role of the NTDC, and DISCOs concerning MG interconnections? What will be the role of provincial/territorial government, if any, in the context of the 18th amendment concerning autonomy in electricity generation? What will be the role of donors and IFIs in the MG deployment in Pakistan?

- Will the tariff of MGs be regulated or not? If yes, what would be the ceiling on non-regulated tariffs assuming that very small MG will not be regulated?

- Will grid-connected MG projects be allowed to become distributors of electricity purchased from the centralised grid?

- How simple regulatory framework will be? Will a license be required to become an MG operator? If yes, will the license be required for all or only for MGs above a certain kW capacity?

- What will be the legal and regulatory framework, and mechanism for the acquisition and the utilisation of public sector land for MGs development and operation?

- Will the MG sector be subsidised or not, e.g. through the allocation of 100% free or partly subsidised Public sector land?

- Will the private housing societies be allowed to have their own MG setup? Will they be allowed net metering or not? Up to what capacity if yes? Will licensing be required or not?

EXISTING MG EXPERIENCE IN PAKISTAN

It is important to mention here that the MG development has already been initiated in a few geographical areas of Pakistan. In order to facilitate new MG projects, there is a need of showcasing the MGs' feasibilities, projects, technologies, ready-made business plans, financing options, etc. Moreover, an integrated study may also be carried out for the whole country with respect to potential and opportunities related to MGs. Master database may be prepared and shared widely (data of all the existing microgrids, potential for new such options, investment opportunities, funding opportunities, etc.) among the potential sponsors and other stakeholders.

Status of MG Projects Under Government of Khyber Pakhtunkhwa (GoKP)

The GOP has done exemplary work in the area of MG development without any structured policy or regulatory framework/guidelines. Currently, it is developing 13 MG projects based on solar PV.

Pakistan Poverty Alliance Fund (PPAF)

The PPAF is implementing 68 state-of-the-art solar energy MG projects in remote and off-grid locations of Lakki Marwat, Swabi, and Karak. These MG systems will provide basic lighting requirements as well as support village-level businesses and local enterprises. An estimated 515 tons of CO2 emissions will be avoided annually through these projects.

INTERNATIONAL EXPERIENCE OF MGs DEPLOYMENT

The democratisation of the power sector is indispensable for sustainability and enhanced access to clean energy. MGs may be explored as an option to provide an optimal value of money to the investor and consumer as well as to enhance supply reliability, optimize operational costs, and protect the environment. However, it poses a difficult and unique set of challenges in terms of design, development, and implementation. This section reviews various dimensions of MG deployment barriers that are needed to be overcome to achieve success in MG deployment. The section also reviews the prerequisites and other implications that may be faced in MG deployment in Pakistan. These dimensions were analysed by studying various case studies of MG deployment in Asian and African regions having demographics and economic conditions similar to that of Pakistan.

Three tiers in MG development were identified to deconstruct the challenges: (1) decision-makers or policymakers, (2) investors, and (3) Consumers. Each of these tiers has its own set of barriers/constraints, which are required to be overcome.

Decision or Policy Makers

This is the most critical tier in the upscaling of MGs in Pakistan. Policymakers, which include regulatory institutions, must design and provide a conducive environment for investors and consumers of MGs. One of the key considerations should be that the tailor-made, bottom-up expectations of the customer meet the top-down decisions of the policymakers (Bijker et al.,1987).

Two fundamental questions are expected to arise while designing this policy. The first is how the different tiers interact from the perspective of upcoming MG solutions. The second question is how different stakes associated with MGs, are managed by the local community and other stakeholders. (Bijker et al.,1987 and Williams & Edge (1996). This may require the policymakers to prescribe institutional changes meant to facilitate the ease of business opportunities (Motjoadi et al., 2020).

In addition to considering the consumer side of the scenario, policymakers must address the investor side as well.

They need to decide the level of participation from both the public sector and the private sector (Motjoadi et al., 2020). One of the key issues regarding the non-involvement of the private sector is the lack of specified policies and regulations for MGs. The policy considerations for investors must include (1) long-term certainty in the market development; (2) addressing risks associated with the presence of a centralised grid; (3) meeting various regulatory requirements; and (4) providing sustainable operation and cost-recovery through tariff regulation and financial support schemes (Williams & Edge, 1996).

The international experience tells that it is important to have dedicated policies for MG deployment. The inclusion of MGs in the national electricity policy and plan may encourage the MG market. For example, Sierra Leone and Rwanda have dedicated policies for MGs deployment. Nigeria, Peru and Tanzania, have all included MG solutions in their plans. Furthermore, Rwanda's National Electrification Plan, published by its national utility, has demarcated areas for MGs expansion (IRENA, 2018).

Another critical policy-level issue is the MGs replacing conventional grids in their application areas and the strategies to deal with the stranded cost of transmission and distribution assets (Motjoadi et al., 2020). The policymakers of Indonesia, Nigeria, Rwanda, and Tanzania, for example, have incentivised MGs operators to utilise net-metering provisions with the central grid at a fixed tariff, and to acquire distribution licenses, relocate assets or sell parts of their assets to the utility (IRENA, 2018). Through the CTBCM interventions in the electricity power sector, the GoP has successfully devised a mechanism for dealing with the issue of the stranded cost related to transmission and distribution assets. This strategy may be customised and utilised as a benchmark for MGs deployment.

Investors

Keeping in view a longer project life, a huge upfront investment is expected. The financial resources for setting up an MG system are presumably greater than the required investment for a diesel generator. Thus, for the implementation of MG systems, particularly in rural or remote communities, access to adequate capital is a major barrier.

There are two parts to this argument. Firstly, a sustainable investor-led MG business requires that the fixed and operational costs of the infrastructure and its operations be sufficiently recovered along with a decent return on the investment. Typical modes of revenue generation are connection fees and electricity sales. Secondly, the communities can pay the cost of services to the project owners. It has been observed that the absence of economic activity in remote rural communities makes returns on investment by insignificantly charging the consumers (IRENA, 2018).

Several ways are being exercised around the globe to ensure a smooth flow of capital from consumers to project owners, which include setting the right mechanism and the tariff for cost recovery, facilitation in project preparation, subsidising MG projects, and facilitation in access to finance and involvement of public sector in financing of community development projects.

In certain cases, policymakers allow project sponsors and the local community to set tariffs through mutual deliberation such that the tariffs are sufficient to cover costs but ensure that consumers are willing to pay. Increasingly, policymakers are taking a custom-built approach to set the tariff for MGs. For example, Nigeria, Rwanda, and Tanzania have allowed deregulated tariffs for MGs under an installed capacity ceiling. However, large MG systems require standardised tariffs, and such tariffs need to be approved by policymakers. Indonesia and Peru have prepared a methodology for standardising tariffs to encourage private sector involvement (IRENA, 2018).

Tanzania has allowed project sponsors to share costs for preparing studies for licenses, feasibility studies, and environmental impact studies. There are also conditional awards available for the support of pre-investment financing of up to 80% of the charges (EUEI, 2014). The Rural Electrification Project in Nigeria provides public financing for the project preparation phase including economic and geospatial data gathering for pre-selected locations (IRENA, 2018).

The upscaling of MG systems includes a key element focusing on a line of credit and direct financing for off-grid electrification. Such initiatives provide lines of credit to financial institutions on a local level for on-lending to micro, small and medium enterprises, households as well as direct loans to private organisations. For example, in Tanzania, a USD 23 million credit line by the World Bank has been agreed to be provided to local commercial banks to refinance up to 85% of loans on low-interest debt to projects under 10 MW (IRENA, 2018).

The countries examined for this study show varying degrees of both public and private sector participation in MG development depending on the context. In Indonesia, the government has provided financial support in developing MG through subsidies and grants. The ownership remains with the public sector, while operation and maintenance are transferred to the community. In India, MG project sponsors are given a choice to opt for a pre-determined subsidy in exchange for other requirements including tariff restrictions, service quality, safety and security standards. In Nigeria, the subsidy is allocated through a bidding process for pre-selected MG locations from private sector developers and operators. Split-assets investments approach is another alternative to encourage public-private partnerships wherein the development of the distribution network is financed by the public utility, while construction, operation and maintenance of the generation assets are taken care of through private sector finances (IRENA, 2018).

Investors, furthermore, fear that the presence of centralised grids may hamper MG development due to their superiority in ensuring a continuous supply of electricity. The details of this critical issue along with its potential mitigation strategies are discussed in Chapter 4.

Consumers

There is an increasing urge for clean, continuous, and economical energy generation, which is causing to search for alternate energy solutions. This is, however, subject to many underlying factors and realities that are either hidden or not adequately evaluated before project development. From the consumers' perspective, the need for energy may be of any type of end-use, such as for lighting, cooking, cooling, heating, irrigating, and charging. The need is to be decided by the consumer, which eventually drives the type of MG solution.

With respect to MGs design and development, customer spread is assumed to be uniform within a particular MG area, whereas the differences in communities and their electricity requirements are discounted. This also refers to the fundamental questions discussed in designing the policy for MGs. For the successful implementation of MG systems, a public-in-particular framework should be employed in which the communities have an identifiable stake. In such a framework, an issue, a controversy, or an internal difference can be solved or mitigated through technological endeavours. (Michael, 1998).

The consumer, whether the energy is clean or not, ultimately requires an uninterruptible supply of electricity. The case study of Bihar, India, clearly indicates that the hunger for more energy exists in the consumer, and they make an intended effort to go beyond the contracted energy needs. Such an increasing appetite for energy then drives consumers toward a centralised grid or the consumer may eventually claim their entitlement to the centralised grid (Sharma, 2020).

POLICY INSIGHTS

Based on the existing policies, gap analysis carried out, and lessons learnt from the international experience of MG design, development, and implementation, the following are the certain policy insights that may be considered for the successful and large-scale deployment of MGs in Pakistan:

- A dedicated policy is critical to scaling up MG development addressing long-term certainty regarding market development, financial support schemes, and addressing risks associated with the presence of the centralised grid.

- Although MG deployment has already been initiated in a few areas, there is an urgent need for a regulatory framework to address various regulatory requirements, sustainable operation, and cost-recovery mechanisms.

- A meticulous identification of requirements becomes imperative in consultation with the local community to arrive at an MG solution. For example, in Balochistan or areas of Thar where there is currently zero access to electricity or any other form of energy, the requirement of energy from an MG system may, perhaps, be getting water from nearby wells, energy for cooling purposes, getting access to telecommunication services, or the internet for a significant part of the day. On the other hand, the requirements of energy use in Northern Areas of Pakistan are quite different as energy is mostly required for heating purposes where one cannot rely on a hydro resource, which becomes simply unavailable or highly unreliable in the winter.

- Extensive stakeholder engagement is vital for moving forward. Stakeholder engagement may be achieved through the involvement of community-based organisations (CBOs), technology demonstration and its effective use, and knowledge creation and institutionalisation.

- As a recent development in the power sector (August 2021), the GoP has approved the exemption of a license for small-scale RE-based systems up to 25 kW for net metering to facilitate the consumers who wish to install small-scale solar systems for their homes and businesses. Similarly, the GoP and NEPRA preferably may develop and implement a simple and encouraging regulatory framework for the development of MGs in Pakistan.

REGULATORY FRAMEWORK

As mentioned in the previous sections, MG regulations are one of the critical prerequisites in achieving widespread MG deployment in Pakistan. Fortunately, in December 2021, when the present study was in progress, NEPRA published the draft licensing regulations for MGs and sought comments from all the interested parties as shown in Figure 27.

Figure 27: NEPRA's Call for Comments

NATIONAL ELECTRIC POWER REGULATORY AUTHORITY (NEPRA)

ویکسین لگوائیں۔ زندگی بچائیں۔
پاکستان کو کورونا سے بچانا
اب آپ کے ہاتھ میں

Power with Safety بجلی حفاظت کے ساتھ
بارش کے دوران، گیلے یا پانی میں ڈوبنے والے بجلی کے آلات
استعمال نہ کریں۔ تربیت یافتہ الیکٹریشن سے معائنہ کروائیں۔

Draft LICENSING (MICROGRID) REGULATIONS, 2021
FOR COMMENTS OF GENERAL PUBLIC & STAKEHOLDERS

1. In exercise of power conferred by Section 47 of the Regulation of Generation, Transmission and Distribution of Electric Power Act 1997, the Authority is pleased to publish draft of NEPRA Licensing (Microgrid) Regulations 2021 for soliciting comments of stake holders/general public.

2. The salient features of Regulations are as follows:
- Microgrid is a self-contained distribution system operating at a voltage not exceeding 33 kV for distribution of electricity with peak distribution load not exceeding 5 MW.
- Microgrid is intended to serve an unserved market.
- Microgrid is not connected directly or indirectly to the national grid; and
- Microgrid will operate in concessional territory of Distribution Companies which are un-electrified.
- Tariff charged by the licensee to the consumers shall be negotiated between the parties bilaterally and submitted to Authority for approval.
- The minimum requirements for the design, construction, operation and safety of Microgrids shall be as set out in chapters IV, V, VI, VII and VIII of the Electricity Rules.

3. All the interested/affected parties are invited to submit written comments or objections on Draft of NEPRA Licensing (Microgrid) Regulations 2021 by 20-12-2021. The draft Regulations can be assessed through NEPRA website under the 'News' section. All communications shall be addressed to:

Registrar NEPRA
NEPRA Tower, Attaturk Avenue (East), G-5/1, Islamabad
Phone: 051-2013200 Fax: 051-2600021, E.mail: registrar@nepra.org.pk

نوٹ: نیپرا دفاتر میں داخلے کے لئے کرونا ویکسینیشن سرٹیفکیٹ فراہم کرنا لازم ہے۔

Accordingly, the study team interacted with NEPRA and subsequently submitted a comprehensive set of comments and observations via email, attached as Annexure II.

In the consultative session on the regulatory regime for the mini-micro grid system, conducted under the convenorship of chairman NEPRA on 21st January 2022, the comments from this team were also discussed and deliberated (as shown in Figure 28).

Figure 28: NEPRA's Presentation

List of Commentators

Commentators

- Ministry of Planning, Development & Special Initiatives (MoPD)
- Ministry of Commerce (MoC)
- Private Power & Infrastructure Board (PPIB)
- Gujranwala Electric Power Company Limited (GEPCO)
- K-Electric Limited
- LUMS Energy Lab
- LUMS Electrical Deptt
- National University of Science and Technology (NUST)
- Lake City
- Energy Futures
- Pakistan Institute of Development Sciences (PIDE)
- Energy Training and Research Center (ETRC)
- GIZ
- Engr. Faizan Ali Shah
- Gul Hasan Bhutto, NEPRA
- Alternative Energy Development Board (AEDB)
- Punjab Power Development Board (PPDB)

The finalisation of the regulations is under process. The regulations are expected to be approved and enforced in the coming months.

6. BUSINESS MODELS FOR MGs

In this chapter, potential business models for MG deployment in Pakistan, keeping in view the existing policies and probable future regulatory framework, are discussed.

EXISTING MG ACTIVITIES IN THE COUNTRY

Although the MGs have started being recognised by the Government of Pakistan mainly through the recently enforced ARE Policy 2019, there are proactive interventions already in place at the provincial levels. For this study, meetings were conducted with the Punjab Power Development Board (PPDB) in Lahore, and Pakhtunkhwa Energy Development Organisation (PEDO) in Peshawar, to understand their workings at the provincial level on the deployment of MGs.

The Government of Khyber Pakhtunkhwa (KP) has a major focus on the social uplift of the deprived communities residing in far-flung areas of the province. In this regard, they have carried out three projects, i.e., a) the development of mini/micro hydropower plants; b) the Solarisation of schools and mosques; and c) the installation of solar mini/micro energy systems. For all these three projects, the project sponsor is the Government of KP, the executing agency is PEDO, and the energy systems are managed by the local community. The objectives of these interventions are to increase economic activity in the region, create employment opportunities, utilise the local resources for the community optimally; and supply low-cost, locally managed, clean energy.

Within the KP Province, 356 mini/micro hydropower projects, ranging from 15 kW to 500 kW, are located in Swat, Shangla, Kohistan, Chitral, Dir Upper, Dir Lower, Abbottabad, Battagram, Buner, Mansehra, and Torghar. Out of these 356, 180 have already been completed, whereas the rest of the projects are under construction. Completed projects are being operated and managed by the local community.

Capitalising on these achievements and experience, the Government of KP plans to provide electricity to 4,400 mosques, 8,000 schools, and 187 basic health centres in the entire province and install 13 micro/mini solar power projects in rural districts of KP, especially in those that have been formed after the merger of Federally Administered Tribal Areas (FATA) with KP. Solar PV MGs are planned to be installed in 13 districts, namely Bajaur, Mohmand, Khyber, Frontier (FR) Peshawar, Orakzai, Kuram, FR Tank, South Waziristan, North Waziristan, FR Bannu, FR Lakki, FR Dera Ismail Khan and FR Kohat. The MG infrastructure comprises 175 kW solar PV, 250-300 kWh lithium-ion battery system, and an AC transmission system to connect with the consumers.

The Government of Punjab has also adopted a similar approach in the development and deployment of MGs in the province. The focus of Punjab is primarily on solar. They have utilised this clean energy to reduce the reliance of public buildings, mainly schools, universities, and basic health units, on the dilapidated electricity distribution infrastructure. The project is funded by Asian Development Bank and the executing agency is the Punjab Power Development Board (PPDB).

PPDB has managed to solarise 2,324 basic health units in Punjab. The project began in 2018-19 with the survey and selection of the basic health units and was completed in 2020-21. This added a cumulative 7.204 MWs of installed capacity of solar in the province with an estimated amount of PKR 210 million. Moreover, 6,991 schools were solarised in Southern Punjab in the first phase. This increased the installed capacity of solar in Punjab to 31.004 MWs. The cost of the project is USD 345 million. The Government of Punjab now plans to include 4,200 schools in Central and Northern Punjab as well. These projects are being operated and managed by local communities or building administrations.

In a bid to reduce the carbon footprint, the Government of Punjab is the first to introduce a business model, Energy Service Companies (ESCOs), in the province. This initiative started with the solarisation of public universities in Punjab on the ESCO model. For this model, CAPEX and OPEX will be borne by the ESCO and the buyer will pay ESCO on a mutually agreed tariff. Major universities that are being benefited from this model include the University of Engineering and Technology, Lahore, and Islamia University Bahawalpur. The ESCO model has now been expanded to various commercial buildings as well as industrial facilities.

POTENTIAL BUSINESS MODELS

In this section, potential business models for MGs deployment are discussed in light of the ARE 2019 Policy and draft NEPRA Licensing (Microgrid) Regulations 2021 (expected to be approved and enforced soon). The ARE Policy 2019 includes off-grid Alternative and Renewable Energy Projects (AREPs) or MGs as per Section 1.3.2 and it further states in Section 3.4 that the public sector MG projects will undergo competitive bidding. For this purpose, Section 3.9 explains:

“NEPRA will modify its regulatory framework accordingly within six months of the promulgation of this Policy.” This became the basis of NEPRA Licensing (Microgrid) Regulations 2021. NEPRA started the preparation process for this important regulation. The MGs being installed or commissioned in the country are currently unregulated and unstandardised, and major interventions have been done by the government through International Financial Institutions (IFIs) with increasing CAPEX, but no plan to sustain the OPEX.

Any successful business model must possess three key features, namely scalability, interoperability, and sustainability. Based on these principles, four potential business models are illustrated and proposed. For this study and based on the ARE Policy 2019, National Electricity Policy 2021, and draft NEPRA Licensing (Microgrid) Regulations 2021, business models are envisaged that capture the future outlook of MG business activities in Pakistan.

Figure 29 provides a model where a government entity becomes the MG licensee and undertakes to plan, design, construct, operate, and maintain the MG infrastructure along with associated generation. This is the existing structure in which the government is investing in a bid to provide economic stimulus to the deprived communities. However, in this model, there is no room for scalability and sustainability of the MG deployments.

Figure 30 shows an investor-owned MG business model, which is based on the prevailing policy and the draft regulation. This is similar to the first model shown in Figure 29, but in this model, the private sector undertakes all the activities of planning, design, construction, operation, and maintenance. For this model, a major concern remains that the investor is deemed to have a monopoly on supply in the specified service territory.

Figure 29: MG Business Model 1 – Utility Owned Model (Generation + Wire Business)

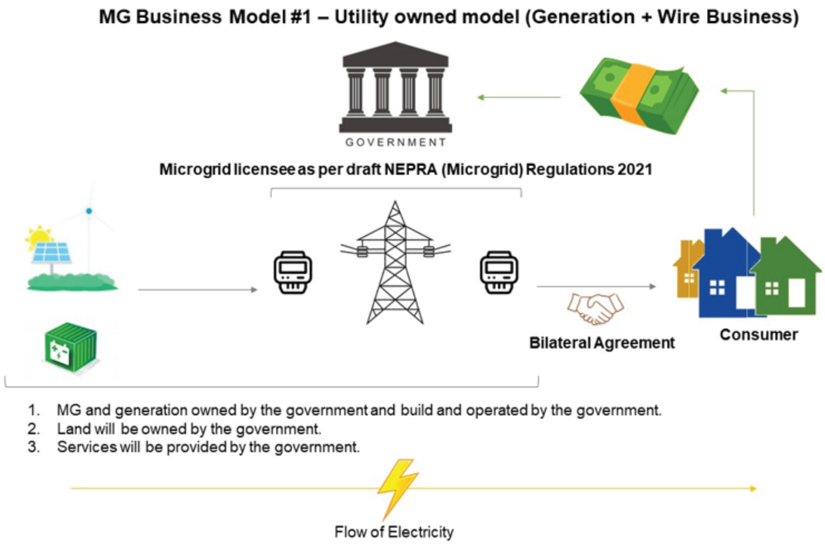
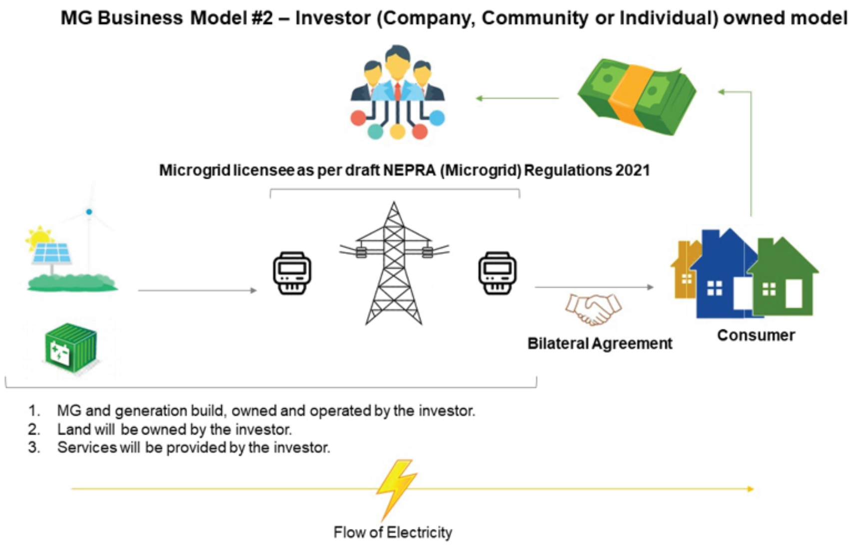


Figure 30: Investor (Company, Community or Individual) owned Model



The business models, as illustrated in Figure 31 and Figure 32, have been proposed for the upcoming MG enterprise, which will outperform the existing and unsustainable business frameworks, increase private sector participation, provide effective operation, and maintenance and ensure more transparency and sustainability in the energy system.

Figure 31 shows an investor-owned model, which is more decentralised allowing more competition and increased private sector participation. In this model, the MG licensee owns the wires and metring infrastructure. Generators in IPP mode supply electricity, which is contracted through Power Purchase Agreements (PPAs). This constitutes the CAPEX of the MG energy system infrastructure. The OPEX part of this model is undertaken and monitored by a Community Based Organisation (CBO), which manages the distribution network and the flow of power from the generator to the consumer. Furthermore, it manages metring infrastructure for the sale and purchase of electricity and provides authorised services to consumers through bilateral agreements. The CBO also acts as a power purchasing agency, which collects the payments from the consumers and disburses them to the wire business owners and the generators. This model manages the community's ownership, making the system more sustainable for a longer period. The CBO includes representation from generators, MG licensees, and the community itself.

Figure 31: Investor-owned model with involvement of CBO

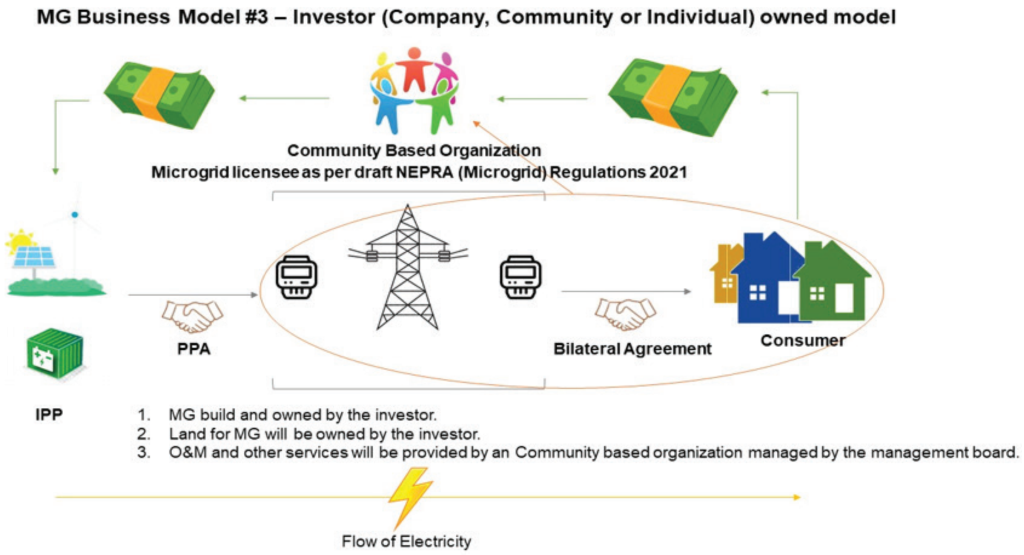
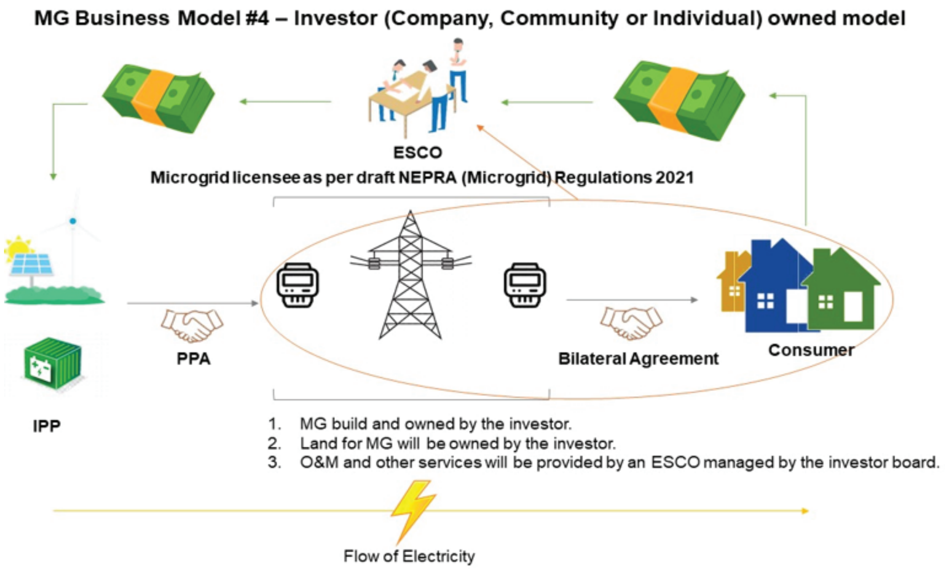


Figure 32: Investor-owned model with involvement of ESCO



A similar approach is adopted in the business model displayed in Figure 32. However, the mandate to operate and maintain the MG infrastructure is transferred to an ESCO, which can be applied for more advanced network control and operations. The ESCO also acts as the power purchasing agency, which manages the sale and purchase of electricity. The ESCO is governed by an investor board, which includes participation from generators, MG licensees, and the community.

The success of any of the business models discussed above is subject to the underlying issues regarding the arrival of the host distribution licensee grid, the stringent regulations even for investors in the range of less than 100 kW, and SOPs on billing and metring to be made by the electricity regulator. These issues are potential impediments to the economic stimulus in the MG business growth in Pakistan.

7. CONCLUSION

- The comparison of different applicable MG scenarios as discussed and analysed in Chapter 3 is provided in Table 26.

Table 26: Summarised Comparison of Scenarios

Parameter	Scenario 1	Scenario 2	Scenario 3
LCOE ($/kWh)	0.111	0.0981	0.0929
Net Present Cost ($)	64,120	78,068	118,903
CAPEX ($)	27,836	34,213	16,048
OPEX ($)	1,587	1,918	4,499
Fuel Consumption Savings as compared to Diesel Generator (Litre/year)	15,216	16,151	-
CO_2 Emissions Savings as compared to Diesel Generator (kg/Year)	39,831	42,276	15,479
IRR (%)	79.5	66.1	20
Payback Period (Year)	1.34	1.57	5.22

NOTE:
*Scenario 1: Off-grid MGs application for rural villages/areas having solar PV and wind potential.
*Scenario 2: Off-grid MGs application for rural villages/areas having solar PV and micro-hydro potential.
*Scenario 3: Grid-connected MGs application for Housing Societies or Commercial Centres in Urban Areas having utility electricity access.

- As shown in Table 26 above, the MG deployment has strong financial viability and presents a lucrative investment opportunity. The upscaling of MGs, therefore, needs to be acknowledged as a business opportunity by the private sector.

- Fuel-based MGs result in CO2 emissions, which is detrimental to the environment. Renewable Energy (RE) based MGs save significant emissions and are, thus, environment-friendly.

- RE-dominated MGs present much more financial feasibility as compared to fossil-fuel-based MGs.

- Due to the increasing trend in electricity prices, the MG deployment has become a cost-effective solution as compared to the conventional integrated grid for particular scenarios/applications.

- The MG option is better than the conventional integrated grid for specific scenarios/applications discussed above. However, it is not an optimal solution in all situations. The feasibility will change significantly depending on various factors, such as no or lesser renewable energy (RE) potential, consumer requirement of 0% allowed capacity shortage, and change in cost trends of REs versus fossil fuels.

- Technical issues associated with the operations of MGs are stability, safety, protective relaying, harmonics, and voltage imbalance. Although MGs present a cost-effective solution for remote unelectrified areas of Pakistan, they may face technical issues if not properly designed. The owners of MG must take care of these issues as highlighted in Chapter 4.

- Keeping in view Pakistan's context, a fundamental outline of customised business models is presented in Chapter 6, which may be helpful for investors and other stakeholders.

- The existing policy and regulatory framework are insufficient to effectively upscale the MG deployment in Pakistan.

- DC MGs have become a reality in many countries in recent years. DC MGs show a promising 12 % decrease in the cost of energy (from 0.111 $/kWh to 0.098 $/kWh) as compared to similar AC MGs.

- The application of MGs for irrigation purposes presents an interesting case. As shown in Chapter 3, hybrid MGs having an irrigation application has more economic viability as compared to similar normal rural MGs since it shows a promising 18 % decrease in the cost of energy, i.e., from 0.119 $/kWh to 0.0976 $/kWh.

- Allowed capacity shortage is an important factor to be considered for MG development since the cost of energy decreases exponentially with the increase in the allowed percentage capacity shortage.

- Discount rate and project lifetime are important factors to be considered to evaluate the feasibility of MGs. The cost of energy (CoE) increases linearly with the discount rate and decreases exponentially with the project's lifetime.

- Allowed percentage capacity shortage significantly affects the energy mix decisions. With the consumer requirement of percentage allowed capacity shortage from 0% up to 0.4%, the inclusion of conventional generators in the optimal energy mix is essential, and cannot be achieved exclusively with renewables and storage systems.

- The demand profile significantly affects the CoE of an MG system. In case the demand profile is changed from 24 hours to 12 hours (day-only load), it shows a promising 40 % decrease in CoE from 0.111 $/kWh to 0.0677 $/kWh.

8. RECOMMENDATIONS

- For the upscaling of MG development in Pakistan, a comprehensive policy is required for addressing the long-term uncertainty of market development, financial support schemes, and risks associated with the presence of the centralised grid. Furthermore, a regulatory framework is required to address various regulatory requirements, sustainable operation, and cost-recovery mechanisms.

- DC MGs should be included in the regulations on microgrids, to be launched by NEPRA. Similarly, MGs should also be allowed to operate in grid-connected mode. For this purpose, the draft regulatory framework may be customised. Moreover, a mechanism for dealing with the technical issues, such as stability, safety, protective relaying, harmonics, and voltage imbalance associated with MGs should be addressed in the final regulations on microgrids.

- Coordinated efforts by the stakeholders are required for utilising the applicability of MGs for irrigation in remote rural areas.

- While assessing the electricity provision for remote unelectrified areas of Pakistan, the system planner must consider and evaluate the MG deployment before proposing huge investments for transmission and distribution infrastructure.

- Based on the study's findings, the optimal solution involving MGs includes a major share of renewable energy resources. Therefore, renewables-based MGs should be promoted in the upcoming policy and regulations. Further, CO2 emissions should be compensated through a carbon-credit mechanism for fossil fuel-based MGs to be provided in the upcoming regulatory framework.

- Given an inverse relationship between CoE and the allowed capacity shortage, the design of MGs should be aligned with the affordability for the customers in the specific geographical area, to create a win-win situation for all the stakeholders.

REFERENCES

Menaem, A. A., & Oboskalov, V. (2020). *Integration of renewable energy sources into microgrid considering operational and planning uncertainties.* Voronezh: Springer International Publishing,982.

Micallef, A. (2019). Review of the current challenges and methods to mitigate power quality issues in single-phase microgrids. *IET Gener. Transm. Distrib*, *13*(11), 2199–2207. doi: 10.1049/iet-gtd.2018.6020.

Rai, A. (2020) Technical Challenges in Microgrid Int. *J. Psychosoc. Rehabil, 24*(5), 3440–3447.

Bijker, W. E., Hughes, T. P., & Pinch, T. J. (Eds.). (1987). *The social construction of technological systems: New directions in the sociology and history of technology*. Cambridge, MA: MIT Press.

EUEI (EU Energy Initiative Partnership Dialogue Facility). (2014). Mini-grid policy toolkit: Policy and business frameworks for successful mini-grid roll-outs. Retrieved from https://energypedia.info/wiki/Mini-grid_Policy_Toolkit.

Homer Energy. (2021). *Homer energy*. Retrieved from www.homerenergy.com

IRENA (International Renewable Energy Agency). (2018). *Policies and regulations for renewable energy mini-grids*. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_mini-grid_policies_2018.pdf

Michael M. (1998). Between citizen and consumer: Multiplying the meanings of the public understanding of science. *Public Understanding of Science*, *7*, 313–327

Motjoadi, V., Bokoro, P. N., & Onibonoje, M. O. (2020). A review of the microgrid-based approach to rural electrification in South Africa: Architecture and policy framework. *Energies, 13*(9).

Gaur, P. and Singh, S. (2017). Investigations on issues in microgrids. *J. Clean Energy Technol., 5*(1), 47–51. doi: 10.18178/jocet.2017.5.1.342

Choudhury, S. (2020). A comprehensive review of issues, investigations, control and protection trends, technical challenges and future directions for microgrid technology. *Int. Trans. Electr. Energy Syst., 30*(9),1-16, 2020. doi: 10.1002/2050-7038.12446.

Sharma, A. (2020). 'We do not want fake energy. The social shaping of a solar micro-grid in rural India. Science. *Technology and Society, 25*(2), 308-324.

Rosado, S. P. & Khadem, S. K. (2019). Development of community grid: review of technical issues and challenges. *IEEE Trans. Ind. Appl., 55*(2), 1171–1179. doi: 10.1109/TIA.2018.2883010

Williams, R., & Edge, D. (1996). The social shaping of technology. *Research Policy, 25*(6), 865–899.

ANNEXURE-I

Data Collection Form for Provincial/Territorial Governments and Other Stakeholders

RESEARCH FOR SOCIAL TRANSFORMATION AND ADVANCEMENT
2020 RASTA Competitive Grants Program for Policy-oriented Research
Under the Public Sector Development Program (PSDP) of the Ministry of Planning, Development and Special Initiatives, the Government of Pakistan
Study "Techno-Economic Analysis of Widespread Microgrid/Minigrid (MG) Deployment in Pakistan's Electrical Power Sector" Awarded by Pakistan Institute of Development Economics (PIDE)

Data Collection Form

Province/Territory	AJK / Baluchistan / GB / KPK / Punjab / Sindh *(please encircle one)*
Focal Person Name	
Designation	
Department	
Cell No(s).	
Email	

#	Parameter	Data
▪	The electrified population of the province (%)	
▪	The unelectrified population of the province (%)	
▪	Is there any microgrid project currently operating/under development in the province/territory? If yes, please provide the details.	
•	Microgrid projects currently operating / under development (Nos.)	
•	Public Sector (Nos.) / Private Sector (Nos.)	
•	Location	

•	Size (kW)	
•	Capital Investment (Pak Rs.)	
•	No. of beneficiary families	
•	The energy source (solar, wind, solar + distributed generation, etc.)	
•	Interconnection arrangements with DISCO or National Grid, if any	
•	Contact person name and contact details	
Please use an extra sheet in case more than one microgrid project is operating or being developed in the province/territory and provide data for the parameters from 3a – 3i		
▪	Please share electricity expansion plans, if any, of each of the DISCOs under the jurisdiction of the province/territory i.e. up to 132 kV grid station(s) and associated distribution system	
▪	Kindly share details and a copy of the existing policy, if any, of the provincial/territorial government for encouraging MGs development in the province/territory.	
▪	Does the provincial/territorial government have any formal rural electrification plans? If yes, please share it.	
▪	Any public sector/private sector/International Financial Institutions' funding available for setting up MGs. If yes, please provide details.	
▪	Potential of Micro/Mini Grids in the Province (Un-electrified Localities) where the utility's network does not currently exist	
•	No. of potential localities	
•	Locality Name (Village, etc.)	
•	Area of Locality (km^2)	
•	Geographical Coordinates	
•	The population of the Locality	

•	Population breakup of the Locality with different income groups (Rs. per month per family)	Up to Rs. 20,000 (______%) Between 20,000 to 40,000 (______%) Between 40,000 to 80,000 (______%) Between 80,000 to 120,000 (______%) Higher than 120,000 (______%)
•	Distance from the nearest town/city (km)	
•	Distance from the nearest electrical interconnection point (Grid Station, Distribution Line, etc.) of the utility network (km)	
•	How do different segments of this population manage their electricity needs such as heating, cooling, light, tube well, etc.?	
•	Priority factor assigned by the provincial/territorial government for each of the potential localities added in this section (use a scale of 1 to 5 with '1' being the top most priority)	
•	Estimated electricity demand (MW) for winter	
•	Estimated electricity demand (GWh) for winter	
•	Estimated electricity demand (MW) for summer	
•	Estimated electricity demand (GWh) for summer	
•	Availability of indigenous energy resources in MW for producing electricity such as Solar, Wind, Micro/Mini Hydro, and others)	
Please use an extra sheet in case more than one potential locality exists in the province/territory and provides data for the parameters from 8a – 8o		
▪	Areas falling under Weak/In-consistent Distribution Network (where heavy load shedding / electricity-outage is being enforced as a frequent feature).	
•	The average number of hours per year of load shedding being performed	

•	The average number of hours per day of load shedding being performed in summer	
•	The average number of hours per day of load shedding being performed in winter	
•	Maximum number of hours per day load shedding being performed in summer	
•	Maximum number of hours per day load shedding being performed in winter	
•	Frequency of power failure other than announced load shedding and its usual restoration time period	
•	Known reasons for load shedding/power failure (Insufficient capacity, Weak network, Non-payment by the customers, etc.)	
•	No. of potential localities for setting up microgrids in these areas	
•	Locality Name (Mohalla, etc.)	
•	Area of Locality (km^2)	
•	Geographical Coordinates	
•	Priority factor assigned by the provincial/territorial government for each of the potential localities (facing issues of severe unreliability of electricity supply) added in this section. Use a scale of 1 to 5 with '1' being the top priority.	
•	Estimated electricity demand (MW) for winter	
•	Estimated electricity demand (GWh) for winter	
•	Estimated electricity demand (MW) for summer	
•	Estimated electricity demand (GWh) for summer	
•	Availability of indigenous energy resources for producing electricity such as solar, wind, micro/mini hydro, and others) with MW potential corresponding to each resource	

Please use an extra sheet in case more than one potential locality exists in the areas with Weak/Inconsistent Distribution networks and mention the same parameters from 9a – 9o		
▪	Potential of Micro/Mini Grids in the Province / Territory (Future Planned Housing Societies / Commercial Centres, other similar localities) for Urban Areas	
•	No. of potential localities	
•	Locality name	
•	Area of locality (km^2)	
•	Geographical coordinates	
•	Estimated population of the locality	
•	Normal population breakup in this locality with different income groups (Rs. per month per family)	Up to Rs. 80,000 (_______%) Between 80,000 to 140,000 (_______%) Between 140,000 to 200,000 (_______%) Between 200,000 to 260,000 (_______%) Higher than 260,000 (_______%)
•	Distance from the nearest electrical interconnection point (Grid Station, Distribution Line, etc.) of the utility network (km)	
•	Please share electricity expansion plans for this locality, if any, of each of the DISCOs under the jurisdiction of the province i.e. up to 132 kV grid station(s) and associated distribution system.	
•	Estimated number of cars per family in the locality	
•	Estimated electricity demand (MW) for winter	
•	Estimated electricity demand (GWh) for winter	
•	Estimated electricity demand (MW) for summer	
•	Estimated electricity demand (GWh) for summer	
•	The availability of indigenous energy resources in MW for producing electricity such as Solar, Wind, Micro/Mini Hydro, and others) with MW potential	

•	Existing/ planned data regarding urban buildings/ homes to be shifted to rooftop solar PVs or other localised RE generation and utilizing (or aim to utilize) net metering options	
Please use an extra sheet in case more than one potential locality exists in the province/territory, and provide data for the parameters from 10a – 10o		

In case of any query with respect to preparing and providing this data, please feel free to contact:

- Engr. Danial Saleem, Cell No.: 0322 4853086, Email: danial.saleem@ntdc.com.pk
- Engr. Yasoon Aslam, Cell No.: 0335 7401200, Email: yasoon.aslam@ntdc.com.pk

ANNEXURE-II

Comments/Observations/Suggestions on Draft National Electric Power Regulatory Authority (Microgrid) Regulations, 2021

By
The Team of PIDE's RASTA Project Having Title 'Techno-Economic Analysis of Widespread Microgrid/Minigrid (MG) Deployment in Pakistan's Electrical Power Sector' With ID # 01-039

Firstly, we would like to congratulate NEPRA to start the development process of such an important regulation. The microgrids being installed or commissioned in the country are entirely unregulated and unstandardised. We strongly hope that this regulation and associated documents will open the doors for upscaling and setting up of microgrids and, hence, enhance the electricity access to a large population, In sha Allah. Also, we would like to extend our compliments to the NEPRA team, who have worked for developing these regulations, and for accomplishing a great job.

Our team has thoroughly reviewed the document in light of the ARE Policy 2019, National Electricity Policy 2021, the ongoing development of microgrid projects in Pakistan and international best practices. Following are the comments and suggestions for the improvement of the draft regulations and, in a larger context, for the betterment of Pakistan. We hope that this will add value to the draft regulation.

Preface/Introduction:

- The draft regulations exclusively cater for microgrids. It would be much more beneficial to the stakeholders if mini-grids are also included in the same regulations.

- The underlined part in the statement "National Electricity Policy 2021 (NEP) has stressed on off-grid and micro-grid solutions to promote electricity access to areas where grid expansion is *financially unviable*", is suggested to be changed to, '*financially and/or technically unviable*'.

Section # 2 ((f), i, ii, iv), Definition of Microgrid

- Although putting the maximum limit of peak load as 5 MW is a subjective decision, it needs to be reconsidered to increase this limit to 10 MW, keeping in view the load requirements, community sizes, and probabilistic load growth patterns in areas/localities suitable for MG applications.

- To facilitate small investors/new entrants, stringent technical and regulatory requirements may be relaxed depending on the size of MGs. Therefore, the classification of MGs may be included below and different standardised procedures (technical, qualification and licensing requirements) may be applied according to the relevant category:
    - Large Minigrid: 5 MW ≤ Large Minigrid < 10 MW
    - Small Minigrid: 1 MW ≤ Small Minigrid < 5 MW
    - Large Microgrid: 100 kW ≤ Large Microgrid < 1 MW
    - Small Microgrid: 10 kW ≤ Small Microgrid < 100 kW

- For the MG once installed/in operation, the option of scaling up beyond its existing installed capacity, especially in case of load growth also needs to be catered for in the draft regulations.

- Through the draft regulations, a licensee is restricted to non-electrified areas or unserved markets. It is suggested to also include privately electrified areas (not the jurisdiction of DISCOs); the price of electricity will govern the feasibility of MGs in such areas. For this purpose, both unserved markets, as well as BPCs (especially privately owned housing societies), intended to shift to the MG system may be allowed to obtain an MG license, under predefined terms and conditions.

- It is not clear whether new housing societies, business centres, etc. within cities/rural areas or territory of DISCOs, where the area is electrified, but a potential customer is yet to be provided connection by a DISCO, are considered an unserved market or not.

- The draft regulations only address off-grid MGs. The grid-connected MGs should also be brought into the ambit of draft regulations. The grid-connected MGs are more stable and reliable than off-grid ones and result in increased efficiency of the system by exchanging (importing or exporting) electricity with the grid.

Section 3, Licensing of Microgrids, Subsection 1 (a & b):

- According to Section No. 3 of the Sustainable Development Goals Achievement Programme (SAP)'s guidelines dated 09-03-2020 issued by the Government of Pakistan, Cabinet Division Development Wing:

  > *"At least, 10 residents of the area, will identify the scheme(s), and the scheme(s) with estimated costs ranging between Rs. 0.25 million to Rs. 50 million shall be included in the Programme. In the case of the gas sector scheme(s), the upper limit will be up to Rs. 300 million. In the case of the power sector scheme(s) the lower limit shall be Rs. 0.15 million."*

  In order to align the objectives of MG regulations and SAP, and achieve optimal impact, it is suggested that the draft MG regulations should also include community based organisations (CBOs) as eligible for securing an MG license since collaboration under a CBO would be ideal to fetch the benefits of a microgrid apart from addressing the lack of ownership issues (on the part of end customers).

- The eligibility/qualification criteria, i.e., minimum skills, experience, financial position, etc. required for the licensee to develop, own and operate the MGs seem to be missing. Therefore, such criteria should be mentioned/included in the draft regulations.

Section # 3 (3)

The emphasis on the utilisation of renewable energy (RE) sources is missing in the draft regulations, which, in our opinion, need to be incorporated. For example, it may be added that the RE sources shall be given preference at the location of the proposed MG, subject to availability. Incentivising RE-based MGs may also be looked into for this purpose.

Section # 3 (5)

- The provision of grid-connected MG along with an option of net-metering may also be allowed/included in the MG regulations as this option is more reliable as well as cost-effective.

- Section 3 (5) allows a provision for the licensee to connect with the host distribution licensee, subject to approval by the authority. However, the development of minimum standards at the point of common coupling is not covered in Section 5 – "Minimum Standards" – and the responsibility to develop such standards should also be mentioned or at least referred to (if available) in the regulations.

Section No. 4, Application Process, Subsection (2)

The mechanism for awarding a license appears to be missing in case two or more candidates apply for the license for the same MG project.

Section # 5, Minimum Standards, Subsection (1)

- Minimum standards for MGs (in the form of SOPs) need to be referred to in the regulations, to be developed in future and approved by the authority.

- It can be conveniently deduced that the draft regulations do not include DC-based MGs. Chapter 4, Section 29 of the Electricity Rules 1937, states that:

  > *"29. Declared frequency of supply to consumers. From the time of commencing the supply of energy to a consumer by means of an alternating current, a licensee shall declare to the consumer the frequency at which he undertakes to supply energy and the licensee shall not, without the written consent of the consumer or the previous sanction of the provincial government, permit the frequency to vary therefrom by more than 4 per cent."*

  In this regard, keeping in view the technological advancements and cost-effectiveness, DC-based MG may also be covered/included in the regulations.

Section No. 6, Tariff, subsection 1

Reference the statement, "tariff charged by the licensee to the consumers shall be negotiated between the parties bilaterally," there must be an upper limit on the tariff set by the regulator. Moreover, there should be competition during the application phase between the potential licensees to secure the best price for the consumers.

Section 6(2)

- Subsection (2) states that *"The licensee shall submit the bilateral agreement signed with consumers to the authority for approval".*

- It is not clear whether the MG owner will provide the agreements signed by all the consumers or just the authorised representative of consumers or some other type of agreements based on the categorisation of load, i.e., domestic, residential, industrial, etc. are to be submitted to the authority. The clause needs to be rephrased to bring more clarity and to make the process simpler.

- Clarity is required for the case of new consumers added after the finalisation of tariff or installation of MG, i.e., whether the owner will have to resubmit the bilateral agreement with new consumers as well to the authority.

- Further clarity is required on whether tariffs for residential and commercial use within a specific MG would be the same or different.

Section 7, Miscellaneous, subsection (1), Grid Arrival

This clause seems unfair to the licensee and it appears to support the host distribution licensee. It is, therefore, suggested that this clause be redrafted to introduce competition between the licensee and the host distribution licensee based on the price of electricity (tariff) so that consumers can opt for affordable electricity. Secondly, in case the licensee voluntarily opts to relinquish the MG facility, an appropriate provision should be added to protect the rights of the licensee.

Section 7(1 (a))

- After grid arrival, the licensee may be empowered to give acquisition to DISCO (host distribution licensee) or continue the business as usual.

- For an investor-based MG project, if the licensee has not fully recovered its investments yet, it will be unfair to acquire the MG even before the break-even point or before it starts making a profit. For this purpose, a minimum period of operation of MGs linked with the payback period may be defined for MG acquisition. Hence, the acquisition by the licensee should be primarily voluntarily. This clause should be incorporated into the regulations.

Section # 7 (2), Standard Operating Procedures

Standard operating procedures (SOPs) regarding billing and collection from consumers, connection and disconnection, suspension of service, etc. may be developed considering the location, size, and other features of the MG. A single set of SOPs may not apply to all.

As per various MG case studies, custom-made solutions for efficient costing and an effective business model for consumers are offered with features that may vary. Strict requirements for adherence to SOPs will impede the efficiency and effectiveness of the MG deployment.

Section # 7 (3), Accounting

Keeping books of accounts, getting them audited annually by a chartered accountant, filing the audited accounts with the authority, and obtaining various other approvals from the authority, appear to be bureaucratic/tough (particularly for small-sised MGs), which may be revisited before finalising.

Other General Comments

In addition to the above, the following aspects are also suggested to be included/covered in the final regulations:

- For monitoring the performance of MGs it is proposed that each MG licensee be required to periodically submit performance reports (the format to be stipulated by the authority) to the authority.
- Why there is no concept of competitive bidding proposed in the draft regulations for solicited projects?
- MGs may be provided with an option to remain available and provide services only during a specific window of hours as per the requirements/needs of the consumers.
- A legal binding may be imposed on DISCOs to share their expansion plans publically so that decision-making for investment for the potential MG developers may become easy.
- The probable impacts of the CTBCM regime and the working of multiple license types need to be addressed for MGs.
- The target of the 'democratisation of the electric power sector' needs to be further depicted in the final regulations.
- Renewable generation sources, especially based on hydel (also for land provision in the case of solar and wind), require the intervention of the provincial/territorial governments. However, the draft regulations do not seem to address this critical aspect. The legal and regulatory framework and mechanism for the acquisition and utilisation of public sector land for MG development and operation may be formulated and referred to in the MG regulations.
- It is suggested to have some binding on the MG licensee to serve for a minimum number of years to the consumers, which may be secured through some security deposit mechanism.
- In order to promote MG development in Pakistan, especially during the transition phase, certain regulations may be added for incentivising the stakeholders.

ANNEXURE-III

Site Visits/Tour Reports

Meeting with Pakhtunkhwa Energy Department Organisation (PEDO) in Peshawar on 8th November 2021 and 9th November 2021

Background

With reference to the data collection form, which was submitted to stakeholders including ex-WAPDA distribution companies and provincial energy departments on 19th August 2021 related to microgrid/mini-grid (MG) development in their respective regions, a 2-day tour to the PEDO office was planned to understand the requirements of the Kyber Pakhtunkhwa (KPK) province and the efforts put forward by the government in this regard.

Meetings were carried out on the 8-9th of November 2021 at the PEDO office and one of the project sites with the project director (solar), PEDO, and his team. The information collected verbally during the conversations with the PEDO officers concerning their solar power-based MG development is described below.

PEDO Working on MG

Description

The Government of KPK plans to provide electricity in the rural districts of KPK, especially to those that have been established after the merger of the Federally Administered Tribal Areas (FATA) in KPK to alleviate poverty and ensure economic growth in the districts.

Location

Solar PV MGs are planned to be installed in the following districts of KPK.

a. Bajaur
b. Mohmand
c. Kyber
d. Frontier (FR) Peshawar
e. Orakzai
f. Kuram
g. FR Tank
h. South Waziristan
i. North Waziristan
j. FR Bannu
k. FR Lakki
l. FR Dera Ismail Khan
m. FR Kohat

Specifications

The MG infrastructure comprises 175 kW capacity solar PV, 250-300 kWh lithium-ion battery energy storage systems and an AC transmission system to connect with the consumers. The electricity system is envisaged to supply electricity to 100 commercial consumers (mainly shops). An area of 10 kanals, owned by the Government of KP, has been allotted in the vicinity of the selected location of consumers for the installation of Solar PV cells and battery systems.

Financials and Tariff

The tariff estimated for the supply of electricity for 5 hours of the day is 10-20 PKR/kWh with cost recovery in 5-7 years. It is important to mention here that the cost of land has been excluded from the tariff calculation, which resulted in a lower tariff. This tariff has not been approved by NEPRA, but it is expected to be charged to the consumers for the supply of electricity provided through the MG system.

The cost of MG installation at each project site is 4.5 Million PKR. The draft PC-1 is yet to be submitted to the KP government by the PEDO, which details the complete business model of the MG.

Project Timeline

The project is expected to be completed by June 2022.

Project Status

A visit to an MG solar installation in the Mohmand district in KP was conducted. The construction work and the installation of equipment at the project site are underway. Similarly, the status of other sites is the same.

However, a critical activity, i.e., the identification of 100 commercial consumers is being planned by the PEDO. The development of evaluation criteria to select prospective consumers is in process. However, it is expected that the provision of electricity to consumers seeking a new connection will be on a first-come-first-serve basis.

Meeting with Punjab Power Development Board (PPDB) at Lahore on 19th November 2021

Background

With reference to the data collection form, which was submitted to stakeholders including ex-WAPDA distribution companies and provincial energy departments on 19th August 2021 related to microgrid/mini-grid (MG) development in their respective regions, a meeting was planned at the PPDB office to understand the requirements of the Kyber Pakhtunkhwa (KPK) province and the efforts put forward by the government in this regard.

Meetings were carried out on 19th November 2021 at the PPDB office with the manager (Thermal) and manager (Renewables and Bio-fuels). The information collected verbally during the conversations with the PPDB officers concerning their solar power-based MG development is described below.

PPDB Working on MG

Description

The focus of the Punjab Government is primarily on solar power and it has utilised this clean energy to reduce the reliance of public buildings, mainly schools, universities and basic health units in remote areas of Southern Punjab, on traditional electricity sources.

The Government of Punjab is, furthermore, the first to introduce the business model of Energy Supply Companies (ESCOs) in the province. Major universities that are benefitting from this model include the University of Engineering and Technology, Lahore, and Islamia University, Bahawalpur. The ESCO model has now been expanded to commercial buildings as well as industrial facilities.

Location

The Solar PV MG systems have, predominately, been installed by the Government of Punjab in schools and basic health units in the Southern Punjab region. Many universities, factories, and public buildings all around Punjab have deployed solar PV MGs on their own through ESCOs.

Project Timeline

The project began in the Fiscal Year (FY) 2018-20 with the survey and selection of the basic health units and was completed in FY 2020-21. The Government of Punjab now plans to include 4,200 schools in Central and Northern Punjab as well.

Project Status

PPDB has managed to solarise 2,324 basic health units in Punjab. This added a cumulative 7.204 MW of installed capacity of solar electricity in the province with an estimated amount of 210 Million PKR. Likewise, 6,991 schools were solarised in Southern Punjab in the first phase. This has further increased the installed capacity of solar in Punjab to 31.004 MW. These projects are being operated and managed by local communities or building administrations.

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

Naveed Arshad

ABSTRACT

Pakistan has faced undersupply and oversupply of electricity over the past few decades. Historically, Pakistan has faced a shortfall of up to 7,000 MWs but at present, the country has 12,000 MWs of excess capacity even after meeting the peak summer demand. The undersupply curtails the GDP growth and is a major cause of the industrial slowdown, 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 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-depth data analytics to assess the impact of demand shifts on an hourly basis. Using authentic and verified data from the power sector the tool provides the impact of demand shifts on WACG. The tool encodes not only the tariffs of all generating units operating in Pakistan but also considers other financial conditions including mandatory capacity and energy payments from IPP agreements in calculating the results. The tool also incorporates the technical parameters of all generating units to create a digital twin of the generation sector. Moreover, the tool also calculates the impact on the environment of operating various sets of generation units.

1. 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. Independent power producers (IPPs) have been provided with the opportunity to begin operations in the country as a part of this restructuring. As public sector entities, electricity generation companies often referred to as GENCOs, are responsible for operating thermal power plants. The Private Power Infrastructure Board (PPIB) was established in 1994 to serve 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 to manage 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 regional jurisdiction and organisational 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 alleviate the NTDC's burden. The goal of CPPA is to regulate energy sales and purchases between the GENCOs and the distributors.

Despite these significant transformations and developments, Pakistan continues to be troubled by large-scale electricity 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. A 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 fiscal shortfall 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
- Inefficiencies of distribution companies in terms of billing and collection
- Agricultural Sector inefficient

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

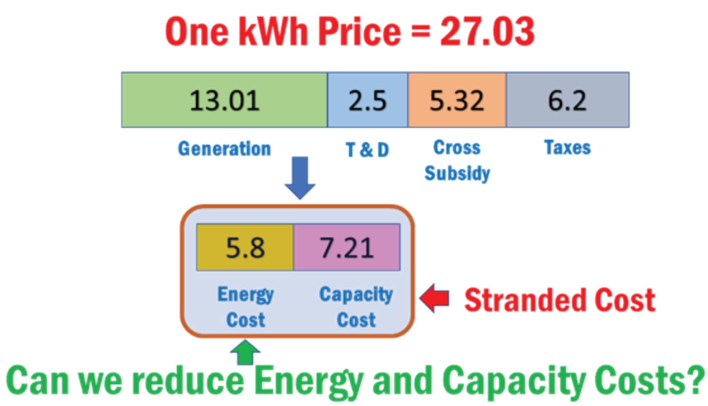


Table 1. Capacity and Energy Invoiced by Generators

S. No.	Fuel Type	FY 2017-2018 (Rs. In Billions)		FY 2018-2019 (Rs. In Billions)		FY 2019-2020 (Rs. In Billions)		FY 2020-2021 (Rs. In Billions)	
		Capacity Charge	Energy Charge	Capacity Charge	Energy Charge	Capacity Charge	Energy Charge	Capacity Charge	Energy Charge
1	WAPDA Hydel	125.6	2.3	160.7	2.3	107.5	2.9	95.8	2.6
2	Thermal	58	219.5	60.5	165	40.1	77.8	31.7	58.6
3	Coal	37.4	74	81.7	112	199.5	180.5	205.6	201.9
4	Nuclear	67.3	9.1	71	9	95	9.8	91.3	11.3
5	IPP Hydel	10.6	0.5	14.5	0.535	89.4	1.4	47.8	0.721
6	RFO	50.3	160	58.7	94.5	84.8	54.2	94	84.2
7	RLNG/Gas/HSD	62.7	208.8	109.3	297.7	132.5	302.2	126.1	304.3
8	Bagasse	3.1	7.9	1.3	5.7	2.3	3.9	5.7	5
9	Wind	0.8	40.3	5	59	85.8	0	76	0
10	Solar	0.03	12.9	0.6	15.3	18.5	0	18.1	0
11	Import	0	0	0	0	0	5.5	0	5
12	Mixed	1.8	10.9	5.1	5.5	0.625	1.1	0.753	1.3
Total		417.63	746.2	568.4	766.535	856.025	639.3	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 underutilised 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 to 2025 (forecasted) (Chaudhry, 2020). Due to the increase in capacity payments, the basket price of energy has increased in Pakistan.

Figure 2. Projection of the weighted average cost of generation (WACG) (Chaudhry, 2020)

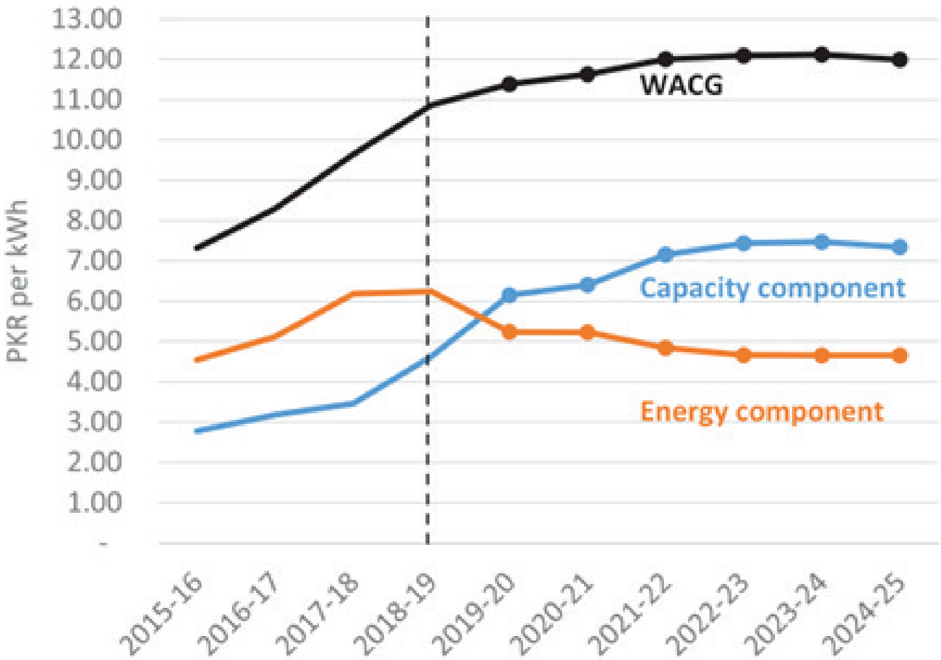
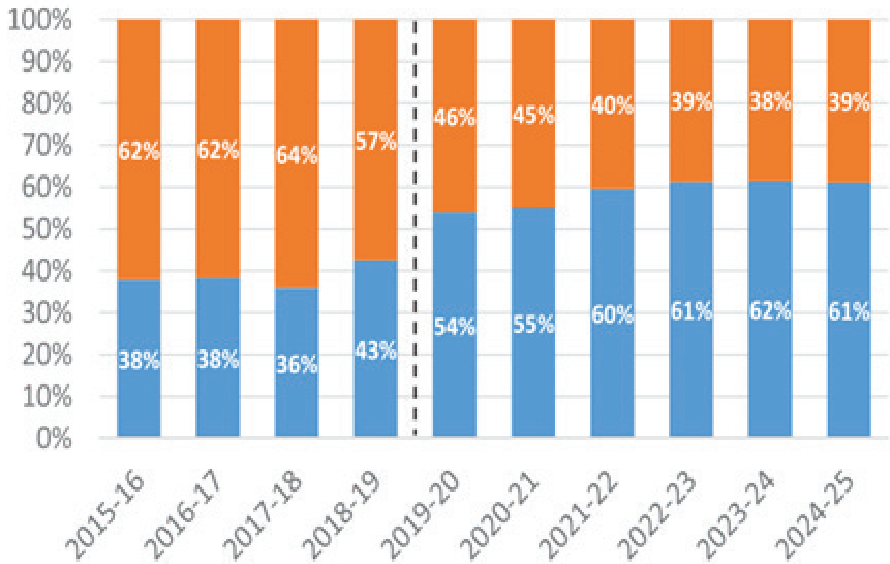
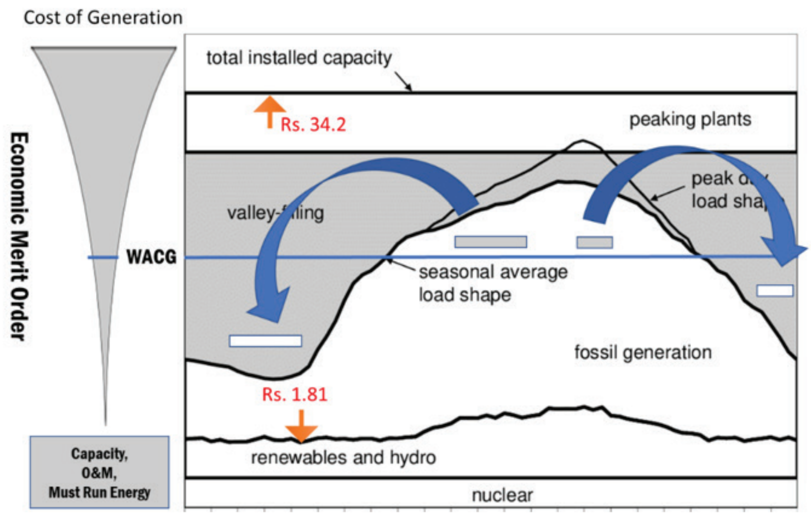


Figure 3. Percentage shares of capacity and energy components (Chaudhry, 2020)



It is critical to establish strategies to curtail 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 utilised during off-peak hours to 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 the utilisation 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 creates a win-win situation for both users as well as electricity generation companies. The power sector increases its load factor by utilising 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 utilisation. It is worth noting that the project's goal is to provide a ToU pricing mechanism for various types of flexible loads (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 the same 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 the promotion of 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 per cent reduction in emissions by 2030 via conditional and voluntary contributions, with a 15 per cent reduction in emissions from domestic resources and a further 35 per cent 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 country total 0.353 kg-CO2/kWh in the fiscal year 2021 and are targeted to fall to 0.202 kg-CO2/kWh by the year 2030, which is significantly lower than the average set by the Organisation 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 results are illustrated in Section 4. Finally, policy implications for stakeholders, policymakers, and power sector professionals are presented in Section 5.

2. LITERATURE REVIEW

The power sector's decarbonisation 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 decarbonisation and climate goals. Large proportions of RE and rapid electrification could jeopardise 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:

- Encourage distributed generation (DG)
- Reducing peak loads and seasonality
- 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 utilised 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 analysed in a study (Mullan et 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 utilisation 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 loads. In a study (Taneja, Lutz, & Culler, 2013), a flexible electrical load in the form of a domestic refrigerator, augmented with a 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 flexible loads (Diaz et al., 2017). A dynamic model for a WBPS was developed 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 loads (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 be achieved while lowering pumping cycles by 57%.

3. METHODOLOGY

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

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 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 utilised has been provided by the NPCC and the 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 power plants. This study used the above-mentioned data sets, which included but were 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 was determined.

Data Synthesis

Data analysis is a process of scrutinising, cleaning, transforming, and modelling data to discover useful information, reach conclusions, and support decision-making. To this end, an automated tool for data cleaning was developed using the R programming language. The tool extracted the relevant data from the extensive data sets provided by the power sector entities and performed data cleaning. It yielded hourly energy generation data in .csv format for further analysis and study. The detailed and rigorous process of data synthesis is outlined below

- The foundation of data synthesis was laid by data preprocessing using a combination of R programming language and MS Excel.
- The raw data was then scrutinised for outlier anomaly detection and removal.
- As a remedial measure, missing values were estimated through mathematical calculations.
- Once the data sets were cleaned, and missing data were evaluated, the unification of data from various formats was performed for standardisation.
- A sanity check was performed to assess the justifiability of data so that irrational values could be removed.
- The exploratory data analysis was performed, which concerned tentative qualitative and quantitative visualisation of data.

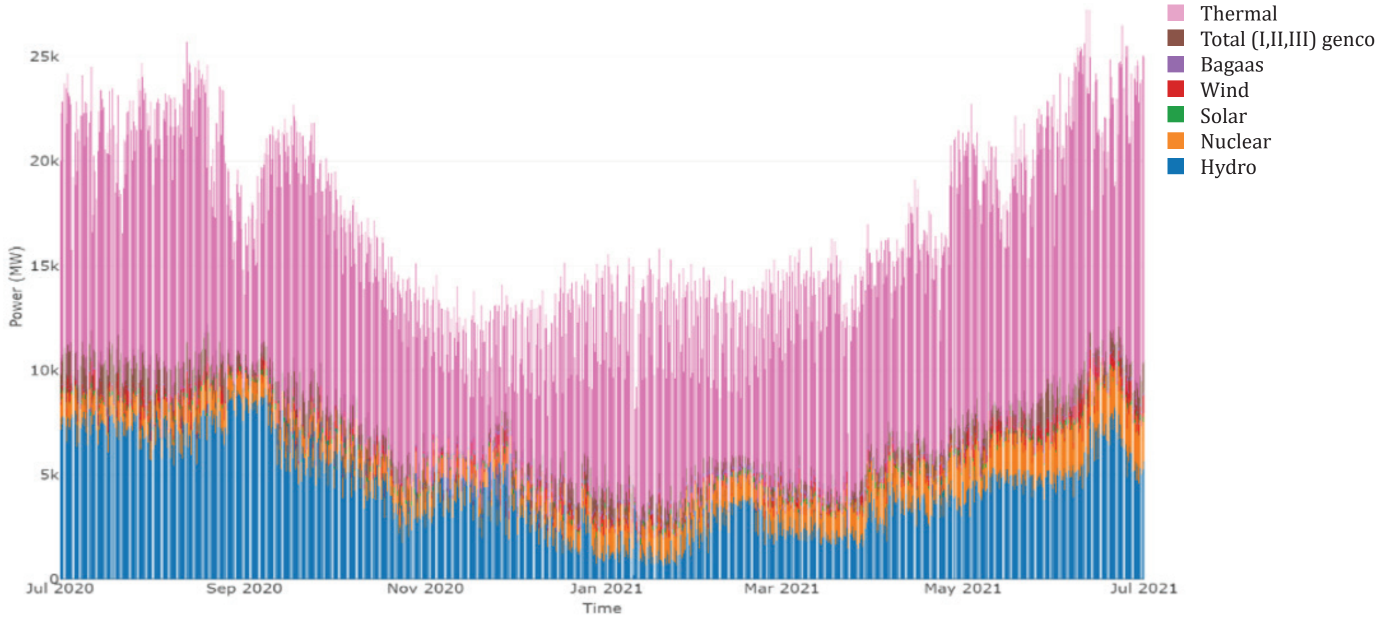
The processed data was in a single file, irrespective of the size of the input data or the number of input files of raw data. It contained hourly generation data for each source of generation.

Load Data Analysis

The synthesised data for the fiscal year 2020-21 was used for load analysis. The generation profile for the year is provided in Figure 6 below. The analysis of data yielded insights regarding the classification of generation profiles based on seasons. This classification was based on generation usage and enabled the development of recommendations for NEPRA for devising tariff models.

According to the analysis of the data, hydel power plants were one of the most cost-effective sources of generation, due to which they were utilised as 'must-run' sources to cater for the baseload. Additionally, these sources had a high ramping rate employing that were used as peaking sources of generation to cater to peak load. Furthermore, the analysis revealed that furnace oil and diesel-based power plants also contributed significantly to meeting peak demand, but their cost of generation was high compared to most other sources of generation.

Figure 6. Pakistan's hourly generation profile FY 2020-21



Analysis of 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, were acquired through the above-mentioned liaison mechanisms of LEI. The data sets provided the annual sector-wise growth of load from the year 2003 to 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 in the fiscal year 2020-2021 (NEPRA, 2021). Figure 7 shows the current and forecasted generation mix for each category. These figures show that the share of renewable energy sources in the energy mix increased over time. Solar capacity was 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.

Figure 7. Generation mix in 2021: Category-wise

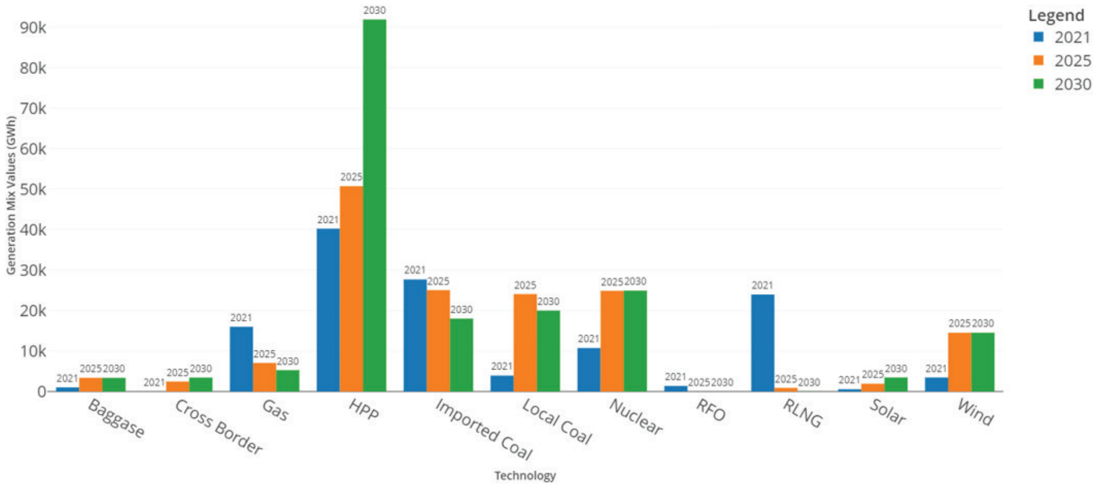


Figure 8 illustrates the forecasted category-wise sale for 2022-23 and 2027-28 in GWh, respectively (Planning, 2019). As seen, the share of commercial load will increase in 2027-28.

Figure 8. Forecasted category-wise sale 2022-23 (GWh)

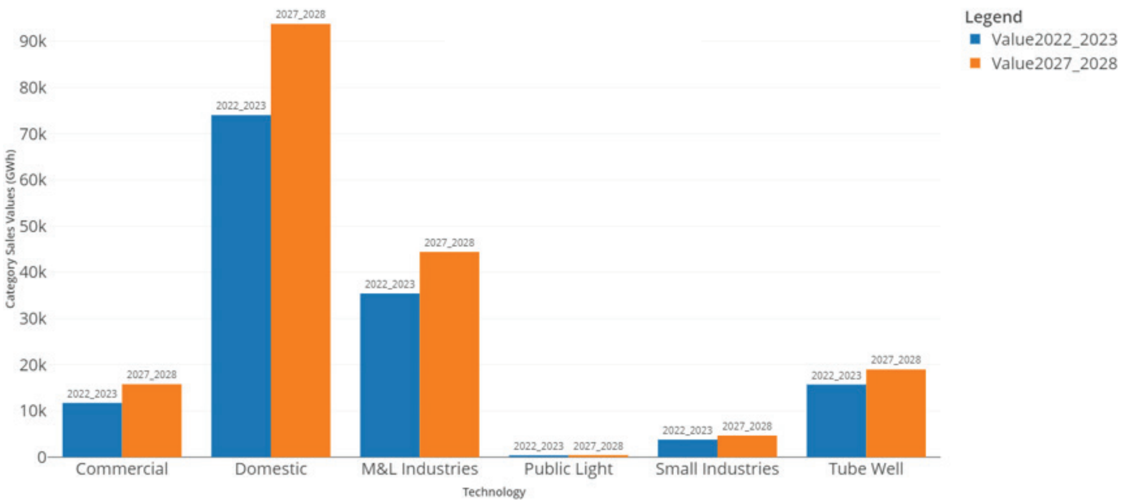


Table 2. Forecasted category-wise sale of energy (GWh)

Year	Domestic Load		Commercial Load		Public Lightening Load		Small Industries Load		M&L Industrial Load		Tube Well Load		Total Load	
	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R	Energy	G.R
2017-18	59,258		8,519		376		3,012		24,326		12,639		108130	
2018-19	61,626	4.0	9,037	6.1	381	1.4	3,160	4.9	26,309	8.2	13,534	7.1	114,047	5.5
2019-20	64,355	4.4	9,676	7.1	386	1.4	3,313	4.8	28,832	9.6	14,045	3.8	120,607	5.8
2020-21	67,293	4.6	10,335	6.8	391	1.4	3,470	4.7	31,342	8.7	14,583	3.8	127,414	5.6
2021-22	70,637	5.0	11,026	6.7	396	1.4	3,631	4.6	33,311	6.3	15,139	3.8	134,140	5.3
2022-23	74,025	4.8	11,740	6.5	402	1.4	3,797	4.6	35,421	6.3	15,721	3.8	141,106	5.2

2023-24	77,611	4.8	12,557	7.0	407	1.4	3,966	4.5	37,324	5.4	16,324	3.8	148,189	5.0
2024-25	81,337	4.8	13,373	6.5	413	1.4	4,139	4.4	39,030	4.6	16,949	3.8	155,241	4.8
2025-26	85,260	4.8	14,144	5.8	419	1.4	4,314	4.2	40,814	4.6	17,597	3.8	162,548	4.7
2026-27	89,434	4.9	14,947	5.7	425	1.4	4,492	4.1	42,565	4.3	18,269	3.8	170,132	4.7
2027-28	93,753	4.8	15,783	5.6	431	1.4	4,673	4	44,416	4.4	18,967	3.8	178,023	4.6
Ave. Growth Rate (G.R) (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 a soft industrial load. Our analysis yields that the load of tube wells, which accounts for 10 per cent 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 costs in terms of subsidies for the government while offering lower tariffs for the farmers within off-peak hours. Furthermore, almost 5 per cent of the total load is industrial load. According to our analysis, 5 per cent of the industrial load is estimated to be soft load, which can be shifted to off-peak hours.

Analysis of the WACG Model

The weighted average cost of generation (WACG) has two components, namely, the capacity component and the energy component. It is given by

WACG = (Capacity Component+Energy Component)/(Energy Utilization) (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 modelled equation for calculating WACG is shown in Equation 2.

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

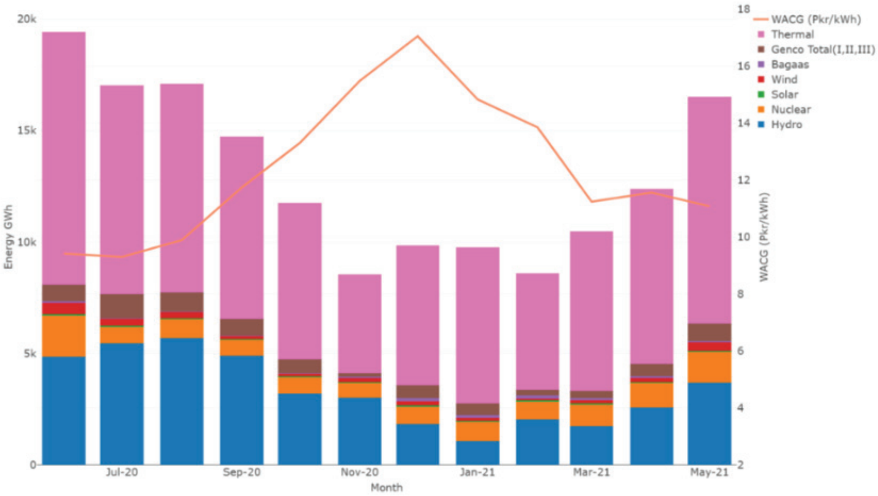
The number of power plants is represented by the value of n, z is the total number of power plants, and P denotes plant number in terms of merit order for the given hours. Equation 3 represents the WACG for a month based on an hour-to-month calculation.

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

Where h represents the number of hours.

The available generation capacity component is fixed for each month. If energy usage is increased, it will decrease the WACG. Therefore, the load should be transferred to the 'valleys' of the 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 9. Variation in WACG for FY 2020-21



4. Results and Discussion

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 utilisation at specific hours. Each power plant's associated emissions were also calculated.

Energy Analytics Visualisation 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 during those hours to serve the load. The energy and capacity components have hourly and monthly variations, respectively. Both components were included in the developed tool. These two components were used to calculate the WACG. The developed tool informed 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 was a total of 20.86 GWh of energy sold by the DISCOs for 95.06 million rupees at that specific hour. The capacity payments were 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 conveniently to the users.

Figure 10. Designed dashboard at Shinyapps.io

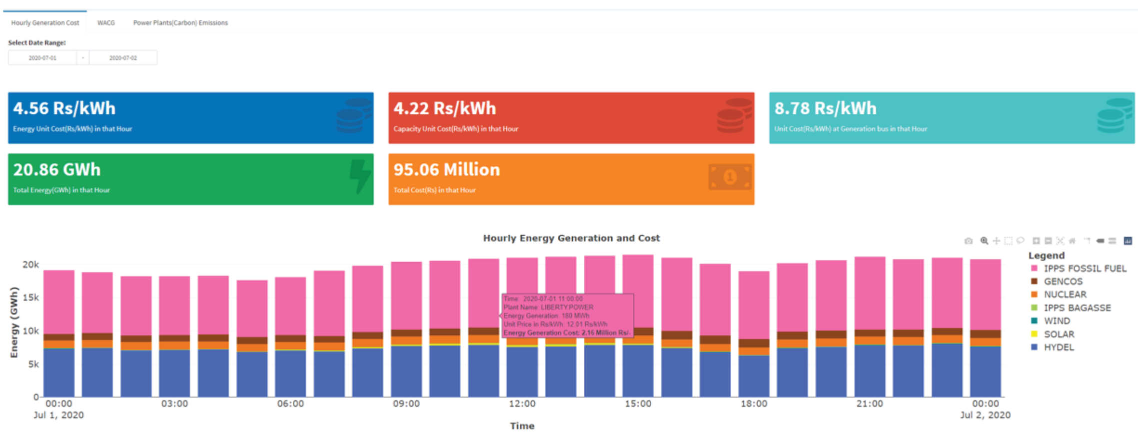


Figure 14 depicts a map of power generation sources, with the circle size indicating the relative power output of the power plants at 11 a.m. on July 1, 2020. The size of the circle is variable according to the power output of the power plants at the specific time interval.

Figure 11. Map of the Power Plants that utilised at the particular hour

Figure 12. Total hourly energy generation and its associated cost

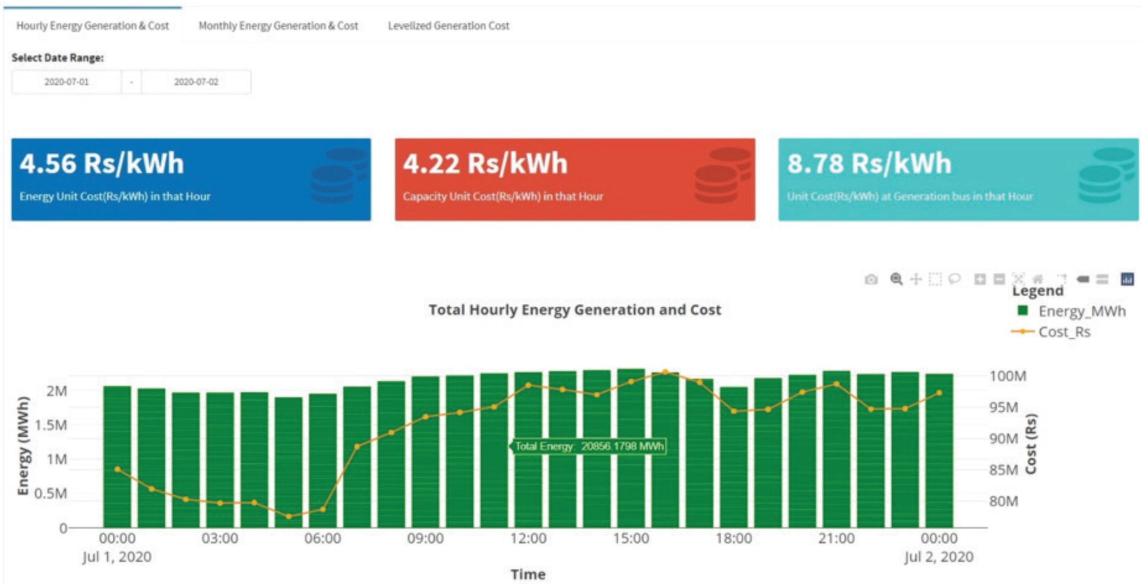


Figure 15 presents the total hourly generated energy and its cost over the following 24 hours. By scrolling the cursor, the value of energy generated in MWh and its generation cost can be computed. Energy cost, capacity cost, and the total cost of generation are represented by the values in the boxes. 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 July 2020. The percentage share of each type of generation source can be seen and located by using the cursor.

Figure 13. Category-wise total monthly energy generation

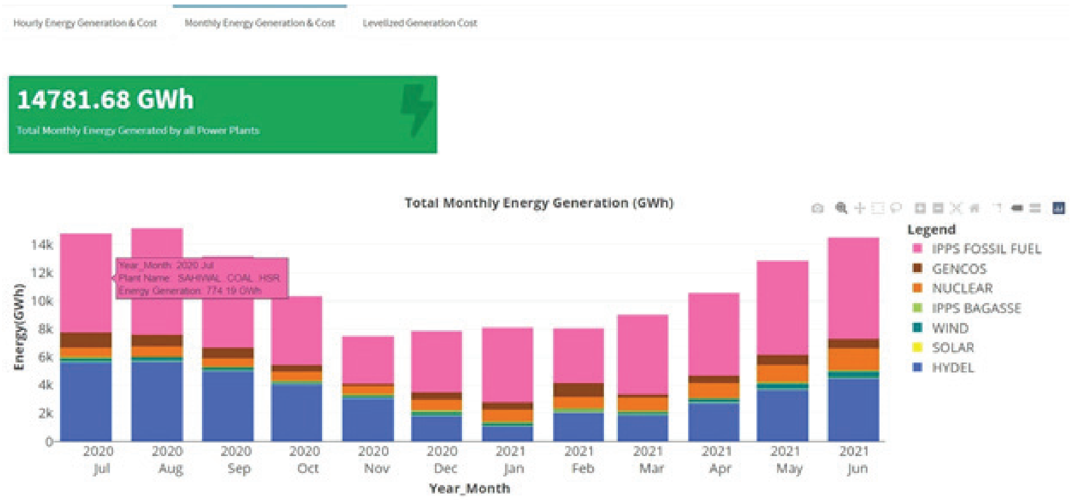


Figure 14. Category-wise Total Monthly Energy Cost

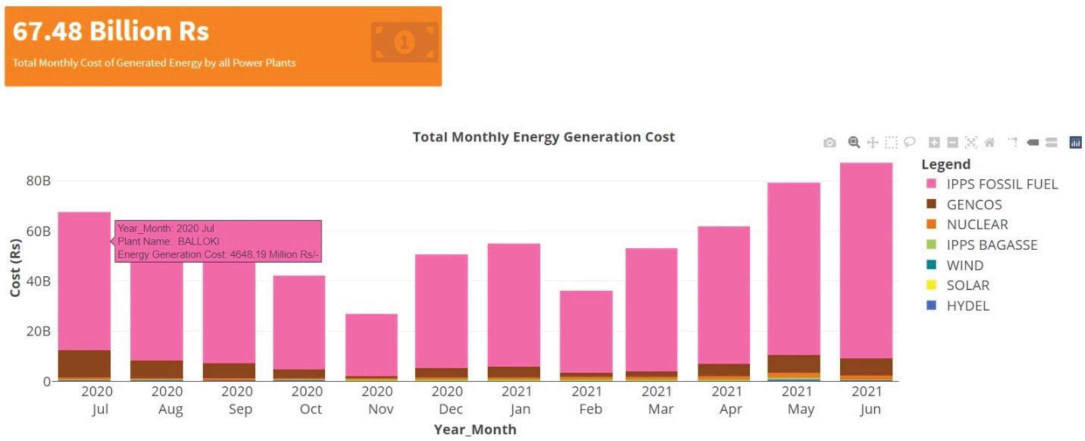
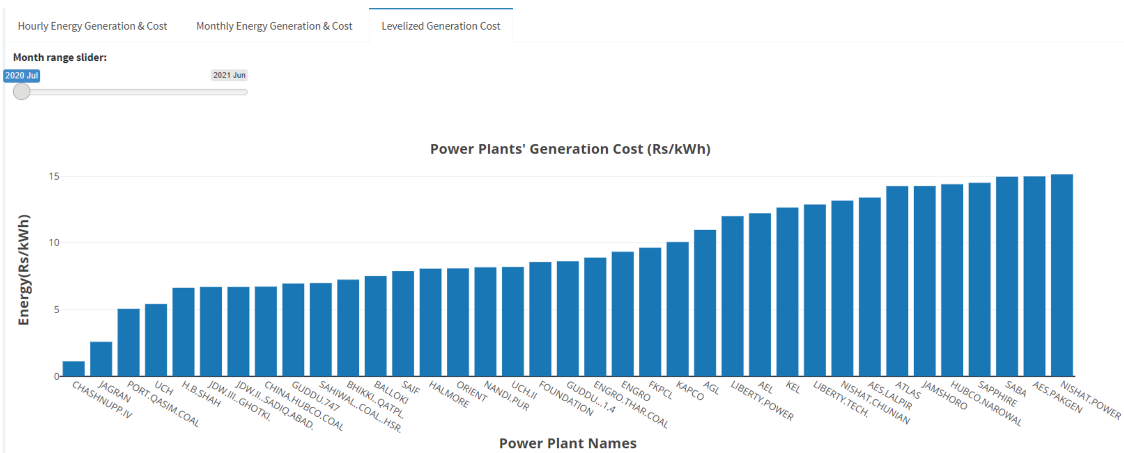


Figure 17 illustrates the cost of generation on a monthly basis. The statistics depict the cost from different generation sources. As the figure indicates, the cost of generation from IPPs was extremely expensive in comparison to hydel. The orange box depicts the cost of generation of the electricity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

Figure 15. Generation cost for each power plant (Rs/kWh)



The weighted average cost of generation was calculated based on the data sets. Many cases and scenarios can be developed, but only three cases are 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 simplification, the report computed and displayed 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.

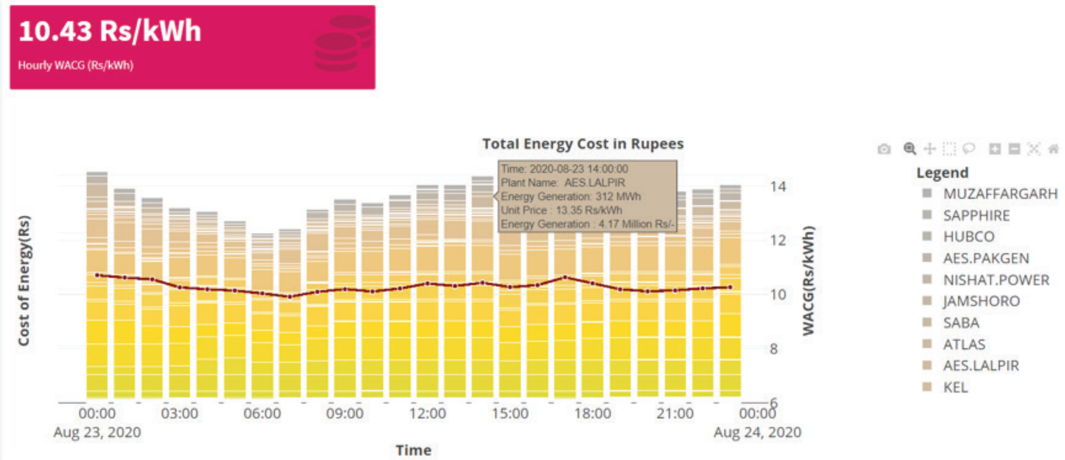
Case A: 5% Load Shifting from Peak hours to Off-peak hours

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)

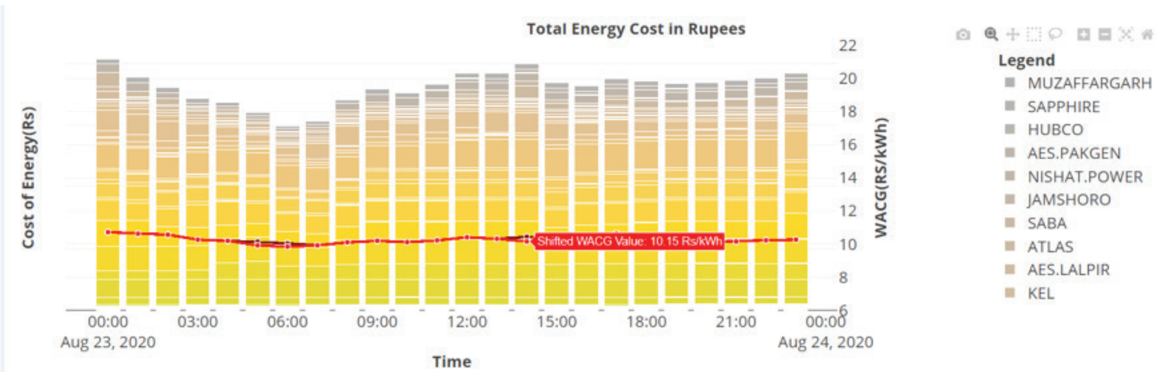
The annual peak in the fiscal year 2020-2021 occurred on 23 August 2020. The WACG at 2 pm on the peak day was 10.43 Rs/kWh. Figure 19 shows the total energy cost for all power plants that were utilised on this day. The red line on the bar graph depicts the WACG values throughout 24 hours.

Figure 16. The generation cost of each power plant and WACG for each hour



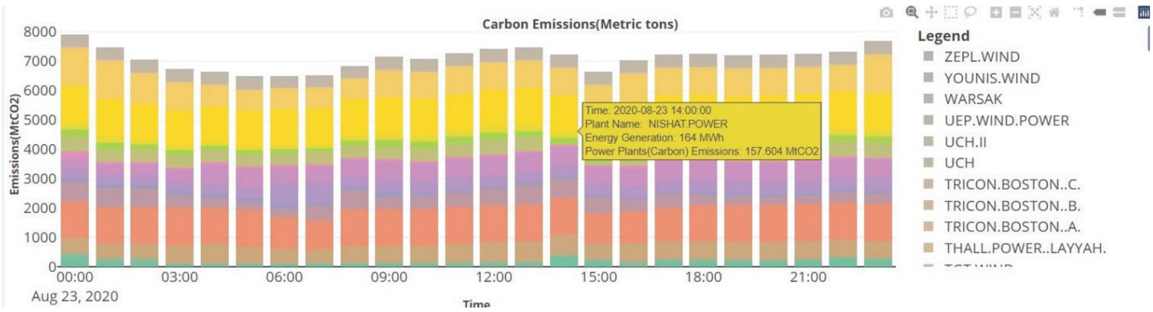
The power sector may save 17.18 million rupees on a single occasion by moving the 5% load from peak to off-peak hours. If this load is moved for a month, the power sector can save 514.41 million rupees from the shifting, as shown in Figure 20. The shifted WACG was 10.15 Rs/kWh, while it was 10.43 Rs/kWh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

Figure 17. 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 CO2 during peak hours, but when the demand shifts by 5% to off-peak hours, CO2 emissions decay to 7,214.92 metric tons. Figure 21 shows the carbon emissions of all the power plants that were in use at that hour.

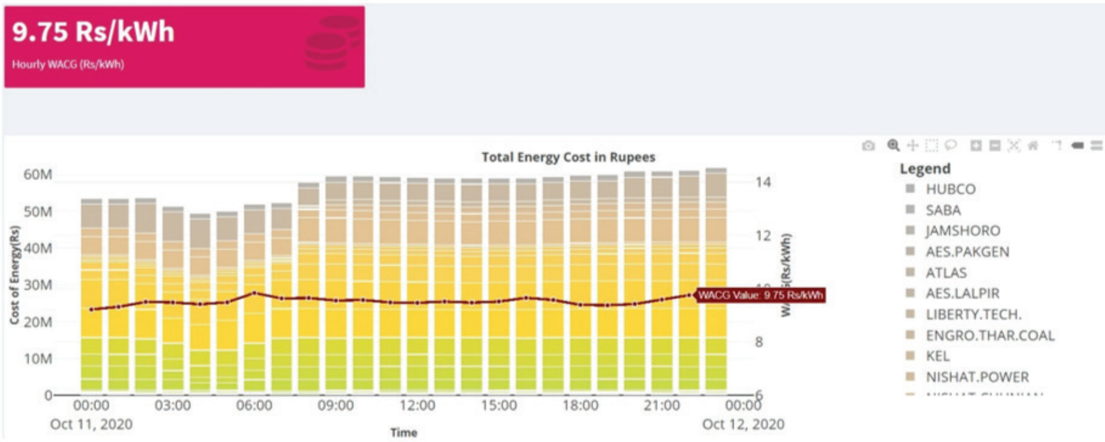
Figure 18. Emission Plot for various Power Plants



Scenario 2- Shoulder Month (Average Load Month)

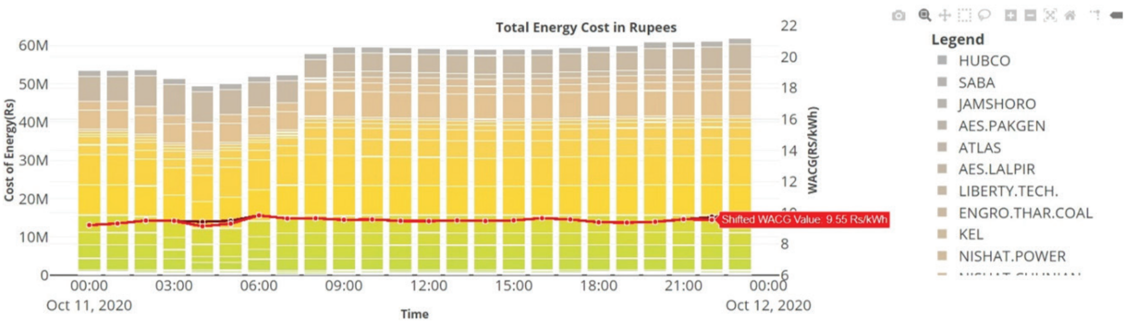
In the fiscal year 2020-2021, the average load occurred on October 11, 2020. At 11 p.m. on this day, the WACG was 9.75 Rs/kWh. Figure 22 depicts the overall energy cost for all power plants in use on this particular day. The WACG values throughout 24 hours are depicted by the red line on the bar graph.

Figure 19. 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 could have saved 8.89 million rupees on a single occasion. As indicated in Figure 23, if this load was shifted for a month, the power sector could have saved 266.68 million rupees. The repositioned WACG was 9.55 rupees per kWh, down from 9.75 rupees per kWh before the shift.

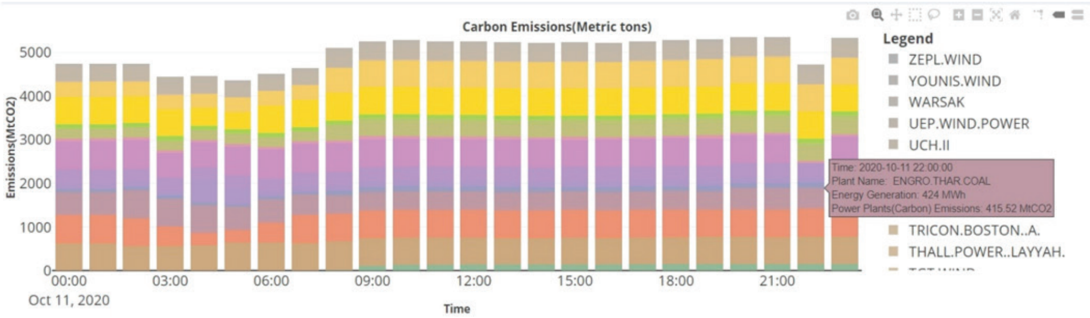
Figure 20. Total energy cost and shifted WACG Value



When power plants were switched from peak to off-peak hours, the power sector might have gained roughly

30.47 million rupees per month in carbon credits for October. The power sector emitted 5357.81 metric tons of CO2 during peak hours, but when the demand shifted by 5% to off-peak hours, CO2 emissions decreased to 4703.51 metric tons.

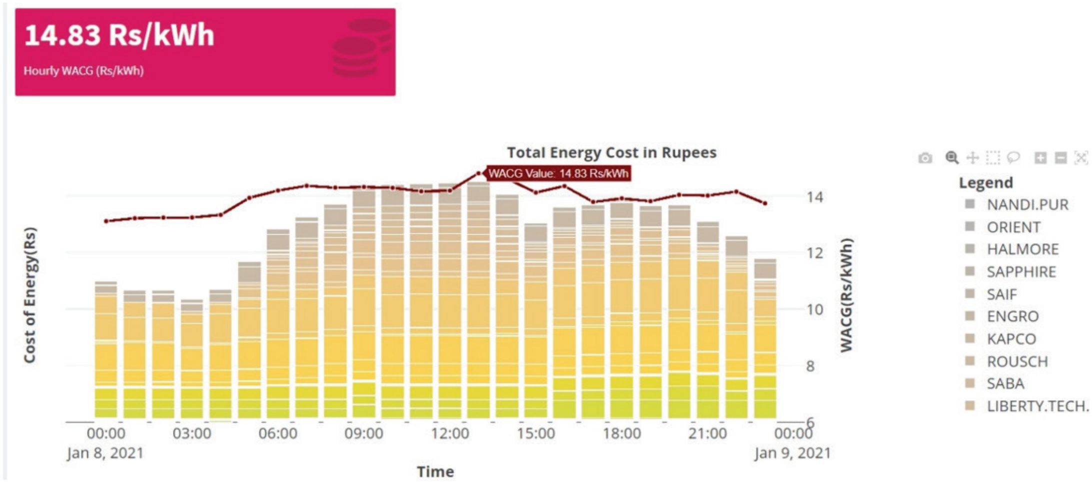
Figure 21. Emission Plot for various Power Plants



Scenario 3- Lowest Load Month

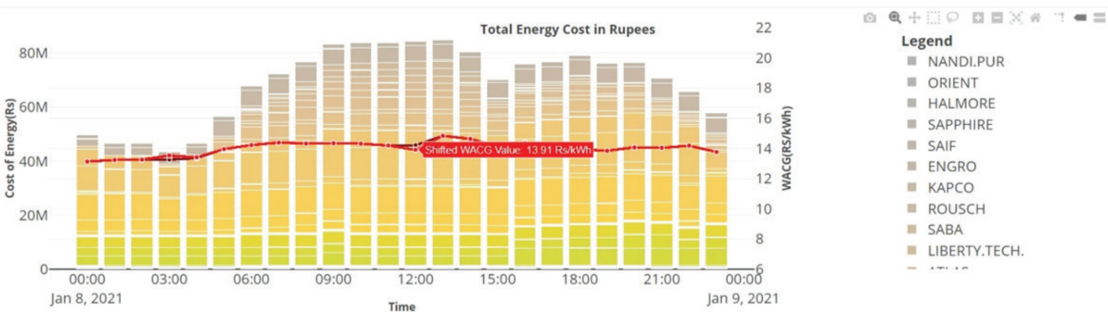
On January 8, 2021, the lowest Load for the fiscal year 2020-2021 was recorded. At 1 p.m. on that day, the WACG was 14.83 Rs/kWh. Figure 25 depicts the total energy cost for all power plants in use on this day. The WACG values throughout 24 hours are depicted by the red line on the bar graph.

Figure 22. The Generation Cost of each Power Plant and WACG for each Hour



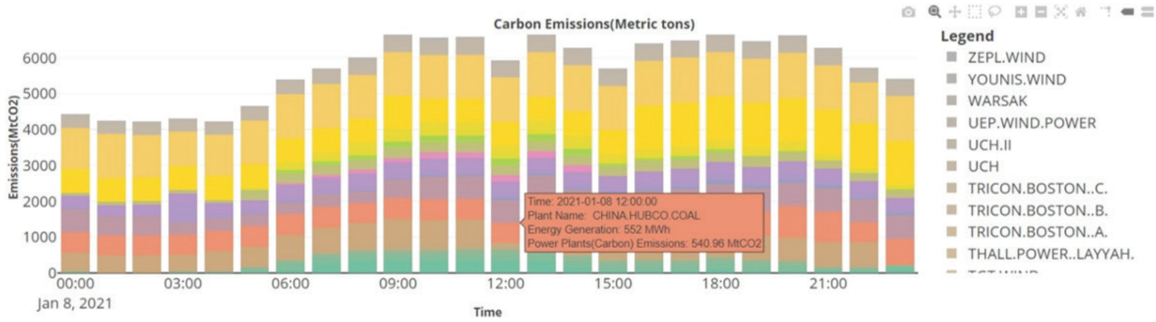
The power sector could have saved 1.78 million rupees on a single occasion by shifting the 5% load from peak to off-peak hours. If this load had moved for a month, the power sector could have saved 53.48 million rupees, as shown in Figure 23. The WACG would have cost 13.91 rupees per kWh, compared to 14.83 rupees per kWh before the shift.

Figure 23. Total Energy Cost and Shifted WACG Value



The power sector could have gained around 27.52 million rupees per month in emission trading value if power plants had shifted from peak to off-peak hours in January. During peak hours, the power sector released 6,586.73 metric tons of CO2, but when demand changed by 5% to off-peak hours, CO2 emissions dropped to 5,915.99 metric tons. Figure 27 depicts the emissions from each power plant used on this day.

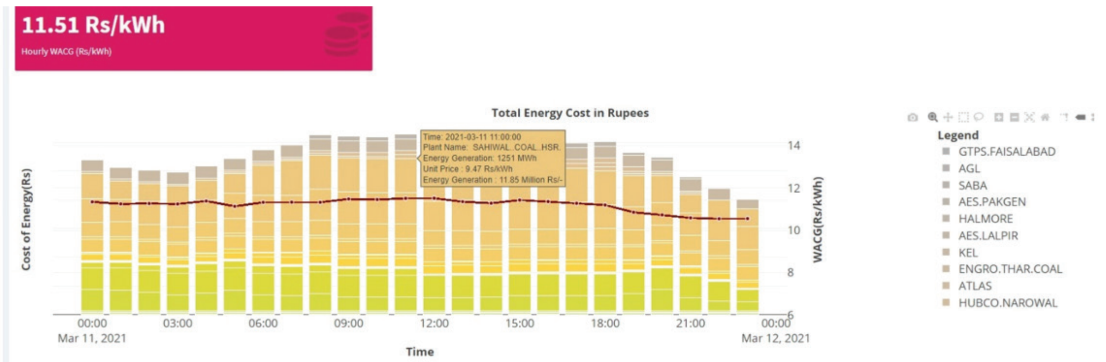
Figure 24. Emission plot for various power plants



Scenario 4- Shoulder Month (Average Load Month)

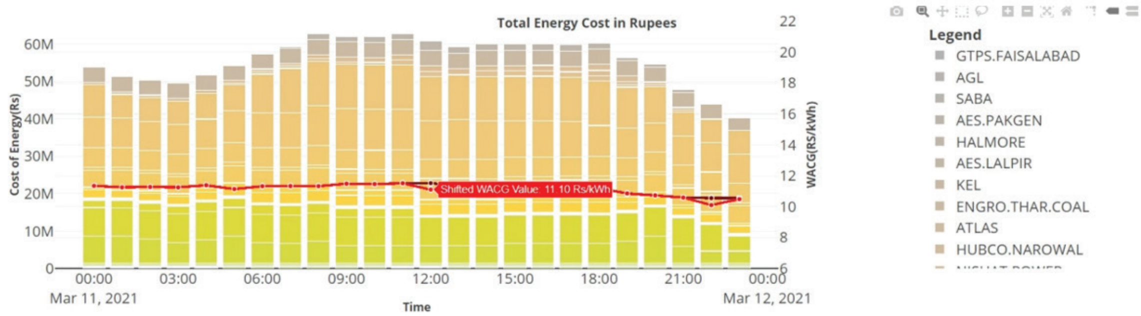
In the fiscal year 2020-2021, the average load occurred on March 11, 2020, which is considered a shoulder month. At 11 a.m. on this day, the WACG was 11.51 Rs/kWh. The total energy cost for all power plants that were in use on this day is depicted in Figure 28. The WACG values throughout 24 hours are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

Figure 25. The Generation cost of each power plant and WACG for each hour



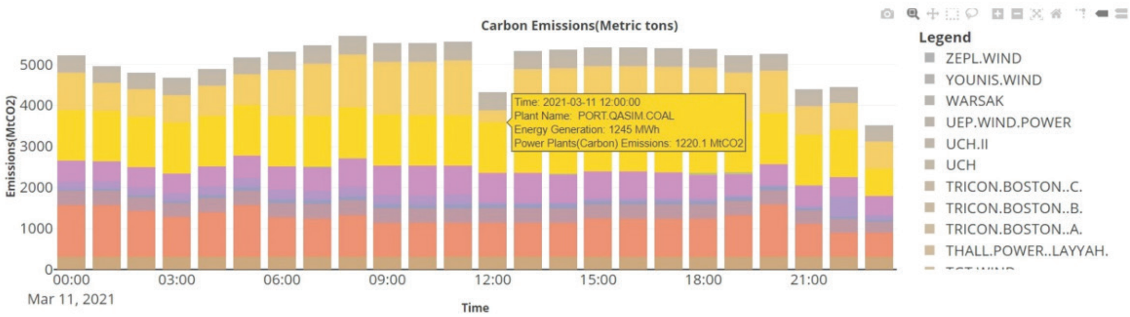
The power sector could have saved 10.52 million rupees on a single occasion by moving a 5% load from peak to off-peak hours. If this load had moved for a month, the power sector could have saved 304.53 million rupees, as shown in Figure 29. The WACG would have cost 11.10 rupees per kWh, compared to 11.51 rupees per kWh before the shift.

Figure 26. Total Energy Cost and Shifted WACG Value



If power plants had switched from peak to off-peak hours, the power sector could have gained around 144.73 million rupees in carbon reduction value for March. During peak hours, the power sector released 5,362.38 metric tons of CO2, but when demand changed by 5% to off-peak hours, CO2 emissions fell to 4,311.74 metric tons. Figure 30 depicts the emissions released by each power plant during this day.

Figure 27. Emission plot for various power plants



5. 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 the short to medium term. However, some unconventional solutions to conventional problems can prove to be highly efficacious in alleviating the burden on the energy sector. To this end, we 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 utilisation of idle generation capacity, decreases reliance on expensive fossil fuel-based peaking plants, increases R.E utilisation, and decreases the WACG. A combination of these factors collectively results in a reduction of circular debt in 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 believe that the work conducted during the course of this study can serve as a valuable guideline in implementing ToU pricing in Pakistan.

6. RECOMMENDATIONS

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

Utilisation of Installed Smart Metres

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 metres are being deployed in Multan Electric Power Company (MEPCO) and Peshawar Electric Supply Company (PESCO) by USAID. Smart metres keep a near real-time record of electricity consumption. The metres communicate the electricity usage trend to the distribution company automatically. During peak periods, customised tariffs may be offered to consumers based on price signals. The DR will minimise electricity generation costs by lowering the peak demand at time intervals.

Incentivised Tariff Offering for Bulk and Industrial Consumer

Once the above-mentioned pilot project is been successfully completed in the MEPCO and PESCO regions, the next target consumers should be bulk and industrial. This strategy will involve the provisioning of dynamic tariffs via price signals to industrial and bulk consumers. The consumers will be responsible for the cost of the smart metres. 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 DISCOs' 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 metres need to be installed at these loads. Through the usage of smart metres, users will get dynamic tariff rates via communication protocols of smart metres and app development. To incentivise 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 to increase flexibility. A wider range of consumers can be welcomed to take advantage of these ToU tariff rates. Smart metres will be used to monitor and signal the pricing. Smart metres will allow the provisioning of real-time pricing and monitor electricity consumption at any point in time. The success of this DR is contingent upon the DISCOs' administration. The initiative will benefit both the consumer and the utility by lowering the utility's peak demand and offering incentives to the consumers.

REFERENCES

Bacon, R. (2019). Learning from power sector reform: the case of pakistan. Policy Research Working Paper. *Washington, DC.: World Bank*.

Bergaentzlé, C., Clastres, C., & Khalfallah, H. J. E. P. (2014). Demand-side management and European environmental and energy goals: An optimal complementary approach. *Energy Policy, 67*, 858-869.

Carlos Fernández, E. T. (2019). *Demand-side flexibIlity for power sector transformation*. Retrieved from https://www.irena.org/publications/2019/Dec/Demand-side-flexibility-for-power-sector-transformation.

Chao, H. (2010). Price-responsive demand management for a smart grid world. *The Electricity Journal, 23*(1), 7-20.

Chaudhry, F. A., Farooq, U., & Chaudhry, T. M. (2020). *Pakistan's electricity outlook 2020-25*. Retrieved from https://lei.lums.edu.pk/index.php/pakistans-electricity-outlook-2020-25/

CPPA-G (Central Power Purchasing Agency). (2019). *Central power purchasing agency annual report*. Retrieved from https://www.cppa.gov.pk/Home/DownloadItems/285?Type=Annual%20Reports.

Davis, S. J., Lewis, N. S., Shaner, M., Aggarwal, S., Arent, D., Azevedo, I. L., *et al*. (2018). Net-zero emissions energy systems. Science*, 360*(6396).

Diaz, C., Ruiz, F., & Patino, D. (2017). Modeling and control of water booster pressure systems as flexible loads for demand response. *Applied Energy, 204*, 106-116.

Hesser, T., & Succar, S. (2012). Renewables integration through direct load control and demand response. In F. P. Sioshansi (Ed.), *Smart grid: Integrating renewable, distributed & efficient energy* (pp. 209-233). Elsevier Inc.

Hogan, W. W. (2009). *Providing incentives for efficient demand response*. Retrieved from http://lmpmarketdesign.com/papers/Hogan_Demand_Response_102909.pdf

Jamil, F. (2013). On the electricity shortage, price and electricity theft nexus. *Energy Policy, 54*, 267-272.

Lopes, R. A., Junker, R. G., Martins, J., Murta-Pina, J., Reynders, G., & Madsen, H. (2020). Characterisation and use of energy flexibility in water pumping and storage systems. *Applied Energy, 277*.

Mullan, J., Harries, D., Bräunl, T., & Whitely, S. (2011). Modelling the impacts of electric vehicle recharging on the Western Australian electricity supply system. *Energy Policy, 39*(7), 4349-4359.

NEPRA (National Electric Power Regulatory Authority). (2021). *State of industry report 2021*. Retrieved from https://www.nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202021.pdf

Planning, P. S. (2019). *Electricity demand forecast based on power market survey 2019-2028*. Retrieved from https://ntdc.gov.pk/ntdc/public/uploads/services/planning/power%20market%20survey/PMS%20NTDC%20System.pdf

Planning, P. S. (2021). *Indicative generation capacity expansion plan*. Lahore: National Transmission & Despatch Company (NTDC).

Rauf, O., Wang, S., Yuan, P., & Tan, J. (2015). An overview of energy status and development in Pakistan. *Renewable and Sustainable Energy Reviews, 48*, 892-931.

Swain, K. P., Lakhara, P., Khetan, K., Mishra, S., & De, M. (2021). Efficient hybrid pricing for optimal DSM of home energy management system utilizing load precedence. *International Transactions on Electrical Energy Systems, 31*(3), e12783.

Taneja, J., Lutz, K., & Culler, D. (2013, October). *The impact of flexible loads in increasingly renewable grids*. Paper presented at the 2013 IEEE International Conference on Smart Grid Communications (INSPEC Accession Number: 13977363).

Zhang, X., Liang, Y., & Liu, W. (2017). Pricing model for the charging of electric vehicles based on system dynamics in Beijing. *Energy, 119*, 218-234.

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: 7,679.17 MtCO2
Emission after shifting: 5,730.97 MtCO2
Monthly gain: 98.6 million Rs.

Figure 28. Total energy cost and shifted WACG value

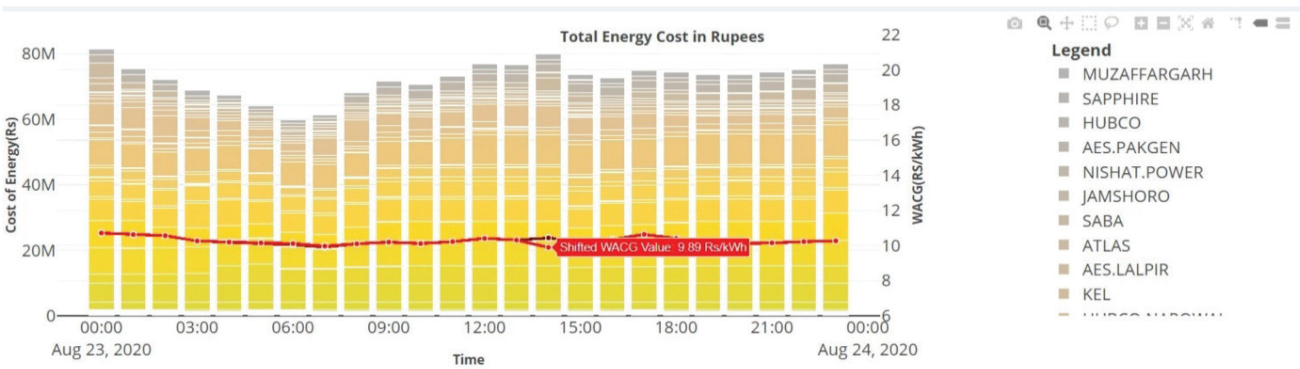
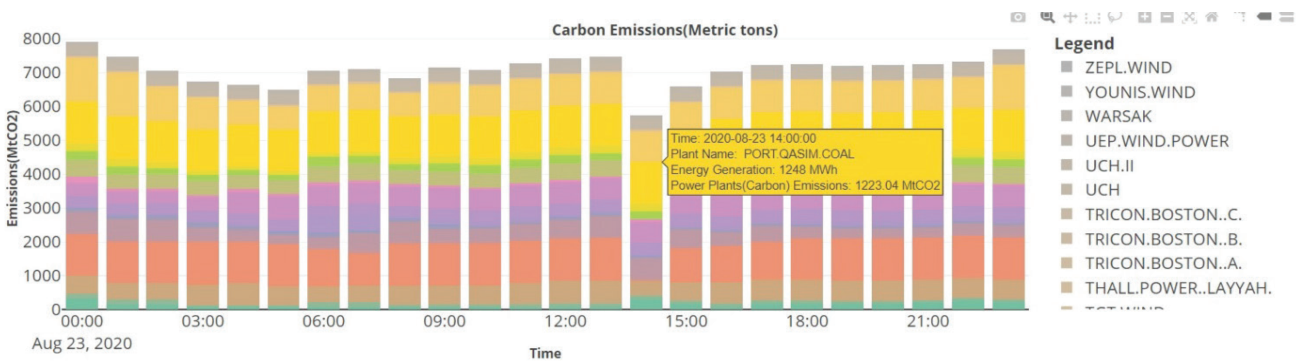


Figure 29. Emission plot for various power plants



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: 5,357.81 MtCO2
Emission after shifting: 4,524.35 MtCO2
Monthly gain: 17.41 million Rs.

Figure 30. Total energy cost and shifted WACG value

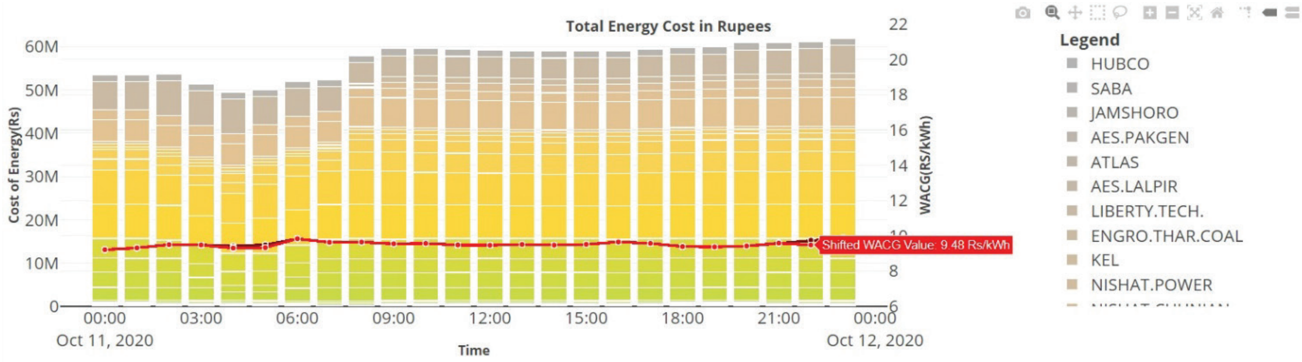
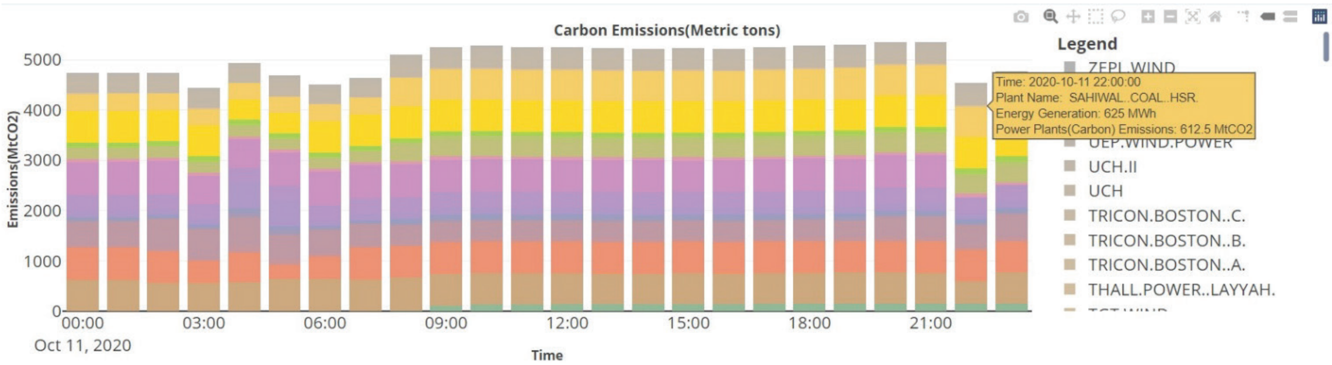


Figure 31. Emission plot for various power plants



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 MtCO2
Emission after shifting: 5903.00 MtCO2
Monthly gain: 55.03 million Rs.

Figure 32. Total energy cost and shifted WACG value

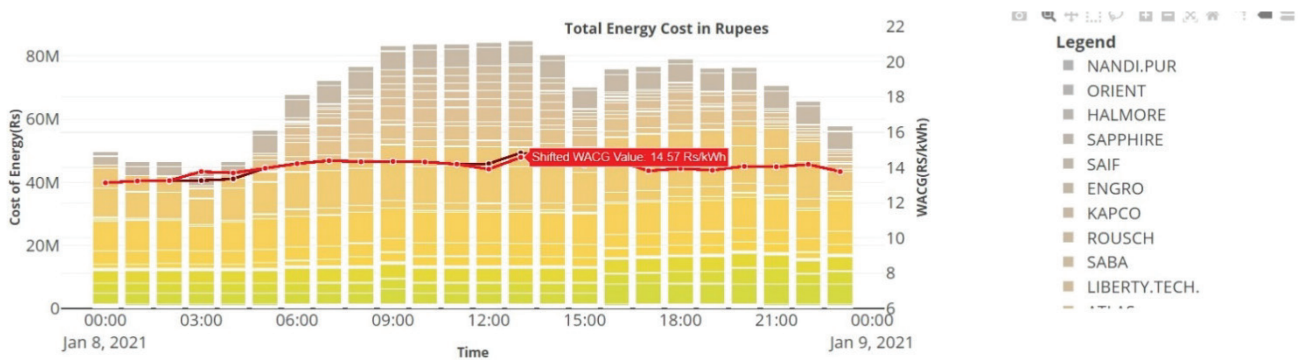


Figure 30. Total energy cost and shifted WACG value

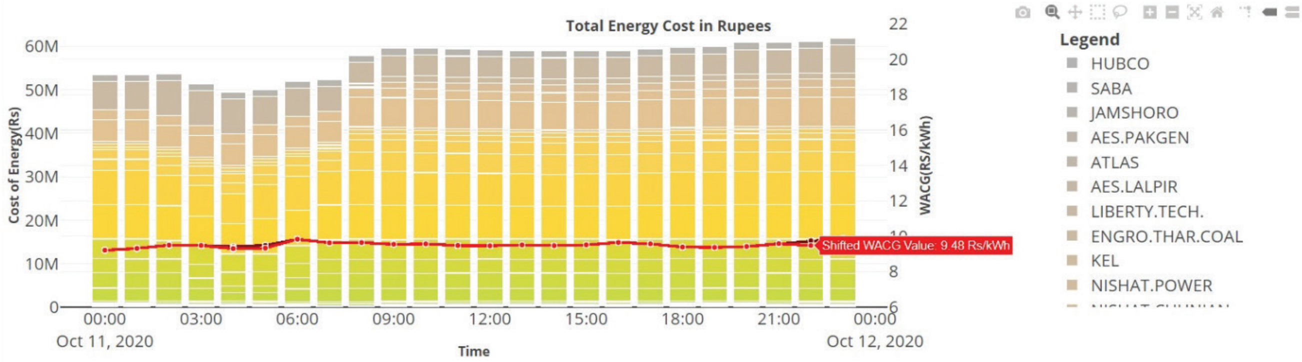
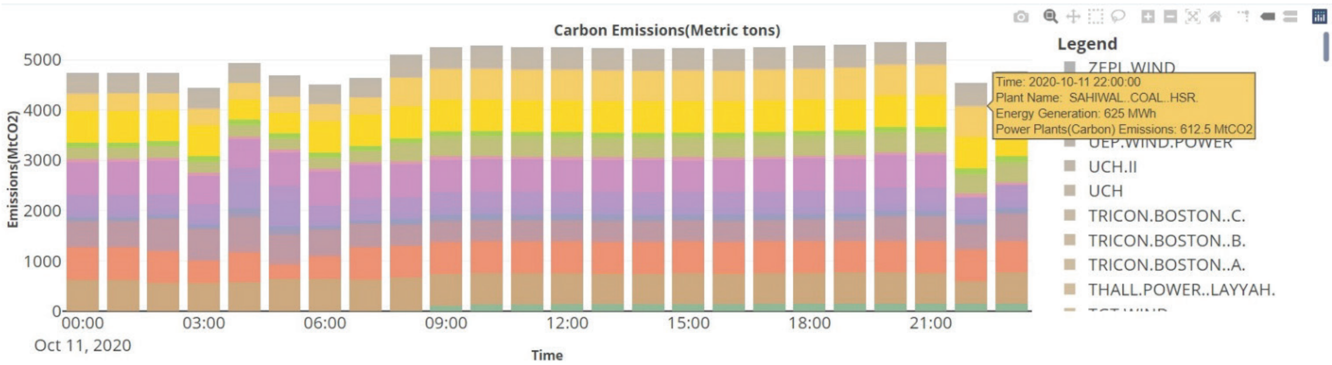


Figure 31. Emission plot for various power plants



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Monthly gain: 55.03 million Rs.

Figure 32. Total energy cost and shifted WACG value

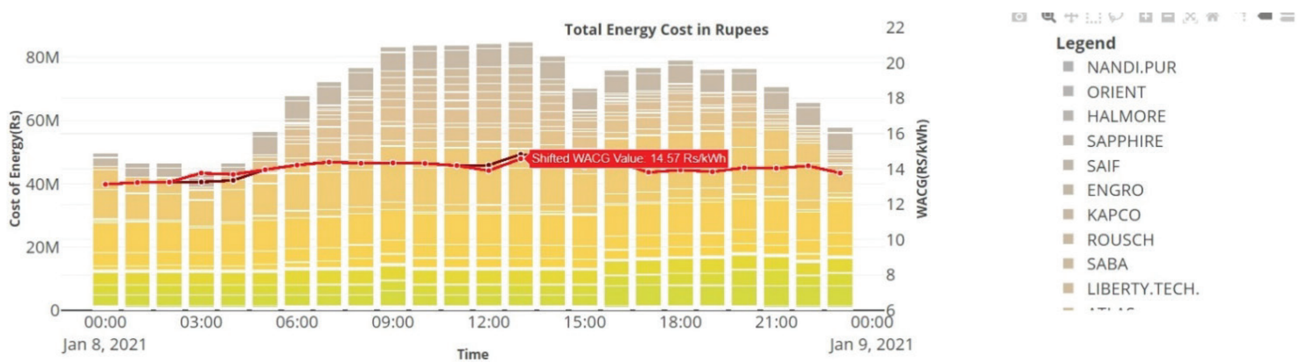
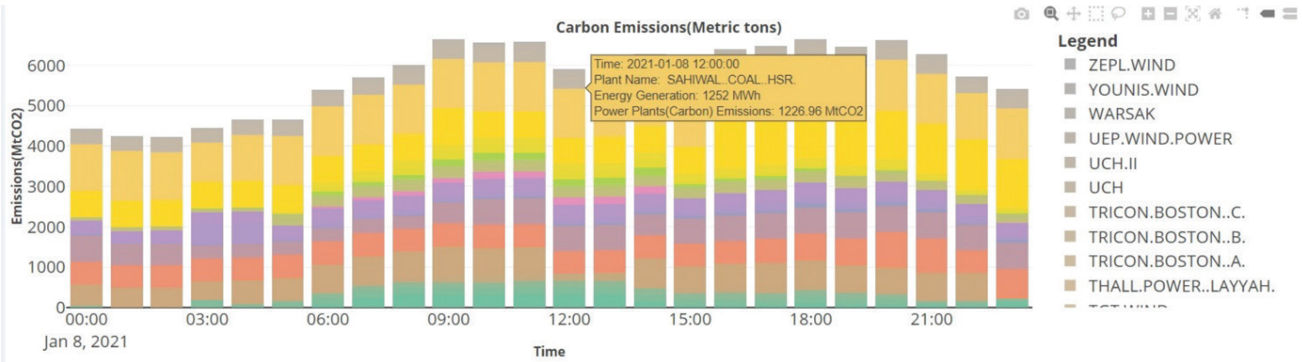


Figure 33. Emission plot for various power plants



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: 5,362.38 MtCO2
Emission after shifting: 4,134.44 MtCO2
Monthly gain: 289.46 Rs.

Figure 34. Total energy cost and shifted WACG value

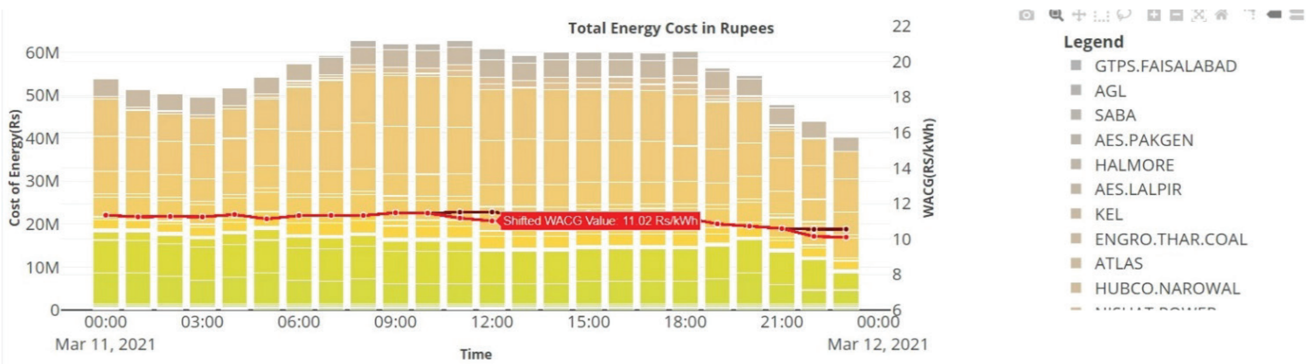
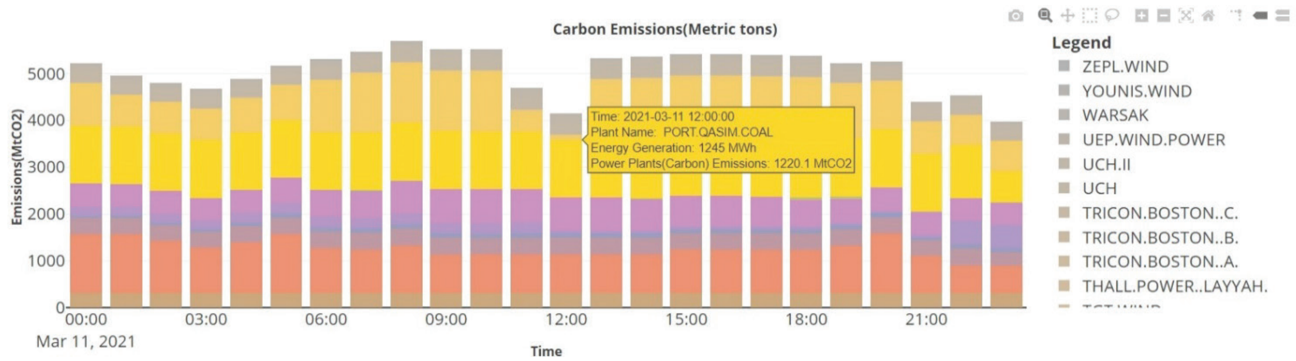


Figure 35. Emission plot for various power plants



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: 7,679.17 MtCO2
Emission after shifting: 4,814.53 MtCO2
Monthly gain: 127.45 million Rs.
Emission after shifting: 4,134.44 MtCO2
Monthly gain: 289.46 Rs.

Figure 36. Total energy cost and shifted WACG value

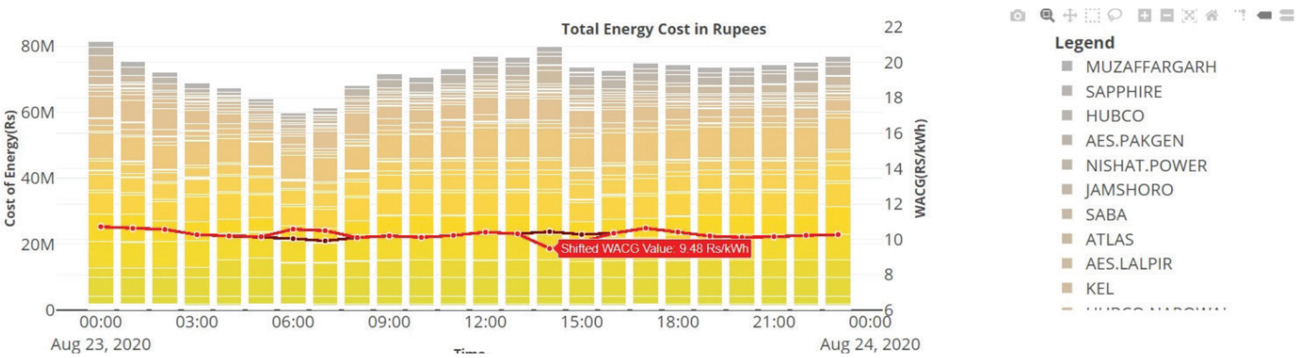
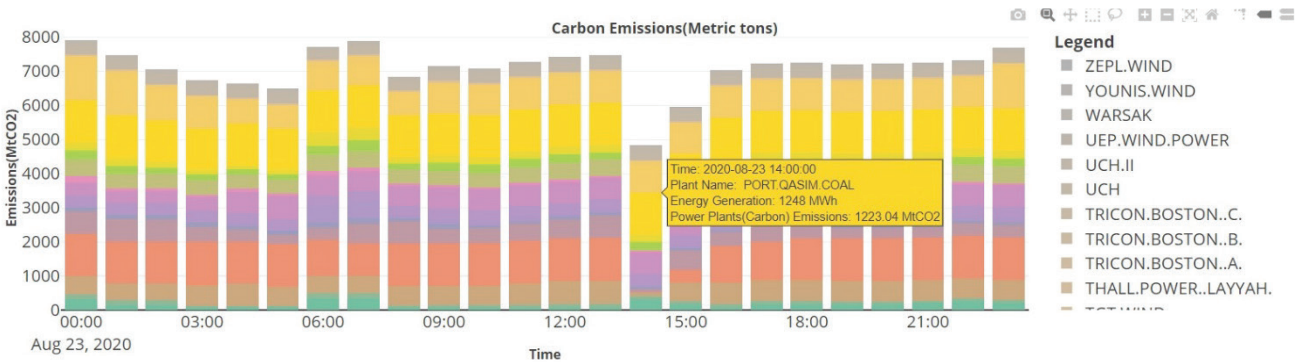


Figure 37. Emission plot for various power plants



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: 5,357.81 MtCO2
Emission after shifting: 4,065.63 MtCO2
Monthly Loss: 129.27 million Rs.

Figure 38. Total energy cost and shifted WACG value

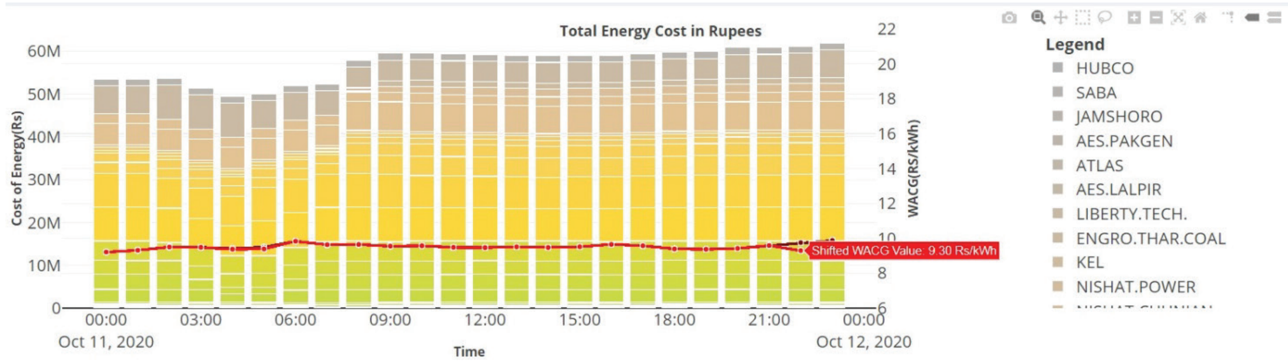
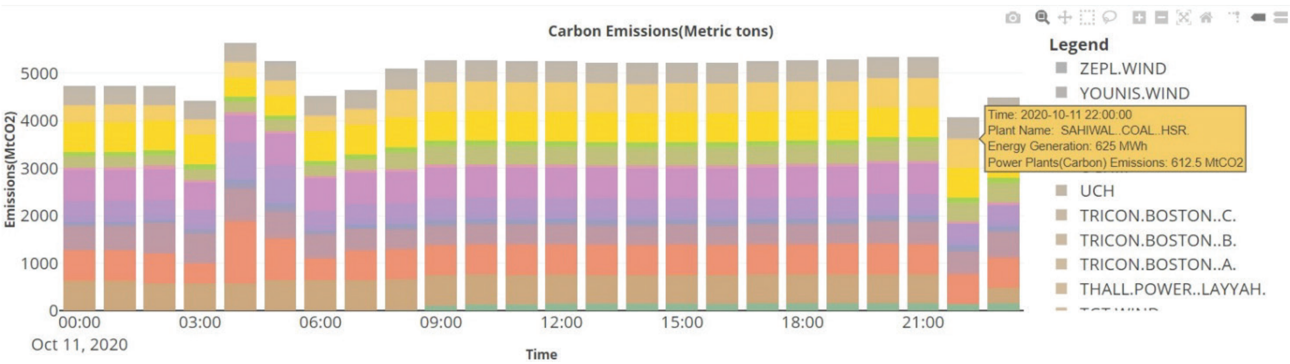


Figure 39. Emission plot for various power plants



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: 6,586.73 MtCO2
Emission after shifting: 5,903.00 MtCO2
Monthly gain: 210 million Rs.

Figure 40. Total energy cost and shifted WACG value

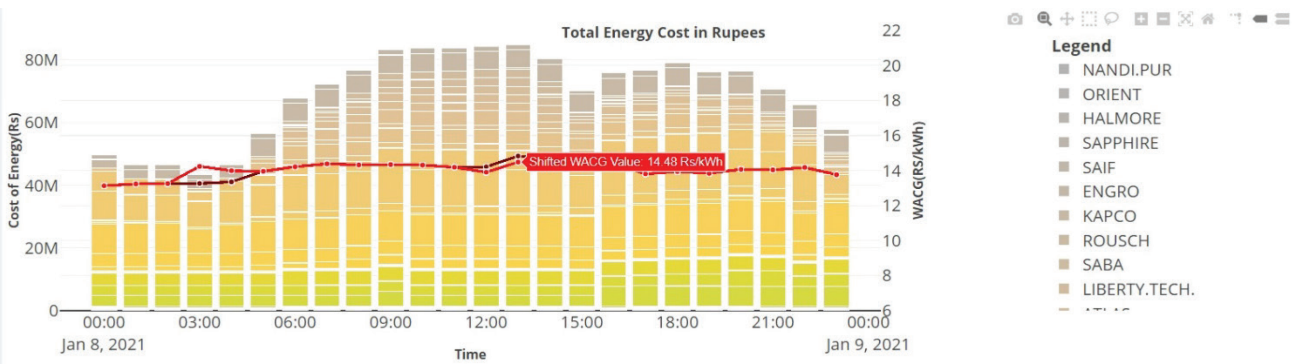
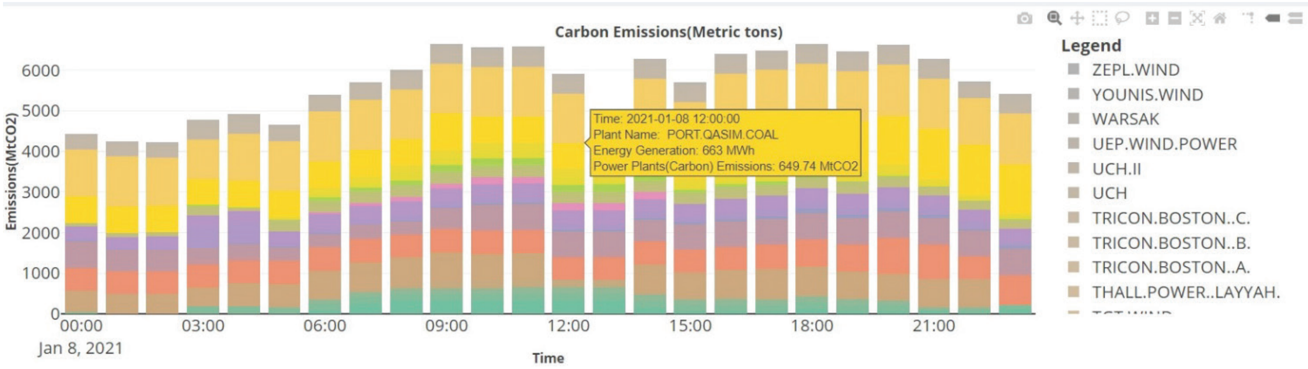


Figure 41. Emission plot for various power plants



Scenario 3- Lowest Load 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: 5,540.67 MtCO2
Emission after shifting: 3,911.56 MtCO2
Monthly gain: 272.11 million Rs.

Figure 42. Total energy cost and shifted WACG value

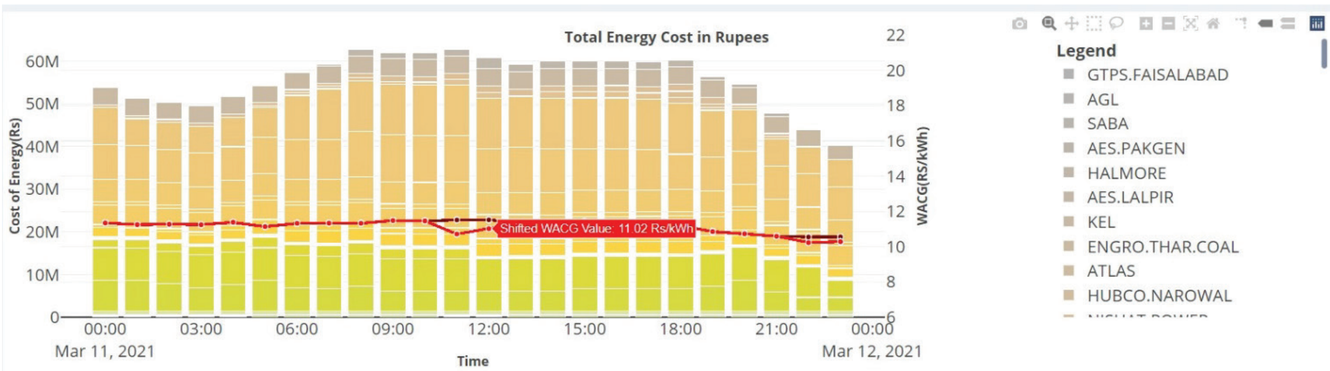
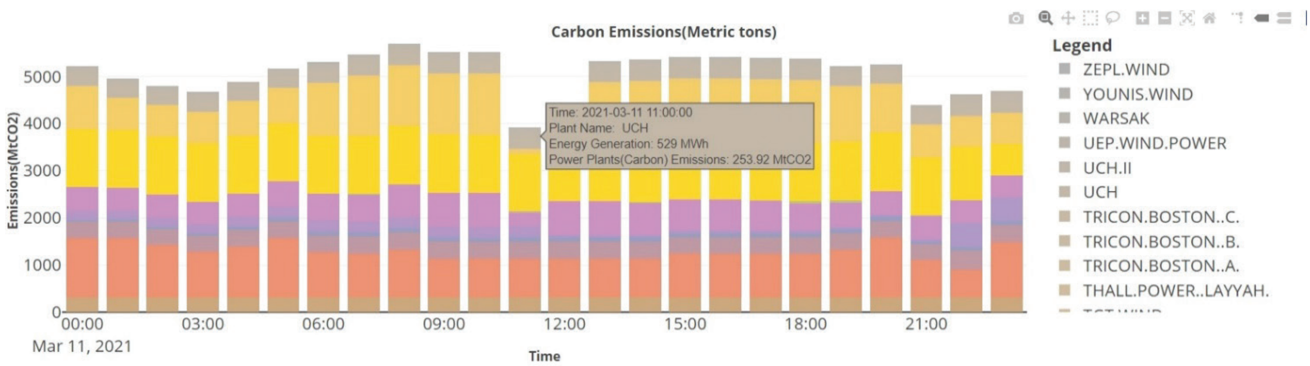


Figure 43. Emission plot for various power plants



HOUSEHOLD ENERGY POVERTY IN PAKISTAN

Fouzia Sohail and Ambreen Fatima

ABSTRACT

This research study examines the impact of electricity sector reforms on household welfare. The ongoing reform process gradually eases the fiscal burden of the government by eliminating subsidies. However, an increase in electricity prices reduces poor households' affordability and is, thus, believed to increase energy poverty in Pakistan.

This study found, by employing secondary data, that increasing electricity prices burdened the limited household resources and altered their budgetary allocation. Furthermore, it was found that without undertaking appropriate measures of compensation, a substantial proportion of poor households would be dragged below the poverty line. The study suggests that successful reforms should be accompanied by compensation packages for the poor and increased service quality and reliability for households paying higher prices.

The study also conducted a household survey in Karachi as a case study to obtain in-depth information on the energy situation. Findings from the survey data show that although tariff rates are still subsidised for lower consumption households, additional charges such as government charges, TVL fees, fuel adjustment charges, etc., constitute a significant proportion of total electricity bills. The study also recognises households' cognitive and behavioural aspects of energy use by incorporating these modules in the survey questionnaire. Hence, numerous viable policy options are recommended in the study to successfully implement reforms without compromising the social aspects.

1. INTRODUCTION

It is evident that despite several reforms, the power sector of Pakistan is plagued with inefficiencies, including low collection, theft, transmission, and distribution losses of around 20%, delays in determination and notifications, increased cost of fuel imports, rupee depreciation, etc. It is found that the cost of generation had a high correlation with oil prices in Pakistan till 2013. After 2013, electricity generation moved from oil-based plants to more RLNG plants, but the generation cost is still increasing because of rupee depreciation. In Pakistan, the cost of generation is 9.2 cents per kWh compared to 5.5, 6.8, and 3.0 cents per kWh in India, Bangladesh, and Nepal, respectively. All these inefficiencies contribute to an increasingly severe circular debt problem. Currently, Pakistan has accumulated a circular debt of 2.4 trillion rupees.

To undertake these challenges, the Government of Pakistan has initiated significant energy sector reforms, including tariff reform, which directly impacts household welfare. As a result of these reforms, the government has started curtailing the electricity subsidies, gradually increasing end-consumer electricity prices. However, changing the policy to raise the subsidised electricity tariff is not easy. An increase in tariff decreases the affordability of a consumer and impacts the overall welfare of a household. The study of Makmun & Abdurrahman (2003) shows that an increase in basic electricity tariffs has a negative impact on the real income of the community. The decline in real income reduces the purchasing power of the people. The decrease in purchasing power that is not accompanied by income improvements potentially increases the number of poor households (Ikhsan & Purbasari 2012). The recent tariff reforms, thus, have a profound economic and social impact, especially on poor households.

It has been argued that not all households respond similarly to tariff reforms. Households with relatively low-price elasticity of electricity demand, predominantly with higher electricity consumption, are less likely to change their electricity consumption in response to an increase in electricity tariff, but this will increase government revenues (Moshiri, 2015). However, households with small electricity consumption generally have relatively inelastic demand. As a result, welfare decline is expected to be hugely related to tariff increase (Lampietti J., World Bank., 2004)

Another critical policy dimension that needs to be addressed is access to more efficient and clean energy sources. According to the World Energy Outlook (2016) statistics, at least 51 million people in Pakistan, representing 27% of the total population, live without access to electricity. In its annual State of the Industry Report, the National Electric Power Regulatory Authority concludes that approximately 20% of all villages (32,889 out of 161,969) are not connected to the grid. Even those households that are statistically connected experience blackouts daily. It is estimated that more than 144 million people across the country do not have reliable access to electricity. A survey revealed that rural households in Punjab spent about 9 % of their total household income on fuel and lighting. However, poor households are forced to invest up to 25% of their monthly income in fuel, kerosene oil, and batteries due to the dysfunctional market.

These sporadic findings from various sources reveal the power sector distortions and their impact on household welfare and poverty in Pakistan. However, the research on energy poverty in Pakistan is very limited. Notably, the welfare impact of the recent upsurge of electricity tariffs due to the gradual elimination of subsidies has not yet been gauged in any study. This study thus aims to analyse the impact of subsidised tariff changes of electricity on the welfare of households. More specifically, the present study attempts to find the crowding-out effect of increased electricity tariffs on the household budgetary allocation of resources at various income levels. It is suggested that an increase in tariff worsens individuals by reducing the income left for spending on other consumption goods and services. Hence, the study also aims to measure the compensation required by the households to mitigate the income effect of rising electricity tariffs on households' welfare. We also endeavour to estimate the proportion of households dragged below the poverty line if these poor households are not compensated. However, because of the existing caveats in the secondary datasets, the study conducted a primary survey of Karachi city as a case study to obtain in-depth information on the energy situation. A primary survey regarding households' energy affordability and accessibility along with the socioeconomic conditions of a household was the need of an hour for conducting the in-depth analysis of rising electricity tariffs on poverty.

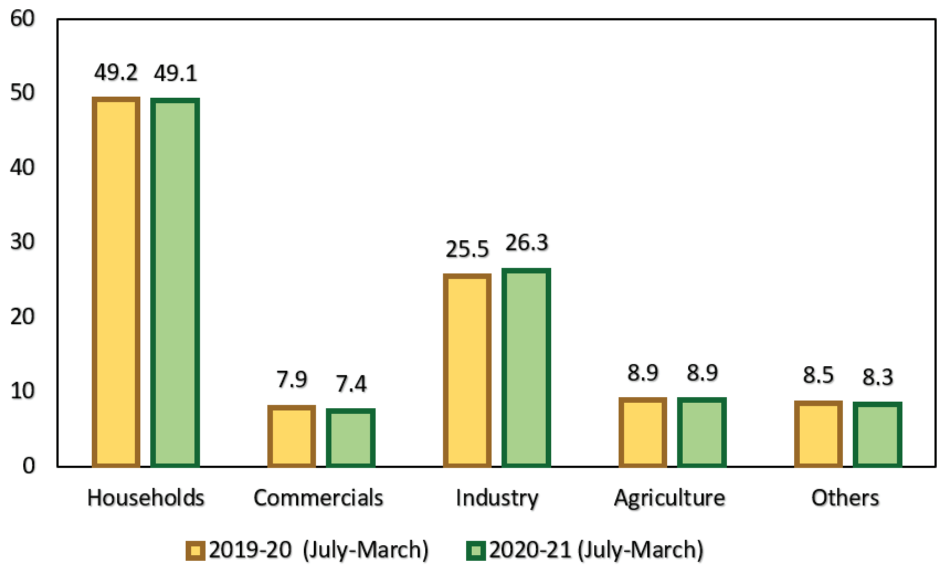
Keeping all these data caveats and limitations, the current study also conducts an in-depth survey of electricity consumers as a case study in Karachi city.

This research paper is organized as follows. The following section traces the progression of electricity tariffs over the last few years. This section provides in-depth information on the breakup of various slabs and the change in applied tariff rates over these slabs. Section 3 presents a review of the literature. This section helps to identify the research gaps in the issue. Section 4 presents a detailed methodology applied in econometric estimations of the above-defined objectives. Section 5 of the research paper provides results, analysis, and thorough discussion, which further support public policy provision in this research area. The last section concludes the study and discusses viable policy options.

Background on Energy Tariff Reforms in Pakistan in the context of household welfare

According to recent statistics on electricity consumption provided by the Economic Survey (2020-21) (reproduced in Figure 1), the residential sector is the major consumer of electricity (49.1%) followed by the industrial sector (26.3%). According to World Bank (2014), about half of the subsidies in 2012-13 were enjoyed by the residential sector, one quarter by the manufacturing sector and industrial sector, and the remaining by other sectors. These statistics show that the residential sector consumes a substantial percentage of total electricity consumption. Therefore, tariff reforms would have a profound impact on the well-being of domestic households. Hence, in this section, we present the evolution of tariff slabs, per-unit change in electricity price for each slab, and structural modification for the residential sector during recent years.

Figure 1: Share of Electricity Consumption by Sector



Source: Economic Survey of Pakistan (2020-21)

Table 1 shows the tariff structure of electricity consumption, which is based on standard slabs of monthly consumption as defined by the government for all distribution companies (DISCOs and K-electric). These slab-wise charges are usually termed the tariff structure for electricity consumption.

Table 1: Slab Structure for Electricity Consumption for Households

S.No.	Before Sep. 2008		After Sep. 2008		S.No.	Since 2014	
	Standard Slabs (units)	Units/ Slab	Standard Slabs (units)	Units/ Slab		Standard Slabs	Units/ Slab
0	≤ 50	50	≤ 50	50	0	≤ 50	50

For consumption exceeding 50 units							
1	1-100	100	1-100	100	1	1-100	100
2	101-300	200	101-300	200	2	101-200	100
3	301-1000	700	301-700	400	3	201-300	100
4	≥ 1000		≥ 700		4	301-700	400
					5	≥ 700	
Total units beyond the Highest rate		1000		700			700

Source: Authors' tabulation based on the data by the Ministry of Energy, Pakistan

Table 1 shows the slab structure before and after September 2008. Prior to September 2008, the highest standard slab was applicable on the consumption of more than 1,000 units, while after September 2008, the highest price slab was applied if the units consumed increased beyond 700 units. Hence, the limit beyond which the highest tariff is to be paid was reduced by 300 units. However, this structural change in tariff slab was believed to affect the affluent the most.

Then in 2014, the second slab was split into two with 100 units in each slab. Thus, the households had to pay a higher tariff than before on the consumption of 201 to 300 units. Through these reforms, the government aimed to reduce subsidies by increasing the per-unit cost of electricity for the middle slab supposedly to target middle-income households.

Another significant structural modification was undertaken in 2013-14, according to which, "all-slab benefit" was replaced by the "previous-slab benefit" policy. Under this new policy of previous-slab benefits, only two rates were applied to each household. This was an important policy shift by the government to limit the affluent class from accessing the more subsidised rates of lower slabs.

Table 2: Tariff Structure for residential electricity consumption

Unit Slabs (units)	2022	2021	2020	2019	2018	2014	2012	2011	2009	2008
w.e.f.	Dec 2021	Jan 2021	May 2019	Jan 2019	Jun 2015	Oct 2014	May 2012	Mar 2011	Dec 2009	Sep 2008
For Sanctioned Load up to 5KW										
≤ 50	3.95	3.95	3.95	2	2	2	2	1.87	1.48	1.4
For consumption exceeding 50 Units										
1-100	9.35	7.74	7.74	5.79	5.79	5.79	5.79	4.45	3.49	3.23
101-200	11.67	10.06	10.06	8.11	8.11	8.11	8.11	6.73	5.26	4.9
201-300	13.76	12,15	12.15	10.2	10.2	12.09	8.11	6.73	5.26	4.9
301-700	22.88	19.55	21.2	19.25	16	15	12.33	10.65	8.51	7.97
≥ 700	25.98	22.65	24.3	22.35	18	17.5	15.07	13.29	10.6	10
For Sanctioned Load exceeding 5KW										
Peak	25.98	22.65	24.3	22.35	18	17.5	13.99	12.25	9.76	9.15
Off Peak	19.66	16.33	17.98	16.03	12.5	11.5	8.22	6.7	5.96	5.56

Source: Authors' tabulation using K-electric and Economic Survey data

Table 2 shows that the applicable tariff has been frequently increased from 2012 to 2021 for all consumption slabs except for the lowest three slabs, that is, slabs of ≤ 50, 1-100, and 101-200 units. This shows that tariff rates are increasing with an increase in the consumption of electricity units. This implies that comparatively lower tariffs are charged from consumers in the lower slabs as lower slab consumers usually belong to lower-income households. Higher-income households are believed to occupy larger housing areas with multi-floor dwellings, hence, use more electrical appliances that would increase household power consumption.

Table 3: Percentage increase in Tariff Structure for residential electricity consumption over time

Unit Slabs (units)	2019 & 2021	2018 & 2021	2014 & 2019	2012 & 2014	2011 & 2012	2009 & 2011	2008 & 2009	2008 & 2021
For Sanctioned Load up to 5KW								
≤ 50	97.50	0.00	0.00	0.00	6.95	26.35	5.71	182.14
For consumption exceeding 50 units								
1-100	33.68	0.00	0.00	0.00	30.11	27.51	8.05	139.63
101-200	24.04	0.00	0.00	0.00	20.51	27.95	7.35	105.31
201-300	19.12	0.00	-15.63	49.08	20.51	27.95	7.35	147.96
301-700	10.13	20.31	6.67	21.65	15.77	24.15	6.78	166'00
≥ 700	8.72	24.17	2.86	16.12	13.39	25.38	6.00	143.00
For Sanctioned Load up to 5KW								
Peak	8.72	24.17	2.86	25.09	14.20	25.51	6.67	165.57
Off Peak	12.16	28.24	8.70	39.90	22.69	12.42	7.19	223.38

Source: Authors' tabulation using K-electric and Economic Survey data

Table 3 reveals that the highest growth of 97 % was recorded between 2019 and 2021 for the lowest slab, which is considered a lifeline tariff slab. Similarly, from 2008 to 2021, the highest increase in tariff rate (182 %) was recorded for the lifeline slab, which is a matter of concern. This increase in tariff is believed to hurt the poorest as a lifeline tariff is envisioned to safeguard the poor. This policy shift, if not accompanied by compensatory measures, may drag a certain proportion of the population below the poverty line. It has been argued in the literature that although the consumption of electricity is lower for lower-tier income groups, an increase in electricity prices would have a relatively higher impact on their well-being (World Bank, 2017).

The last two rows of Table 3 show tariff increases for households having sanctioned loads greater than 5 KW and a special time-of-use (ToU) metre. For such consumers, ToU tariff rates are applied. The off-peak rates that apply for most of the daily hours grew by 223.38 % in thirteen years, while during the peak hours, the highest rates are charged irrespective of the total number of units consumed.

2. REVIEW LITERATURE

Energy subsidies, particularly electricity subsidies, have been the focus of research in various policy institutions like IMF and World Bank as well as in academia. Although the timeline of a policy shift, concerns and welfare impact may vary from one country to another, the foremost aim is to reduce electricity consumption (or move towards efficient consumption), reduce government expenditures and increase the overall well-being of the poor through income redistribution (Granado et al., 2012). In this section, a summary of valuable international and national research on the issue is presented to determine, firstly, the outcomes of policy shifts in various economies. Secondly, the literature on Pakistan's economy is reviewed not only to determine the policy objectives of the electricity price reforms in Pakistan but also to find the research gap.

International Scenario

Like many other transition economies, Poland has made substantial efforts in bringing energy prices to the most efficient levels. Freund & Wallich (1995) explained the new pricing system for residential electricity consumption, which was introduced in Poland in the early 1990s. As a result of four years of reforms, electricity prices for the residential sector increased more than three times. Because of the regressive nature of electricity subsidies, Freund & Wallich (1995), suggested increasing electricity tariffs, accompanied by a public support programme for the poor, including cash transfers, discount vouchers, etc., as well as lifeline electricity block/ slab. The study, however, preferred lifeline pricing over in-kind transfers as the implementation of the latter is difficult to administer.

Lampietti J. (2004) investigated the impact of electricity price reforms in Eastern European and Central Asia, which were initiated in the early 90s. Countries that were selected in this study for analysing the reforms' after-effects included Hungary, Poland, Armenia, Azerbaijan, Georgia, Kazakhstan, and Moldova. Reforms in these countries were based on the advice of the World Bank and other donor agencies. The main feature of electricity sector reform was the complete removal of subsidies through an increase in tariffs for full recovery of cost. Donor agencies supported and funded these countries in the implementation of reforms, energy efficiency, and the targeting of poor households for compensation. In the study, the author concluded from the experience of these countries that tariff increases should be accompanied by enhanced service quality for better general public acceptance of reforms and to minimise the negative effects on well-being. It was noticed that the expenditure share of electricity increased for each income quintile in all of these countries, depending on the increase in tariff, inelasticity of demand, etc. The poor segment of society experienced relatively greater welfare loss and started searching for other substitutes in response to the tariff rise. The study mentioned various indicators to measure welfare loss. These indicators were the budgetary share of electricity expenditure, which shows the households' total requirement of electricity; their access to low-priced substitutes; changes in the tariff; and the price elasticity of electricity demand. The results of the study revealed the highest welfare loss was in Armenia and Georgia because of greater increases in tariffs and relatively higher dependence on electricity for heating, lighting, and cooking. The study suggested the important role of the government in mitigating the negative welfare impact of tariff increases, particularly on the poor segment.

Unlike the above transition economies that proved relatively successful in the implementation of the reform process, IMF (2013) is sceptical of the success of energy price reforms in many developing countries. However, Moshiri (2015) exemplified the Iranian energy price reforms as a guideline to other nations, who are in the process of undertaking these reforms. This study explained the successful implementation of societal recognition of energy price reforms as these were accompanied by cash handout packages by the government. The study also mentioned mixed responses by various social groups to the price change. For instance, households with high energy consumption and the low price elasticity of demand did not reduce their consumption in response to a price change. In this case, government revenues increased as a result of the policy shift but the consumption of electricity did not reduce. The results of the study show that the Government of Iran successfully achieved the objective of easing the fiscal pressure through these reforms. However, for achieving the efficient consumption objective, other measures should also be accompanied by subsidy removals.

The Jordanian economy also initiated the gradual removal of subsidies from various energy sectors, including the electricity sector. Atamanov A. et al. (2015) studied the impact of electricity price reforms on the well-being of the Jordanian population. As in many other developing countries, the initiation and implementation of the reform process in Jordan was not an easy task, especially in the presence of political and economic unrest. However, as this reform process became imperative, Atamanov A. et al. (2015) suggested that a flat increment in electricity tariff would decrease the welfare of the poorest households. The study suggested progressive increments in prices along with a compensatory mechanism for protecting the poorest segment of the Jordanian society as well as for the successful implementation of the reforms.

Enormous international literature on several countries is available and conclusions of the most of the studies are almost similar.[1] It is concluded that the reform process in the energy sector, including the electricity sector, has been initiated in countries on the advice of international donor agencies for reducing the fiscal pressure by a gradual elimination of subsidies provided to all sectors, including the residential sector. Besides, the reform process is believed to reduce inefficiencies in electricity consumption that have increased the consumption of electricity, mostly by higher income groups. As the residential sector is a leading consumer of electricity, researchers are more concerned and sceptical of the welfare impact of these reforms. The implementation of electricity tariff reforms is believed to depend on politico-economic as well as social acceptance of reforms. The experience of the above countries, thus, provides guidelines for developing countries, such as Pakistan.

Literature on Pakistan

The onset of power sector restructuring and reform mechanism in the 1990s was initiated in Pakistan at a very slow pace primarily because of the unstable political situation of the country. There was also great resistance from the general public to any rise in electricity tariffs at that time. However, Pakistan practically initiated the tariff reform process more than a decade ago but again the pace of reform was sluggish until at least 2013. According to WB (2017), electricity subsidies in the residential sector were reduced to about 0.4 per cent of GDP from 2013 to 2016. Like many other developing economies, national literature on the issue expressed scepticism regarding the well-being of society due to increased electricity tariffs. One of the objectives mentioned in the National Power Policy (2013) was to insulate poor households from tariff reforms through various compensatory mechanisms. Another objective was to create a sense of responsibility among consumers and ensure efficient utilisation of electricity.

Considering the above National Power Policy objectives, WB (2017), through a qualitative survey of households in Khyber Pakhtunkhwa (KPK), Punjab, and Sindh, found the affordability issues for paying electricity bills for households, even though the reform process was not in a full swing at the time of the survey. The recipients of the Benazir Income Support Programme (BISP) also complained of higher electricity bills. The study revealed the insufficient compensatory efforts by the government. Besides affordability, the unreliability of electricity service was another major problem faced by households. The study revealed a lack of confidence and trust on the part of the general public in DISCOs and K-electric. However, the study suggested further reforms in the sector. The author was of the view that subsidy elimination from this sector would further ease the fiscal pressure and bring sustainability, while fiscal resources would be used for eliminating the negative effects arising from tariff reforms through more spending on social assistance programs and other compensatory mechanisms for the poor.

Walker T. et al. (2014), a policy paper published by World Bank, also considered the impact of electricity tariff reforms on welfare while demonstrating how to continue subsidy elimination reforms in Pakistan. This study simulated the welfare impact based on the 2014-15 budget forecasts of electricity subsidies with the assumption of a sufficient increase in electricity prices to achieve the government's subsidy target and with no compensatory measures taken. With these assumptions, the study found that 97 per cent of electricity consumers, except for lifeline users, would face a rise in electricity expenditure. However, lifeline users and nonusers would also face relatively small indirect welfare losses. The study estimated only 1.7 per cent welfare loss for poor households, while richer households would face greater welfare losses. The study proposed various compensatory options to the government to mitigate the negative impact of policy reforms. These included amendments to BISP, targeted cash payments to poor households based on poverty scores, etc., along with improving efficiency in electricity usage, production, and distribution.

Zhang, Fan. (2019), another study by the World Bank, assessed the welfare impact of tariff reforms and estimated the economic cost of distortion for three main South Asian economies, including India, Bangladesh, and Pakistan. The study considered economic losses resulting from subsidy elimination more distortionary than fiscal losses due to subsidies. For Pakistan, the estimated economic cost due to energy sector distortions was 6.53 per cent of GDP in 2015, of which 4.75 per cent of GDP was because of unreliable access to electricity. The estimated fiscal cost, due to electricity subsidies, was 0.80 per cent of GDP.

It has been noticed that scarce economic literature exists on Pakistan that focuses on welfare or poverty aspects.

[1] Nguyen, q. K. (2021), IMF (2013), Clements et al. 2014)

However, the importance of the topic can be realised by the characterisation of losses mentioned by Joskow, (2008). According to Joskow (2008), a lack of efficiency in production and distribution, poor or unreliable services, social and environmental losses, etc., are all first-order effects, while price distortions are second-order losses. It is a matter of fact that Pakistan is currently facing both types of losses. It seems that the government's electricity policy is more inclined towards correcting second-order distortions. Therefore, it is recommended that at least similar attention should also be given to fixing the first-order distortions in the power sector.

3. METHODOLOGY

Crowding out Effect of Electricity Expenditure and Its Implications on Household Resource Allocation in Pakistan

The first specific objective of the study is to estimate the crowding-out effect of increased electricity expenditure and its impact on intra-household resource allocation through the estimation of the conditional demand function. More specifically, we endeavour to analyse the difference in the affordability of electricity between the periods of low and high tariff rates. For achieving these objectives, we employed the HIES 2013-14 and 2018-19 datasets, assuming that electricity tariffs were relatively low in 2013-14 as compared to 2018-19. HIES 2018-19 was the latest survey at the time of the study.

For explaining the crowding-out effect of electricity expenditure and its impact on intra-household resource allocation, the conditional demand function, as suggested by Pollak (1969), was estimated. In the context of the current study, the crowding-out effect of electricity expenditure entails reduced consumption of goods and services because of the increasing cost of electricity consumption. The conceptual framework of this paper followed the most recent generation of empirical studies on the crowding-out impact of commodity expenditures (John, 2008; John et al., 2012; Hussain et al., 2018; etc.).

Conceptual framework

Households report zero electricity expenditures either because households do not have the access to grid electricity, even if they have adequate income or because households cannot afford electricity expenditure, given their income. For this analysis, households using grid electricity were used for the analysis, while households that did not have grid electricity connections were excluded from the sample.

The study assumed that households faced lower tariff rates and, thus, lower expenditures in 2013-14 compared to a significant increase in tariff and, thus, higher electricity expenditures in 2018-19. This implies that there was a difference in the spending patterns of households between the two periods. The crowding-out attribution of electricity expenditure in displacing expenditure on other commodities comes with the assumption that a household that spends on electricity decides on paying the electricity bills before deciding on the quantities of the other goods and services. Given this, a household's demand for a particular commodity is conditional on the household's electricity expenditures and the remainder of household income after paying electricity bills. Following the recent literature, we estimated and compared a set of Engel curves for electricity expenditure during low tariff rates with conditional Engel curves for electricity expenditure during high tariff rates for a common set of commodities. If, on average, the quantity demanded of a commodity for the typical household in 2013-14 was less (more) than the quantity demanded of the same commodity for a typical household in 2018-19, then the difference could be attributed, ceteris paribus, to the increase in electricity tariff during this period.

For estimation purposes, we assumed that the household had already decided on its budget for electricity consumption and a certain amount was been pre-allocated for it. This effectively means that the household now had to maximise its utility subject to the expenditure above the pre-allocated expenditure for electricity. If electricity is the nth good, we assumed that the first n−1 goods were available in the market for the prices $\{p1, ..., p_{n-1}\}$ over which the household had no control and the total expenditure on these goods were given by M ($M = Y - P_eE$), where P_e is the price of electricity and E is the quantity consumed.

Empirical Technique: Quadratic Almost Ideal Demand System (QUAIDS)

In the first stage of our empirical approach, we compared the mean expenditure shares of food and various non-food expenditure categories between the two time periods, using the t-test on the equality of means. Statistically significant differences in the expenditure dedicated to other commodities in the budgets of households between 2013-14 and 2018-1, indicated an unadjusted difference in budget share between the two periods. However, these unadjusted differences in expenditure shares did not take into account the household's socioeconomic, housing. and demographic characteristics that might influence spending patterns. Therefore, we formally tested the crowding-out hypothesis using multivariate regression analysis, controlling for household-specific characteristics. To determine differences in spending patterns of households between the two periods, the regression models estimated conditional Engel curves for 11 expenditure categories using the Quadratic Almost Ideal Demand System (QUAIDS) developed by Banks, Blundell, & Lewbel (1997).

Several studies on the crowding-out effect emphasise the potential endogeneity of total expenditure and expenditure on a predetermined commodity (electricity expenditure in this case) and, therefore, use the instrumental variable (IV) method to obtain consistent and unbiased estimators. In this study, we instrumented household total expenditure by total income and total assets of a household. Electricity expenditure was instrumented by electrical equipment owned by a household.

If household expenditure in one category is correlated with expenditures in other categories, the error terms in the Engle curve estimations are likely to be correlated, potentially leading to increased variance in the estimated coefficients and inefficient coefficient estimates. Because of this, we used an estimation method which is robust to the use of instrumental variables along with Seemingly Unrelated Regression (SUR). Hence, the paper estimated the system of Engel curves using the three-stage least squares (3SLS) method which is robust to the application of IVs in SUR. Because the dependent variables of the 12 equations add up to one (adding up restriction), we arbitrarily dropped one equation from the system of Engel curves before proceeding with the 3SLS estimation. The equation of ''Miscellaneous goods'' was dropped here.

$$G_i = \alpha_{1i} + \alpha_{2i} afford + \alpha_{3i} P_e E + \delta_{0i} a + \beta_{1i} lnM + \beta_{2i} lnM^2 \qquad (1)$$

Where,

G_i = the budget share of commodity i in the remaining budget excess of expenditures on electricity
M = the total expenditure minus the expense on electricity bills.
A = the set of socio-economic characteristics of the households, such as household size, age, average education of a household, dwelling type, number of rooms in a household, and occupancy status of a household.
afford = the binary variable that takes the value 0 for the year 2013-14 and 1 for 2018-19

Data Description

Household cross-section data from the household income and expenditure survey (HIES) for the years 2013-14 and 2018-19 collected by the Pakistan Bureau of Statistics, the Government of Pakistan was employed for this study. The data contain information on consumption expenditure for a wide variety of goods from 17,301[2] households in 2013-14 and 24,114[3] households in 2018-19. This nationally representative and official household consumption survey collected information on the consumption of over 350 commodities in 2018-19 and more than 200 commodities in 2013-14. Expenditures on 12 distinct categories which are exhaustive and mutually exclusive, including food, tobacco, clothing & footwear, housing & fuel, furniture, health, transport, communication, recreation and culture, education, restaurant, and miscellaneous expenditure were considered for the analysis. The consumption module in HIES recorded expenditures on food items either as monthly or fortnightly expenditures. Similarly, expenditures on non-food items, such as tobacco products and energy and fuel commodities were recorded as monthly expenditures, while other non-food commodities as yearly expenditures (for instance, clothing, housing, recreation, education, and health). For our analysis, all consumption expenditures were converted into average annual expenditures for both years.

[2] A total of 17,989 households were sampled in 2013-14, but 688 re excluded because of incomplete information.
[3] A total of 24,809 households, excluding Gilgit Baltistan and AJK, were sampled in 2018-19 HIES but 695 household were excluded during the estimation because of incomplete information.

Among households with electricity connections, vast heterogeneity in the expenditure on electricity was noticed among income groups. Analyses were carried out for three income groups. The middle-income group represented households between the 3rd and 8th quintiles of the distribution of household income. Lower and higher income groups were those that were below and above this range, respectively.

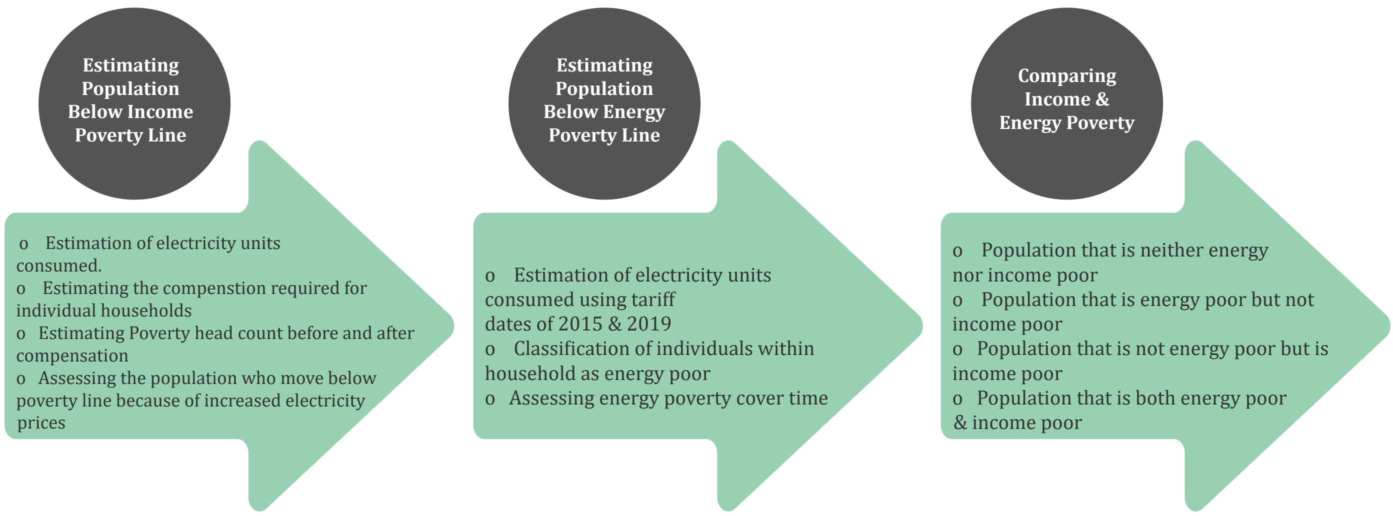
Electricity Tariff Reforms and Household Welfare Analysis for Karachi City

The second objective of the study is to examine the impact of changes in the electricity tariff structure on household welfare in the megacity of Karachi. More specifically, the study determined the proportion of the population dragged below the poverty line after being worse off as a result of the rise in electricity tariffs. The study also estimated the proportion of the population considered energy poor using a minimum energy poverty threshold as suggested by Moss et. al. (2020). Moreover, the link between income poverty and energy poverty was explored. These core objectives were achieved by following a sequence of steps that began by understanding the slab and tariff structure applied to residential electricity consumption and eventually leads to the welfare impact. Thus, the analysis demanded an in-depth understanding of the electricity tariff structure enforced. The slabs used for residential electricity consumption, tariff rates applicable as per the sanctioned load and duties such as GST, excise duties, etc., are the key components of residential electricity prices.

Assessment Framework:

The assessment framework is demonstrated in Figure 2.

Figure 2: Assessment Framework for the Analysis

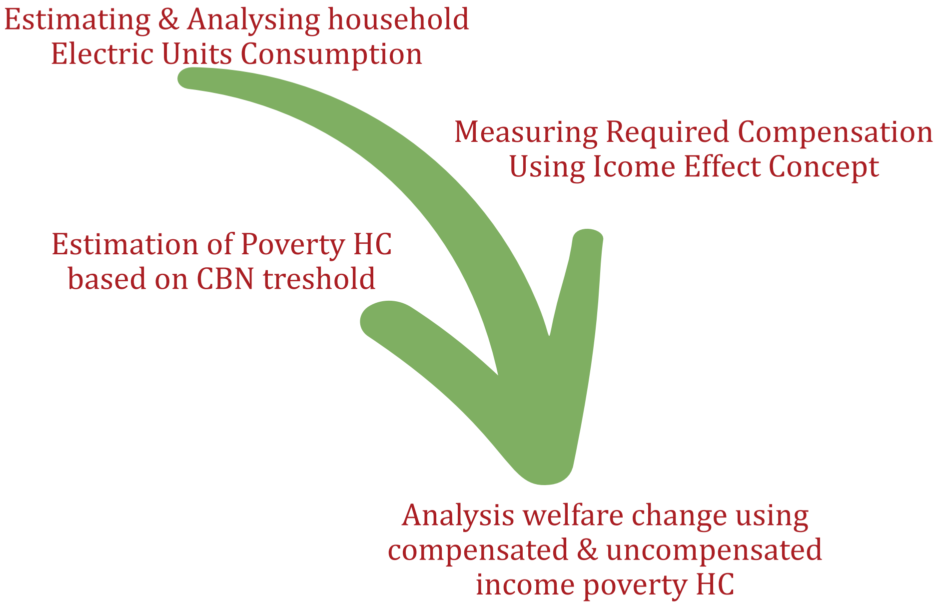


Source: Authors' illustration

Analysing the impact of electricity tariffs on income poverty involves the steps portrayed in Figure 3. As a first step, electricity units consumed by each household are estimated, which are based on their electricity expenditures.

It is argued that an increase in tariff worsens off individuals by reducing the income left for spending on other consumption goods and services. To estimate the compensation for the additional income that a household spent on electricity consumption, current and previous tariff structures were used. Assuming the household consumption patterns remained consistent, the compensation was measured for individual households in accordance with the slab they ended up consuming in. Once the compensation was estimated, poverty head counts before and after compensation were measured using both national and international thresholds. Finally, the welfare effect of rising electricity tariffs was reflected by the difference in the two head counts. It mentions those who moved below the poverty line because of increased electricity prices.

Figure 3: Steps Involved in Analysing the Impact of Electricity Tariffs on Income



Source: Authors' illustration

In the next step, energy poverty head counts were estimated using the estimated electricity consumption units for 2018-19 and 2015-16 for analysing energy poverty over time. Finally, the study explored interconnections between income and energy poverty head counts.

Computation of Electricity Units Consumed

As mentioned above, there were multiple steps involved in this analysis, and each step has its methodology. For understanding the slab and tariff structure, in-depth scrutiny of the available data from the Ministry of energy and other tariff documents was conducted, which is presented in the introduction section. The electricity units consumed by the households were computed from HIES 2018-19. For determining the total electricity units consumed by households in Karachi exogenously, slab-wise tariff rates specified by K-Electric for the year 2019 were used. As HIES provides electricity expenditures instead of electricity units consumed, the estimation of electricity units consumed by the HH was performed backward, i.e., from expenditures to units. The computational steps are given below.

Firstly, the household's electricity expenditures were adjusted to exclude 17% general sales tax (GST), 1.5% electricity duty, and the TVL fee of Rs 35 as:

$$TEE_{HH} = TEE_{HH\_G}\left(\frac{100}{118.5}\right) - 35 \text{ .... } (2)$$

Where,

TEE_{HH_G} = Gross household electricity expenditures inclusive of the GST and the TVL fee
$TEE_{\_HH}$ = Household electricity expenditures, exclusive of these the GST and the TVL
Then, the household's slab-wise electricity expenditure disaggregation was estimated. The household's total electricity expenditures are simply the sum of expenditures in the second last slab and the highest slab

Mathematically,

$$T\ E\ E_{HH} \quad = E\ E_{-1} + E\ E \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

$$TEE_{HH} = STR_{s-1}(SEU_1 + SEU_2 + \cdots + SEU_{s-1}) + STR_i(EUC_s)$$

And

$$TEE_{HH} = STR_{s-1}(\textstyle\sum_{j=1}^{i-1} SEU_{s-1}) + STR_s(EUC_s) \ldots\ldots\ldots\ldots (4)$$

Where,

s = Highest slab in which the HH ended up consuming
EE = the electricity expenditure
STR = the standard tariff rates
SEU = the standard electricity units
EUC = electricity units consumed in the highest slab.

Equation (4) shows that the household was charged for all the units consumed till the second highest slab as per the standard tariff rate of the second highest slab.

Total energy units consumed by HH were then aggregated to the slab in which the specific HH fell.

$$TEUC_{HH} = \textstyle\sum_{j=1}^{i-1} SEU_{s-1} + EUC_s \ldots\ldots\ldots\ldots (5)$$

Where,

TEUC = the total energy units consumed by the household.

Estimation of Required Compensation by a Household:

Assuming the household consumption patterns remained consistent, household's compensation (CHH) was estimated by taking the difference between the household's electricity expenditures before and after the increase of tariff.

Mathematically,

$$C_{HH} = TEE_{HH}^{N} - TEE_{HH}^{P} \ldots\ldots\ldots\ldots (6)$$

Where,

TEE_{HH}^{N} = new (after tariff increase) electricity expenditure of a household

TEE_{HH}^{P} = previous (before tariff increase) electricity expenditures of the HH.

To estimate Equation (6), we substituted the values of total electricity expenditure from Equation (4).

$$C_{HH} = [STR_{i-1}^{N}(\textstyle\sum_{j=1}^{i-1} SEU_{i-1}) + STR_i^{N}(EUC_i)] - [STR_{i-1}^{P}(\textstyle\sum_{j=1}^{i-1} SEU_{i-1}) + STR_i^{P}(EUC_i)] \ldots\ldots (7)$$

The household compensation amount estimated through Equation (7) was then linearly combined with the current household income.

$$Y_{HH}^{C} = Y_{HH}^{UC} + C_{HH} \ldots\ldots\ldots\ldots (8)$$

Where,

Y_{HH}^{UC} = uncompensated income

Y_{HH}^{C} = household's compensated income.

For estimating income poverty, equalised per capita income was calculated, using both national (Pakistan Planning Commission, 2015-16) and the modified OECD equalisation scales[4] as mentioned in Haagenars et al. (1994).

$$EqY_{pc}^{UC} = \frac{Y_{HH}^{UC}}{Eq\ Size_{HH}} \quad \& \quad EqY_{pc}^{C} = \frac{Y_{HH}^{C}}{Eq\ Size_{HH}} \quad \text{......... (9)}$$

Where

EqY_{pc}^{UC} = equalised per capita (uncompensated) income

EqY_{pc}^{C} = equalised per capita (compensated) income.

Estimation of Head Counts (HC) below Income Poverty Threshold

Finally, the proportion of the population below the income poverty threshold was estimated by using Equation (9) as:

$$\frac{HC_{UC}}{Tot.Pop} * 100,\ if\ EqY_{pc}^{UC} \leq Income\ Poverty\ Threshold \quad \text{......... (10)}$$

Similarly using compensated income

$$\frac{HC_{C}}{Tot.Pop} * 100,\ if\ EqY_{pc}^{C} \leq Income\ Poverty\ Threshold \quad \text{......... (11)}$$

Where,

$HC = \sum_{i=1}^{n} P_i$, P stands for poor individuals

Tot. pop = total population of country
i = individuals.

Income poverty was calculated using national and international poverty thresholds. The national poverty threshold using the cost of basic needs (CBN) methodology of Rs 3,250/adult equivalent/month (Pakistan Planning Commission, 2015-16) was used after adjusting it with CPI for reaching the threshold for 2018-19. For the international poverty line, the $ 1.25 threshold was used after converting it into rupees using the dollar exchange rate for 2018-19.

Energy Poverty

For estimating the proportion of the population considered energy poor (HC_E), a threshold of 300 KWh / person/ year was taken as standard following Moss et. al. (2020).

$$EUC_{PC} = \frac{TEUC_{HH}}{Size_{HH}} \quad \text{......... (12)}$$

$$\frac{HC_{E}}{Tot.Pop} * 100 \quad if\ EUC_{PC} \leq Energy\ Poverty\ Threshold \quad \text{......... (13)}$$

Where,

$HC_E = \sum_{i=1}^{n} EP_i$, EP stands for energy poor, i for individuals

EUC_{PC} = electricity units consumed per capita in a household

$size_{HH}$= total members in a household.

[4] The national equalisation scale weighs individuals aged 18 and above as 1, otherwise 0.8. As per OECD head of the HH is given a weight of 1, while other adults and children are assigned a weight of 0.5 and 0.3, respectively.

Karachi: The City of Lights

In the previous section, we discussed the most rigorous methodology, which is employed in this study, to determine the impact of the increase in tariff on income and energy poverty. However, there are certain limitations in the use of secondary data describe above. Firstly, the methodology for electricity consumption units discussed above is confined to the use with the standard slab-wise tariff rates under the sanctioned load of less than 5kWh because the HIES survey questionnaire does not have any questions on the sanctioned load of the household. Hence, information regarding electricity consumption in peak and off-peak hours cannot be incorporated into the methodology. Furthermore, the estimation was adjusted for the GST, the TVL fee, and electricity duty but not for other surcharges or taxes that may exist and are included in the household electricity expenditures. It is also worth mentioning that the electricity expenditures reported in the survey are usually not the exact expenditures but rather are an approximation made by the household member interviewed.

Considering these caveats, the study conducted a primary survey of Karachi, known as the "City of Lights", as a case study for obtaining in-depth information on the energy situation. This study, thus, aims to form a rigorous analytical basis for energy policy-making in Pakistan. A primary survey regarding households' energy affordability and accessibility along with the socio-economic conditions of a household is the need of an hour for conducting the in-depth analysis of rising electricity tariffs on poverty. Keeping in view all these caveats and limitations, we conducted an in-depth survey of electricity consumers in Karachi city. [5]

Hence, in this section, we describe the sampling technique of the survey and the econometric specification of the models used for the analysis of the survey data. The questionnaire module and results of pre-testing are included in annexures A6 and A7

Sampling Design & Survey Details

Table 4 provides the details of the household sample selected from each town of Karachi. To reach an appropriate household sample, different combinations of confidence interval and specification errors were considered for statistical validity and representativeness. Given the above, the sample size with a 95% confidence interval and less than 10% specification error was considered appropriate. The following formula was used, which yielded an optimal sample size of around 455 households:

Optimal Sample Size = Z^2 [p (1-p)]/e^2 (for known population)

Where,
Z = Specification of confidence coefficient
p = Estimated proportions of population (based on 2005 and projected population for 2020)
e = Specification error

The sample size was determined according to the proportion of the population. Furthermore, the town-wise estimated population was extracted from the 2017 Census provided by the Pakistan Bureau of Statistics.

Table 4: Household Sample

S. No.	Town Name	Total Population	Proposed Sample	Actual Sample Used
1	Baldia	616,721	20	20
2	Bin Qasim	480,855	15	15
3	Gadab	439,675	14	13
4	Gulberg	688,581	22	21
5	Gulshan-e-Iqbal	949,351	29	40
6	Jamshed	1,114,138	34	37

[5] See Annexure B for complete questionnairele other adults and children are assigned a weight of 0.5 and 0.3, respectively.

7	Kaemari	583,641	19	19
8	Korangi	829.813	26	26
9	Landhi	1,012.393	31	32
10	Liaqatabad	985,576	30	34
11	Lyari	923,177	29	30
12	Malir	604,766	19	20
13	New Karachi	1,038,863	32	34
14	North Nazimabad	753,423	24	21
15	Orangi	1,098,858	34	35
16	Saddar	935,565	29	30
17	SITE	709,944	22	23
18	Shah Faisal	509,916	16	17
	City Total	14,275,256	445	467

Source: Authors' calculations based on Pakistan Bureau of Statistics.

Econometric Model Specification and Variables Construction

To estimate the impact of electricity tariffs on household expenditures, the study employed the following econometric model, based on simple regression analysis. Furthermore, the analysis was based on a household-level primary survey carried out in Karachi.

$$\log(EXP_i) = \alpha_o + \alpha_1 Tariff + \alpha_1 HHC + \alpha_2 HC + \alpha_3 EV + \alpha_4 IQ + \square \text{ .... } (14)$$

Where

$\log(EXP_i)$ = household's expenditures on commodity i: food, health, education, clothing, transport, furniture, communication & recreation. This model was repeated for each commodity expenditure to analyse the impact of electricity tariffs more comprehensively.
Tariff = household's electricity tariff.
HHC = household-level characteristics: household size, household average years of education, and household average age.
HC = housing characteristics: the number of rooms and area of the dwelling
EV = electricity related variables: sanction load in KWH
IQ = income quartiles (lower income, middle income & higher income)

In Table 5 below, the construction of variables used in Equation (14) is described in detail.

Table 5: The Construction of Variables

Variables	Definition & Construction
Expenditures	Household's monthly expenditures on each commodity
Tariff	It is the average tariff rate which is faced by the household, depending on the units consumed. It is obtained by dividing total electricity units expenditure by total electricity units consumed.
Household Size	The number of individuals in a household
Household Average Years of Education	The average completed years of education of a household

Household Average Age	The average age of all the members of a household
No. of Rooms	Total number of rooms in a dwelling
Area of the house	The total area of single residential unit
Sanction Load in KWH	The sanction load in KWH
Income Quartiles	Higher income (upper 20% of income group), Middle income (middle 60% of income group) & lower income (lower 20% of income group)

Source: Authors' illustration

4. ANALYSIS AND DISCUSSION

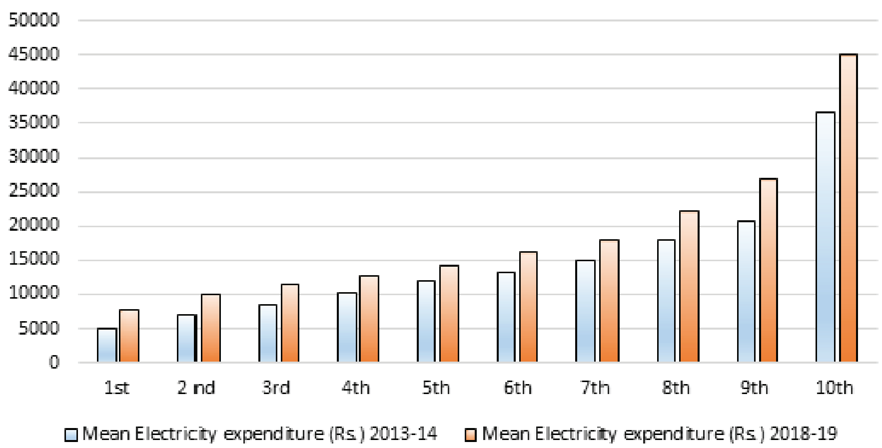
The Crowding-out Effect of Increased Electricity Tariff and its Implications for Household Resource Allocation

This section aims to study the difference in resource allocation of a household and the crowding-out effect of increased electricity tariff on household budget expenditure from 2013-14 to 2018-19.

According to HIES-2018-19, about 97 per cent of urban and 83 per cent of rural households consumed grid electricity, hence, reporting positive electricity expenditure for these households. All such electricity consumers are believed to be affected directly by increasing electricity tariffs.

Figure 4 shows a gradual increase in electricity consumption expenditure with income quintiles. In 2013-14, the average electricity expenditure for the lowest income quintile was less than Rs. 5,000, which increased by about 56 per cent to Rs. 7,632 in 2018-19. For the fifth quintile, mean electricity expenditures were Rs. 12,000 in 2013-14 and increased to more than Rs. 14,000 in 2018-19, recording an 18.4 per cent increase. For the highest income quintile, electricity expenditure increased by more than 23 per cent between the two periods (from Rs. 36,525 to Rs. 45,070). This simple analysis shows that the lowest income group faced the highest increase in electricity expenditure even though electricity prices for the lowest three slabs remained unchanged from 2012 to 2018 (see Table 2). This fact, however, points towards the other factors contributing to the electricity expenditure of households other than the tariff.

Figure 4: Mean Electricity Expenditure by Income Quintiles



Source: Authors' illustration

Table 6 gives the mean consumption share of expenditure categories by income quintiles for households during the low electricity tariff (2013-14) and high electricity tariff (2018-19). The food group had the highest share in consumption expenditure across all income quintiles. However, the percentage of food groups was comparatively higher in the lower-income households and lower in the higher-income households.[6] The expenditure shares of furniture, transport, communication, recreation, and education were comparatively higher in the higher-income group and lower in the lower-income group.

Results of the Student's t-test for the differences in mean expenditures between the periods of high and low electricity tariffs for low-, medium-, and high-income groups are also reported in Table 6. Expenditure category shares during the low tariff period are considered reference categories. A positive percentage difference implies that households spent more, on average, in that consumption category during the high tariff period. In contrast, a negative percentage change suggests less expenditure on that particular consumption category. T-stat columns show statistically significant differences in budget shares between the two periods for all income classes except for health for low-income households, tobacco for middle-income households, and health and education for high-income classes.

Table 6: Student t-test for the difference in budget allocation between low and high electricity tariff

Expenditure categories	Low Income Households				Middle Income Households				High Income Households			
	Shares: Low tariff	Shares: High tariff	Difference	t-stat	Shares: Low tariff	Shares: High tariff	Difference	t-stat	Shares: Low tariff	Shares: High tariff	Difference	t-stat
Food & Beverages	51.03	46.08	-4.95	-17.6	45.38	42.46	-2.92	-20.3	35.10	34.42	-0.68	-2.3
Tobacco	1.77	1.49	-0.28	-4.2	1.25	1.24	-0.01	-0.6	0.73	0.85	0.12	3.6
Clothing & Footwear	6.62	8.07	1.45	18.0	7.20	8.25	1.05	23.8	6.91	7.83	0.92	11.1
Furniture	2.62	3.37	0.75	15.6	2.75	3.54	0.79	23.3	3.65	4.03	0.38	4.0
Health	3.55	3.68	0.13	1.4	3.34	3.54	0.2	3.8	3.48	3.33	-0.15	-1.0
Transport	4.73	4.00	-0.73	-6.5	7.23	6.31	-0.92	-12.3	10.31	8.29	-2.02	-10.5
Communication	1.64	1.49	-0.15	-4.5	2.09	1.73	-0.36	-17.1	2.74	2.35	-0.39	-8.2
Recreation & Culture	1.78	1.15	-0.63	-8.2	1.96	1.45	-0.51	-15.6	2.08	1.44	-0.64	-11.7
Education	0.68	0.48	-0.2	-4.7	2.27	2.06	-0.21	-4.3	4.93	5.18	0.25	1.5
Restaurant	2.33	3.39	1.06	6.0	1.77	2.42	0.65	12.1	2.41	3.02	0.61	5.5
Housing, water and fuel	16.16	20.27	4.11	18.9	16.04	18.70	2.66	23.6	16.45	18.76	2.31	9.7
Misc.	7.09	6.53	-0.56	-5.6	8.72	8.30	-0.42	-6.7	11.20	10.50	-0.7	-3.6

Source:Authors' calculations

The differences in resource allocation observed in Table 6 for various expenditure categories were not controlled for the demographic and socioeconomic characteristics of households. To examine the crowding-out effect, more vigorous and theoretically sound econometric analyses were carried out by employing the conditional demand model as expressed in Equation 1. The model, which is conditional on electricity expenditure, was estimated, first to test whether the increased tariff altered the preferences over the commodity categories from one period to another. Secondly, this model statistically examined the nature of the crowding-out of other categories because of increased electricity expenditure – as a result of increased tariff – controlling for demographic and socioeconomic characteristics of households. [7]

Table 7 shows adjusted differences of increased tariffs for different income levels. It demonstrates the mean share of expenditures on various categories (columns 2, 4, and 6) during the low tariff period (2013-14), which was considered as the reference category. Similar to Table 6, a positive percentage difference implies that households, on average, allocated a more significant share to that consumption category during the high tariff

[6] In this study, the first two income quintiles are considered low-income groups, the middle six are middle-income groups, and the last two are considered high-income groups.

[7] Detailed STATA output is shown in annexure A4

period than the low tariff period. In contrast, a negative percentage difference implies households allocated a smaller share in the high tariff period.

Table 7: Adjusted Differences of Increased Tariff on Expenditure Shares by Income Groups

Expenditure categories	Low Income Households (lower 20%)		Middle Income Households (Middle 60%)		High Income Households (Highest 20%)	
	Low Tariff	High Tariff	Low Tariff	High Tariff	Low Tariff	High Tariff
	Mean Share (%)	Difference (% point)	Mean Share (%)	Difference (% point)	Mean Share (%)	Difference (% point)
Food & Beverages	51.03	0.84***	45.38	-0.14	35.10	-1.79*
Tobacco	1.77	0.27*	1.25	0.17*	0.73	0.14*
Clothing & Footwear	6.62	0.73*	7.20	1.18*	6.91	1.11*
Furniture	2.62	0.53*	2.75	1.00*	3.65	-0.83*
Health	3.55	-0.19*	3.34	0.66*	3.48	1.92*
Transport	4.73	-2.72*	7.23	-1.57*	10.31	0.29
Communication	1.64	-0.18	2.09	-0.13	2.74	-1.28*
Recreation & Culture	1.78	-1.04*	1.96	-0.98*	2.08	-1.06*
Education	0.68	-1.10*	2.27	-1.66*	4.93	-2.79*
Restaurant	2.33	4.06*	1.77	1.52*	2.41	0.01
Housing, water & fuel	16.16	-1.59*	16.04	-0.16	16.45	3.97*

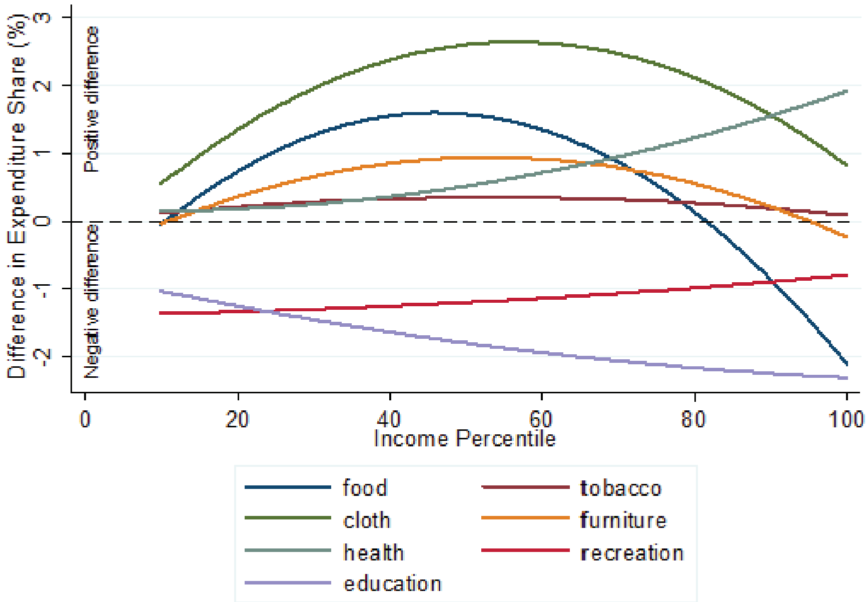
Source: Authors' calculations

Table 7 reveals statistically significant differences in expenditure allocations for most of the expenditure categories. For instance, after the increase in tariff, low-income households, on average allocated less to health, transport, communication, recreation, education, housing and fuel, while the share allocated to most of the necessities, such as food, tobacco and clothing increased. A more or less similar pattern was observed for middle-income households, except that their share allocated to food and beverages shows statistically insignificant results, while the allocated share to health increased to 0.66 per cent. High-income households also altered their budgets except for transport and restaurants.

Similar to the estimated results shown in Table 7, the adjusted differences were estimated using Equation 1 for household expenditures at the 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100th income percentiles. Coefficient estimates for α_2i from Equation 1 are statistically significant for the consumption groups (i.e., food, tobacco, clothing, furniture, health, recreation, and education) as demonstrated in Figure 5. Adjusted differences < 0 means households allocated fewer resources to the consumption group after the increase in tariff.

Figure 5 illustrates that adjusted differences in the food and beverages increased for low- and lower-middle-income households' consumption expenditure distribution, gradually decreased for higher-middle-income households, and were negative for higher-income households. It is also observed that the magnitude of the difference was greater for higher-income households. In 2018-19 (the period of tariff increase) at the 90th percentile, households allocated about 2 per cent less of household spending on food and beverages compared to 2013-14.

Figure 5: Adjusted differences in consumption share by income percentiles



Source: Authors' illustration

Adjusted differences in the clothing or apparel share were positive at entire household expenditure levels. In contrast, adjusted differences for education and recreation were negative for all the households. At the 10th percentile (lower-income households), the mean share of education was 1.15 per cent less; at the 60th percentile (middle-income), the mean share of education was two per cent less; and at the 100th percentile (high-income households), the mean share of education was 2.64 per cent less. Adjusted differences in the health expenditure share, on the other hand, were positive at all levels of household expenditure distribution; however, the magnitude of the difference was lower for low-income households and higher for high-income households.

These results show a nontrivial difference in the composition of budgetary expenditures of households during the low tariff period compared to the high tariff period. An increase in the cost of electricity has a direct and indirect effect on welfare. It is well documented that electricity prices sometimes bring macroeconomic instability, such as rising inflation and higher unemployment rates, which hurt the poor (Moshiri, 2015). Therefore, the indirect effects of increased electricity prices compelled poor households to cut their spending on commodities other than necessities. It also raised the cost of different food and non-food items, which increased the expenditure of poor households on essentials.

Table 8: Crowding-in and Crowding-out by Income Group

Expenditure Category	Low Income Households		Middle Income Households		High Income Households	
	Crowding-in	Crowding-out	Crowding-in	Crowding-out	Crowding-in	Crowding out
Food & Beverages		✓		✓	✓	
Tobacco		---		✓	✓	
Clothing & Footwear	✓		✓		✓	
Furniture	✓			✓	✓	
Health	✓			✓		✓

Transport	---			✓		✓
Communication	✓			---	✓	
Recreation & Culture		✓	✓		✓	
Education	✓		✓		✓	
Restaurant		✓		✓		✓
Housing, water & fuel	✓		✓			---

Source: Authors' calculations

In the context of the current study, the crowding-out effect is the mechanism through which rising electricity expenditure negatively impacts households' well-being due to the alteration in the consumption of necessities because of spending on electricity. Table 8 shows the regression outcomes for the crowding-out effect of electricity expenditure for various income groups. Estimates of α_{3i}in Equation 1 are significant for all the categories except for tobacco and transport for low-income groups, communication for middle-income groups, and housing, water and fuel for higher-income groups. The heterogeneous crowding-out effect of electricity expenditures for various income groups is observed. An increase in the outlay of electricity led to a fall in the budget shares devoted to food, tobacco, recreation and restaurant for low-income households. The crowding-out effect of electricity expenditure on middle-income households was the most significant. An increase in electricity expenditure crowded out almost all the allocated shares to various categories except for clothing, recreation, and education. For high-income households, increased electricity expenditure crowded-in all expenditure shares except for health, transport, and restaurant.

Table 9 shows that for low-income households, a Rs.1,000 increase in electricity expenditure was accompanied by a 1.24 per cent decrease in food expenditure. For the middle-income group, electricity expenditure crowded out most of the expenditure categories but with relatively slighter percentage points. However, for the high-income class, a Rs. 1,000 increase in electricity expenditure led to 0.28 and 0.33 per cent decrease in health and transport expenditures, respectively.

Table 9: Crowding-out effect of electricity expenditure by Income Group

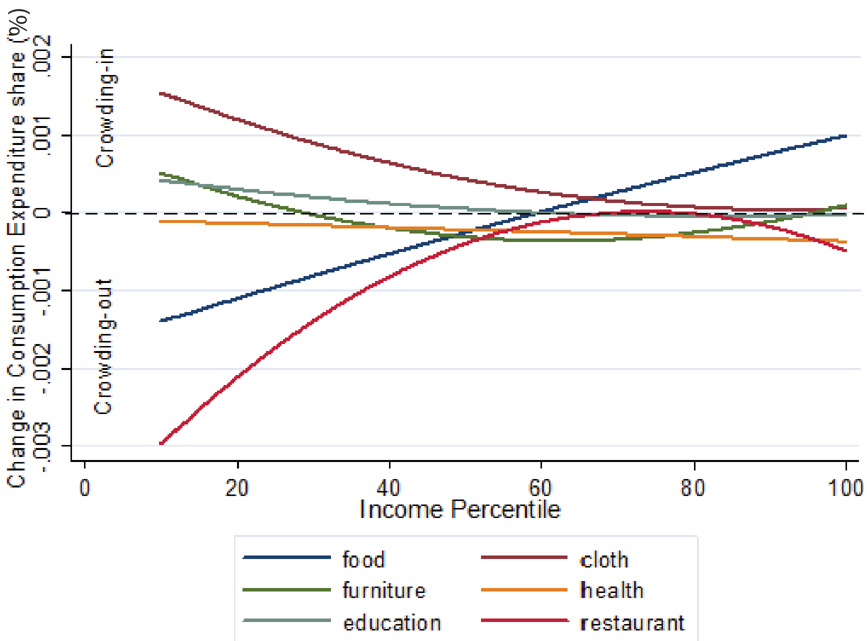
Expenditure Category	Low Income Households	Middle Income Households	High Income Households
Food & Beverages	-0.00124*	-0.00017*	0.00061*
Tobacco	-0.00003	-0.00002*	0.00002*
Clothing & Footwear	0.00157*	0.00023*	0.00006*
Furniture	0.00031*	-0.00018*	0.00012*
Health	0.00009**	-0.00029*	-0.00028*
Transport	0.00001	-0.00008*	-0.00033*
Communication	0.00029*	-0.00001	0.00010*
Recreation & Culture	-0.00027*	0.00004*	0.00002*
Education	0.00032*	0.00022*	0.00007*
Restaurant	-0.00272*	-0.00049*	-0.00002**
Housing, water & fuel	0.00189*	0.00138*	-0.00004

Source: Authors Calculation

Figure 6 shows the crowding-out effects estimates for various income percentiles. Estimates on the Y-axis are computed by employing Equation (1) for expenditures at the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, and 100th percentiles. Coefficients of α_3i from Equation (1) are statistically significant for the expenditure categories, such as food, clothing, furniture, health, education and restaurant. Values on the vertical axis refer to adjustments in consumption expenditure share for a particular category due to an increase in electricity expenditure by Rs.1. Values less than zero on the vertical axis are considered as crowding out, and, on the other hand, values greater than zero are considered as crowding in.

The most important point to be noticed in Figure 6 is that the size of crowding in and crowding out effects are greater for poor households. It has been demonstrated that electricity expenditures crowd out food expenditures in lower and middle-income households, while crowd-in for higher income group households. However, the size of crowding out effects was higher for the poorest percentiles. Health expenditures were crowded out at all income levels. As far as education expenditures are concerned, crowding in is noticed for lower-income groups, while crowding out with insignificant magnitude is noticed for higher-income percentiles. The largest magnitude of crowing out was noticed for restaurant expenditures for poorer households. At the 10th percentiles (poorest households) of household expenditures, a Rs. 1,000 increase in electricity expenditure led to a 4 per cent fall in restaurant expenditure.

Figure 6: Crowding-out of consumption by Income percentiles



Source: Authors' Illustration

Undernutrition is already the main reason for infant mortality in Pakistan (Hussain et al., 2018). Crowding out of food and beverage consumption might have implications for children's physical and intellectual growth and nutritional deficiency in mothers, notably, for lower-income households. Electricity expenditure, through increased tariffs, could further deepen the nutrition uncertainty by reducing food expenditures.

Results show that the displacements due to electricity expenditure occurred for commodities that constitute human capital investments, such as food and nutrition, health etc., thus, having severe implications for households' well-being. Electricity tariff reforms, with the nonexistence of adequate health compensation, insurance or other public provision of finances, could lead to welfare loss, particularly among poor households. Therefore, inadequate measures by the government could adversely affect human capital investments crucial for long-term prosperity.

It is also worth mentioning some limitations. Firstly, consumption expenditure data for all categories, including electricity expenditures, were estimated and self-reported values, and not the exact ones. Therefore, recording or misreporting mistakes could have created biases in crowding out computations.

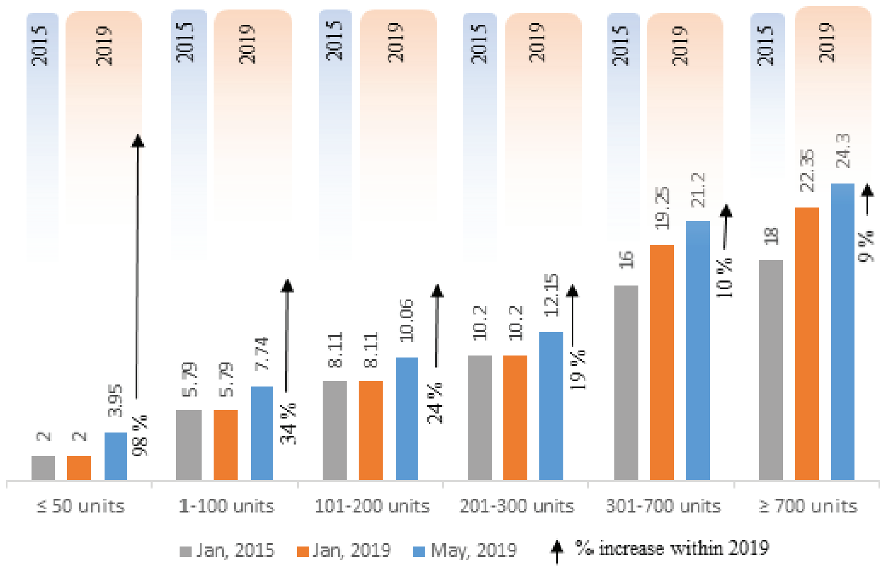
Electricity Tariff Reforms and Household Welfare Analysis for Karachi City

This section discusses the welfare impact by employing HIES 2015-16 and HIES 2018-19 for Karachi city as a case study.

For achieving these objectives, we first analysed the increase in tariff rates from June 2015 to January 2019 and then from January 2019 to May 2019. Figure 7 shows that the residential electricity tariff rates remained unchanged from June 2015 till January 2019, except for the two higher slabs. Such a reform aimed to safeguard consumers with relatively inelastic electricity consumption in lower slabs. However, per unit tariff rates for higher slabs were increased, considering elastic electricity consumption at higher slabs, thus, discouraging inefficient use of electricity, on the one hand, and reducing fiscal pressure, on the other.

However, in May 2019, the tariff rates were increased by a flat rate of Rs 1.95 per unit. In percentage terms, this increase was more oppressive for lower slab consumers, particularly for lifeline consumers. Black arrows in Figure 7 show that the impact of a flat rate increase was more burdensome for consumers in the lower slab compared to the upper slab consumers.

Figure 7: Change in residential electricity tariff from 2015 to 2019

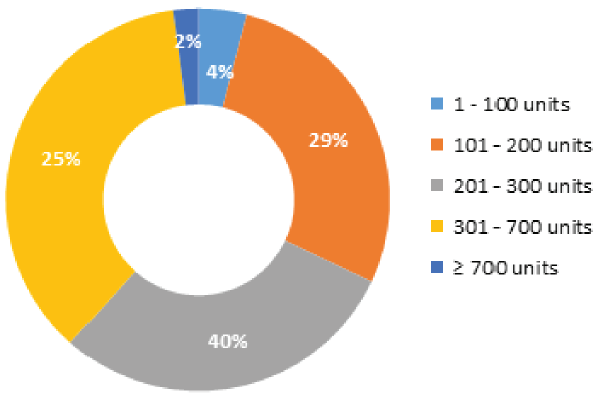


Source: Authors' illustration using KE applicable tariffs

According to Figure 3, the first step of estimation in this section involved computing electricity units consumed by each household. Figures 8 and 9, and Table 10 describe unit consumption of electricity computed from HIES 2015-16 and 2018-19 for Karachi[8] city by employing June 2015 and January 2019 tariff rates, respectively.

[8] In 2015-16, information on 2,446 households for Karachi city was available, while in 2018-19, 1,413 households were included in the survey.

Figure 8: Slab-wise Electricity Consumption (% of Households)



Source: Authors' estimations

Figure 8 displays the estimated percentage of households in each consumption slab in 2019. It shows that only 2 per cent and 4 per cent of households consumed electricity in the 5th and 1st slabs, respectively, while around 94% of households consumed in the 2nd, 3rd, and 4th slabs. It is worth mentioning that households consuming in the lifeline tariff slab cannot be computed from HIES data. However, according to Walker T. et al., (2014), the lifeline tariff rate is ineffective in Pakistan as merely around 3 per cent of households consume below 50 kWh. However, this limitation is assumed not to alter the results significantly.

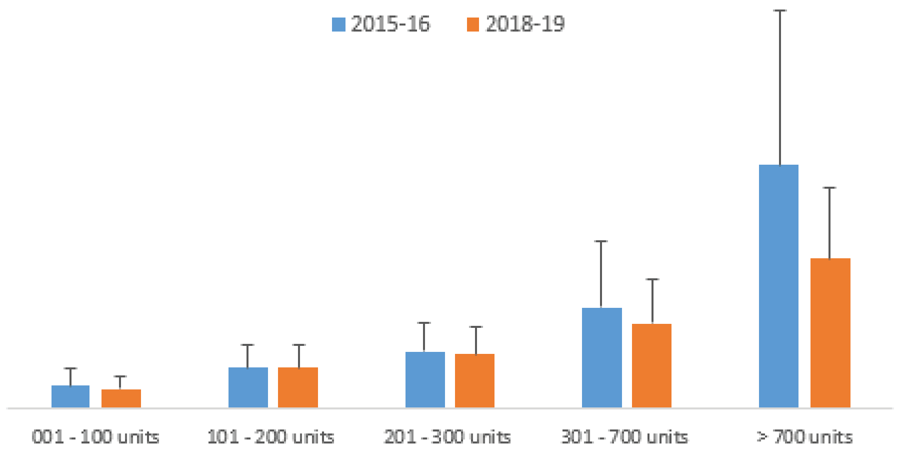
Table 10: Percentage of Households by HH Income Quintiles and EC Slabs (2019)

% of HHs across HH Income quintiles and EC slabs (2019)						
Unit Slabs	HH Monthly Income Quintiles					Total
	1st	2nd	3rd	4th	5th	
1 - 100 units	63.16	22.81	8.77	3.51	1.75	100
101 - 200 units	45.57	26.33	17.22	8.61	2.28	100
201 - 300 units	22.78	28.06	20.14	21.34	7.67	100
301 - 700 units	12.89	9.77	20.31	22.27	34.77	100
≥ 700 units	0	0	6.67	6.67	86.67	100
Total	26.71	20.13	18.64	17.08	17.43	100

Source: Authors' calculations

Table 10 reveals the estimated households within each electricity consumption slab and income quintile. It is observed that lower-income households consumed, on average, fewer units of electricity compared to higher-income households.

Figure 9: Deviation from mean electricity consumption by slabs



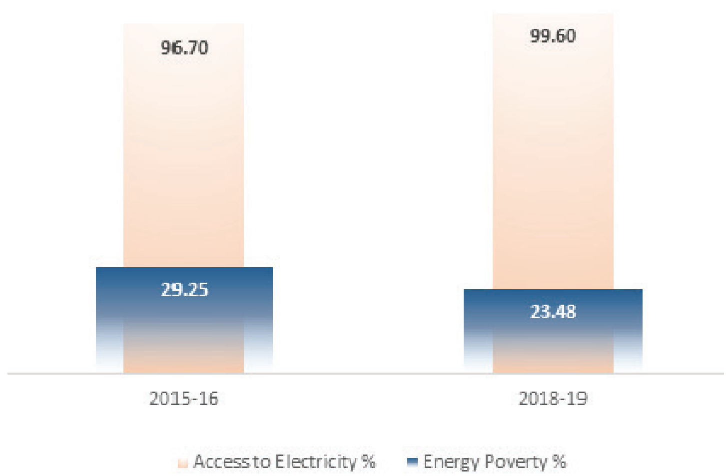
Source: Authors' calculations

This graph (Figure 9) represents the deviation of average consumption in each electricity consumption slab. The vertical lines above the bars reflect the deviation from the mean within a specific slab. It can be seen that the deviation increases as we move towards higher slabs indicating that electricity consumption in lower slabs is relatively inelastic in comparison to upper slabs. Thus, any price increase worsens households in lower slabs relatively more than the households in the upper slabs. In contrast, the benefits to upper slab consumers will be more significant in relation to the lower slab households for any price decline.

Energy Poverty

Given the energy threshold and electricity units' estimates, energy poverty for 2015-16 and 2018-19 was calculated. Interestingly, Figure 10 shows that the population below the energy poverty threshold in 2015-16 was 29.3 per cent, while it decreased to 23.5 per cent in 2018-19, despite the increase in tariff. The figure demonstrates that access to grid electricity also increased significantly during this period. Hence, increased access might have reduced energy poverty in Karachi city during this period.

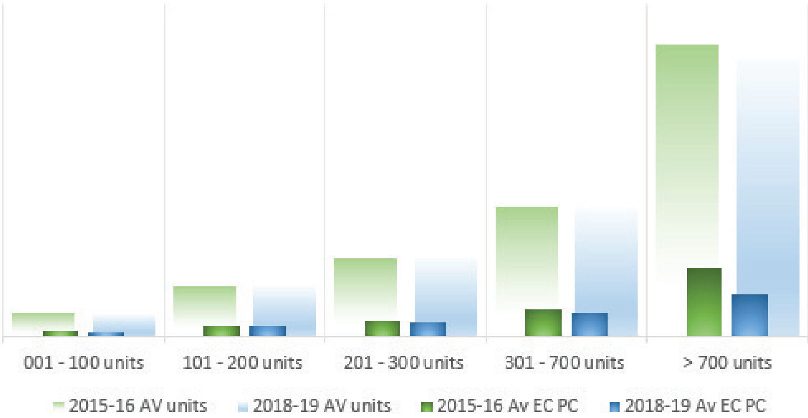
Figure 10: Percentage of population below the energy threshold



Source: Authors' estimations

Furthermore, for exploring the tariff effect on energy consumption, average energy household consumption and average per capita energy consumption by electricity consumption slabs were also analyzed. Figure 11 below reflects that both, households' electricity consumption as well as per capita electricity consumption declined over time for the upper two slabs. However, for lower slabs electricity consumption remained almost unchanged.

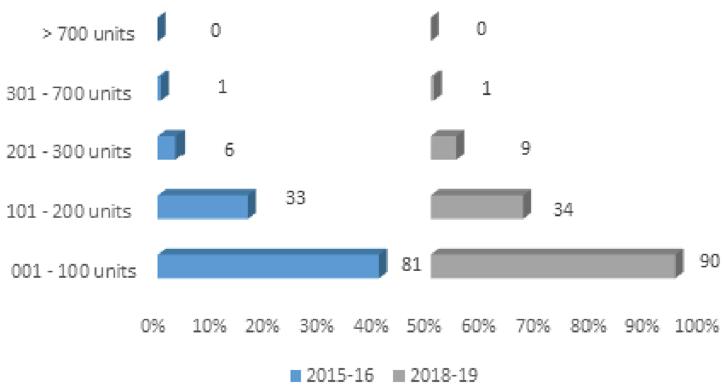
Figure 11: Electricity Consumption Units by Electricity Consumption Slabs



Source: Authors' estimations

Figure 12 confirms that the majority of energy poor was in lower electricity consumption slabs in both years. Lower electricity consumption slabs usually comprise a greater proportion of lower-income households. It is shown that 81 per cent of the population consuming in the first slab one weres energy poor and this percentage increased to 90 % in 2018-19. For the second and third slabs, the proportion of energy poor increased over time.

Figure 12: Proportion of energy poor by electricity consumption slabs (%)



Source: Authors' estimations

Income Poverty

Table 11 shows the increase in income poverty as a result of increased tariffs from January 2019 to May 2019. Uncompensated household income is the income of households if no compensation is provided for the rise in tariff rate, whereas compensated income is calculated by adding the increased amount that a household pays as a result of increased tariff in the total income of households. The amount of compensation was, thus, calculated as the difference between the compensated and uncompensated household income. Table 11 shows the proportion of the poorest households living below the poverty line by employing standard thresholds and equivalency scales.

Table 11: Percentage of income Poor Population in Karachi

	National Equivalency Scale	OECD Equivalency Scale
	HC international Poverty Line $ 1.25= Rs 170.11	
Uncompensated HH Income	37.74	3.82
Compensated HH Income	33.08	3.20
Change in Poverty	4.67	0.63
	HC national Poverty Line Rs 125.87	
Uncompensated HH Income	14.52	1.14
Compensated HH Income	12.49	0.92
Change in Poverty	2.03	0.22

Source: Authors' estimations using HIES 2018-19

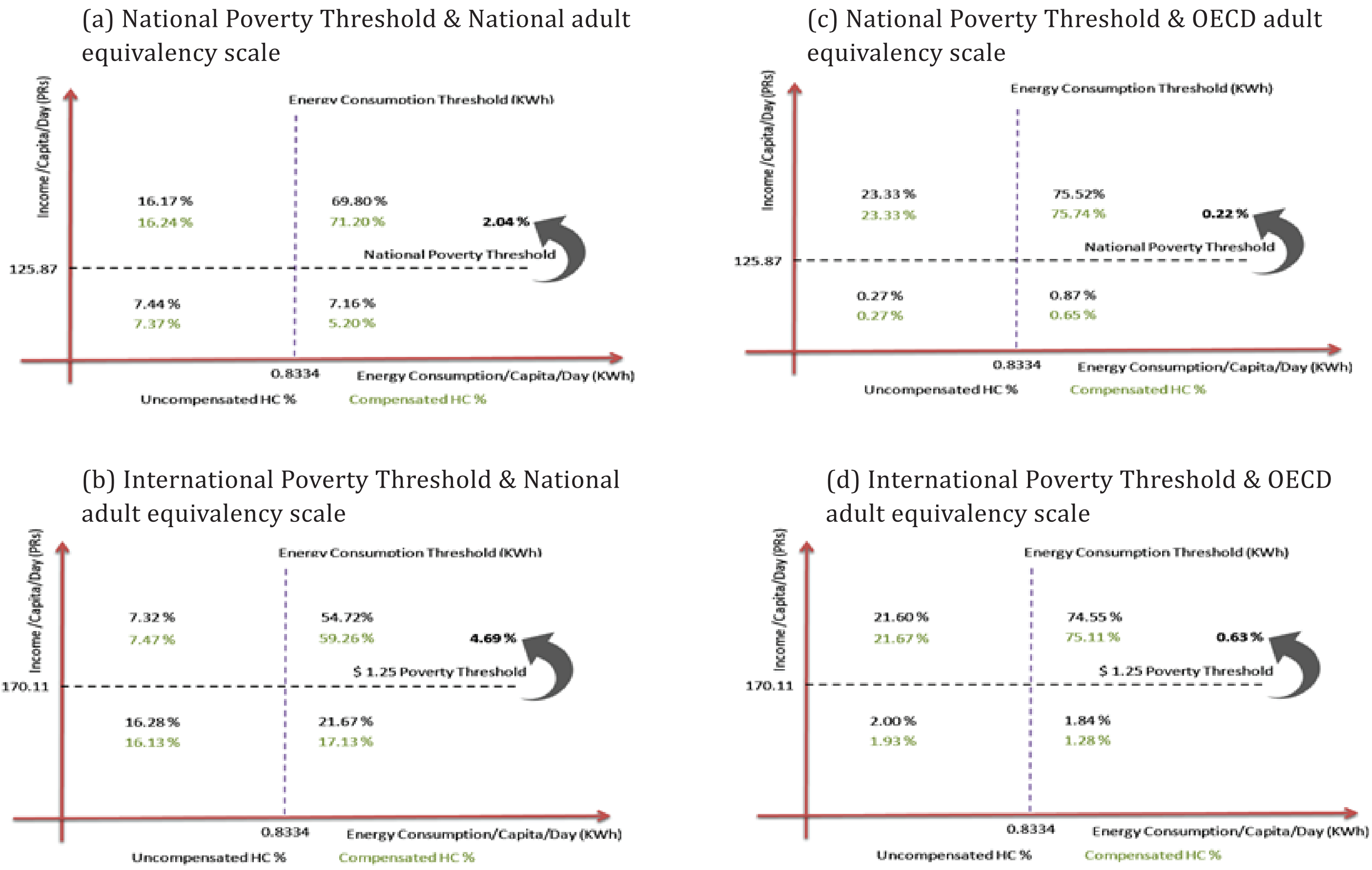
In Karachi city, around 38% and 4% of the population was below the international poverty threshold of $ 1.25 per day per adult equivalent using the national and OECD equalisation scale. However, as per the national income poverty threshold based on the cost of basic need (CBN) methodology and national equivalency scale, approximately 14.5 % population in Karachi was income poor. Using the same threshold as the OECD equivalency scale resulted in about 1.14 % income poverty. Poverty estimates using OECD equalization standards were less than those calculated using the national one because of the difference in assigning weights to the members of the households.

It was estimated that if the compensation had been provided to the poor households, all the poverty estimates reported in the third and seventh row of Table 11 would have declined. Considering only the national equalisation scale, about 4.7 per cent of the poor population would have been pulled above the international poverty threshold. In contrast, around 2 per cent of the poor population would be able to escape the national CBN poverty threshold. These estimates indicate the impact of the electricity tariff increase in inflating income poverty in Karachi as well as the significance of compensatory mechanisms in reducing poverty.

Finally, to explore the interconnection between income and energy poverty, the plots below categorise all the surveyed households into four groups. Per-capita energy consumption per day is measured along the x-axis, while income per adult equivalent per day is plotted along the y-axis. The vertical dashed line represents the electricity consumption threshold. Individuals consuming below the dashed line are considered energy poor. At the same time, the horizontal dashed line measures the minimum income threshold. Individuals with income below these thresholds are considered income poor.

Figure 13 pooled the impact of tariff reforms in exacerbating energy poverty and income poverty in Karachi city. Figure 13 (a) and (b) are based on the national adult equivalency scale, and (c) and (d) are computed on the OECD adult equivalency scale.

Figure 13: Income and Energy Poverty Before and After Compensation



Source: Authors' estimations using HIES 2018-19 and KE data.

Figure 13 (a) split the population based on the national poverty threshold of Rs 125.87 per day per adult equivalent. It depicts that about 69.8% of the population was in the 4th quadrant indicating that they were neither income nor energy poor, while 7.44% of the population was the most deprived as facing both income and energy poverty. Around 7.16 per cent of the population was income poor but not energy poor, while 16.17 per cent of the population fell in the polar opposite group. If the compensation were provided, around 2.04 per cent population that was below income poverty could have been dragged above the poverty threshold. Figure 13(c) reveals that after compensation, the decrease in income poverty would have been about 0.22%.

Figure 13 (b) is plotted for the $1.25 international poverty threshold. It shows that 37.9% of the population was income poor of which 16.28 per cent of the population was energy poor as well. After compensation this estimate would have reduced to 33.26 per cent, showing a 4.69 per cent decrease in headcount ratio. At least 54.72 per cent of the population was still above the income and poverty threshold. Considering the OECD scale, however, the headcount estimates were reduced by 0.63%.

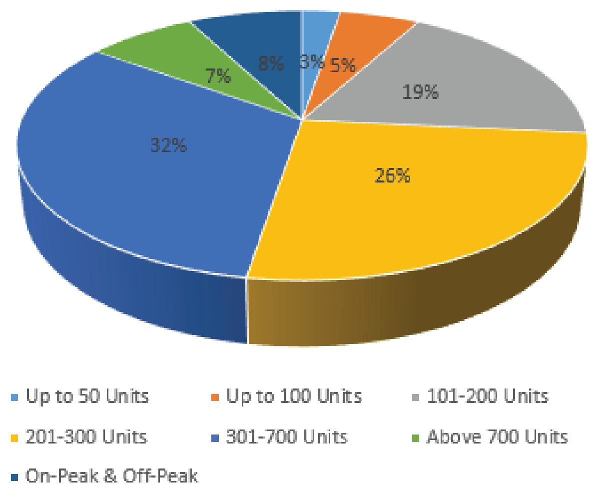
It is concluded that whatever threshold is being used as a policy tool, the impact of electricity reforms could be mitigated only through a more comprehensive and long-lasting compensatory mechanism.

Findings of Survey, "Karachi: The City of Light"

The previous section provided a detailed assessment of increased electricity tariffs on household welfare in Karachi city by employing the HIES dataset. As mentioned earlier, there are limitations of PSLM/HIES datasets for a comprehensive energy policy analysis. Therefore, the primary survey, titled, "Karachi: The City of Lights", incorporated energy modules into PSLM/HIES survey. The information gathered provides greater insight into the role of energy prices on household welfare.

This section of the study discusses the findings, which are based on descriptive and empirical analysis of the household-level primary data of Karachi city. The descriptive analysis presents the consumption, expenditure, and changes in the recent increases in electricity tariffs by electricity consumption slabs. The analysis also provides estimates of the empirical model discussed in equation 14. The last part, however, provides information on energy literacy, consumer satisfaction, and household behaviour regarding electricity use.

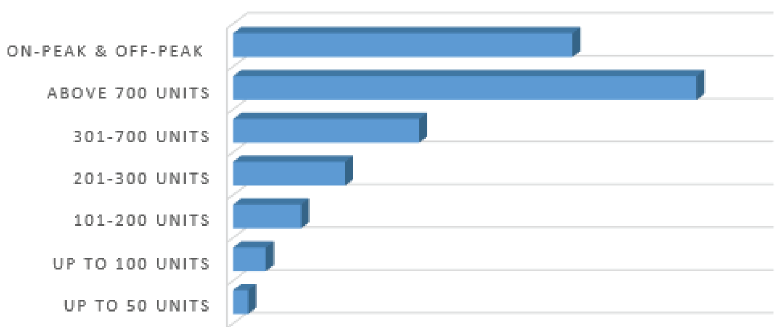
Figure 14: Households by Electricity Slabs (%)



Source: Authors' illustration based on a primary survey of Karachi.

Figure 14 above illustrates the percentage of households in each consumption slab. The figure depicts that most of the households were middle-slab consumers, i.e., 32 per cent in the 5th slab (301-700), 26 per cent of households in the 4th slab (201-300), and 19 per cent in the third slab. As argued by Walker T. et al. (2014), survey results validate that the lifeline tariff slab is nearly ineffective in Pakistan as a meagre 2.57 per cent of households were lifeline consumers consuming less than 50 units per month. The Proportion of households consuming in the lowest and highest slabs was also relatively low, whereas the ToU tariff applies to households having sanctioned load equal to or greater than 5 kWh. Hence, according to the survey results, only 8 per cent of households fell under this category.

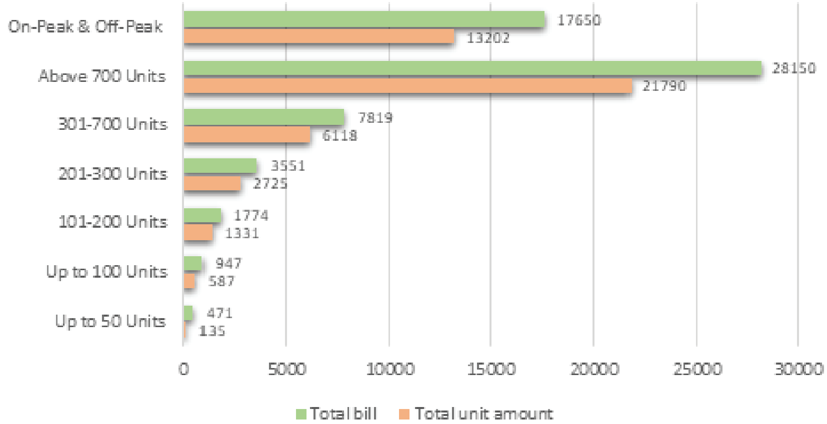
Figure 15: Average Monthly Electricity Consumption (Units)



Source: Authors' illustration based on a primary survey of Karachi.

Figure 15 portrays the average electricity consumption in units by electricity slabs. The figure depicts that on average, the highest units of electricity (1058) were consumed by only 7 per cent of households. Following this, on average, about 775 units of electricity per month were consumed by only 8 per cent of households who belong to the ToU category. However, the highest proportion of the households in Karachi, i.e, 32 per cent, on average, consume only 425 units of electricity per month. This is followed by an average consumption of 256 units by 26% of households.

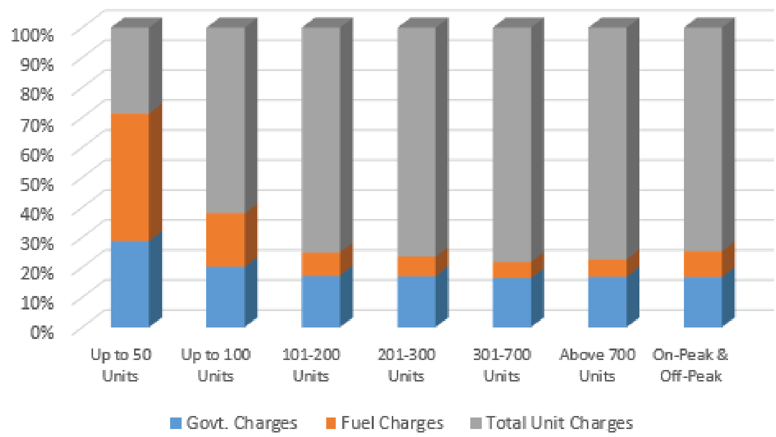
Figure 16: Average Monthly Electricity Expenditures (Rupees)



Source: Authors' illustration based on a primary survey of Karachi.

Figure 16 illustrates the average expenditures of electricity by households in Karachi. The smaller bar in each slab represents the consumption expenditure of units (kWh), while the bigger bar shows the total amount of the electricity bill inclusive of government charges, fuel adjustment charges, etc. The figure depicts that, on average, households that consumed more than 700 kWh per month paid about three times more than the households that ended up consuming just below 700 kWh. Similarly, the difference in the expenditure between households that consumed in the fourth (201-300 units) and fifth slabs (300- 700units) was about two times. Another significant feature of Figure 16 is that the government charges and other charges such as the TVL fees, fuel adjustment charges, etc., constituted a significant proportion of total bills. Figure 17 shows the disaggregation of total billing components for each slab.

Figure17: Comparison of Unit Expenditure with Other Charges of Electricity (Rs)



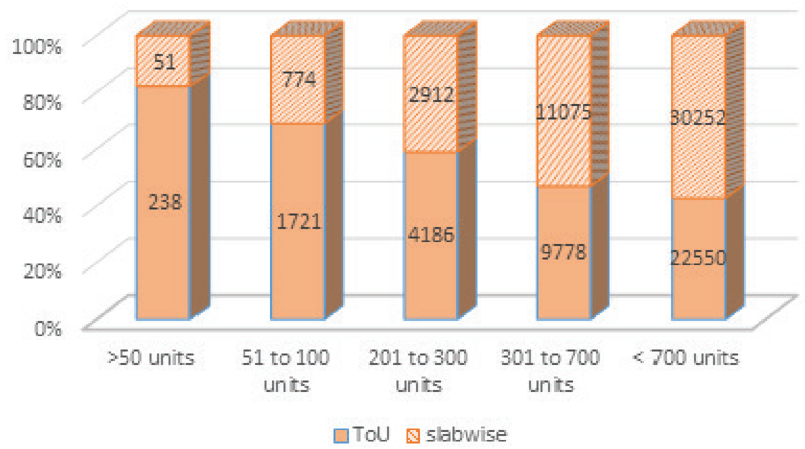
Source: Authors' illustration based on a primary survey of Karachi.

Figure 17 presents the comparison of electricity unit charges with other charges of electricity that the households are bound to pay with an electricity bill. These charges consist of government charges and fuel adjustment charges, imposed by the K-Electric. The figure shows that the proportion of total units' charges was highest, followed by government charges and fuel adjustment charges for electricity. The most significant information detected from this graph is that the fuel adjustment charges for the lifeline slab were more than the total amount spent on units consumed, whereas government charges also constituted a significant proportion. This information reveals that, on the one hand, the lifeline slab is supposed to be the most protected and subsidised but, on the other hand, various additional charges significantly increase the total electricity bill. Conclusively, it can be depicted from the figure that households bear an extra burden in the form of these charges.

Another foremost reform in the tariff structure is the implementation of the time of use (ToU) metring arrangement. According to this reform, all the new and existing customers having sanctioned loads of 5 kWh and above have installed ToU meters and are, therefore, billed based on the peak and off-peak tariff structure.

Figure 18 shows the electricity expenditure of households having sanctioned loads greater than 5. The amount in rupees mentioned in the bars is the unit consumption amount (government and other charges are not included). This figure is constructed for comparison purposes as the rate of peak hours are charged at the highest rates irrespective of the number of units consumed. In the figure, each bar is divided into two, where the solid part represents the actual expenditure of these households based on the ToU tariff structure and the textured part is constructed on the basis that if these households were billed under the slab-wise tariff structure. The figure reveals that households consuming less than 300 kWh units, on average, were worse off under this new reform. Such households were bound to pay more than two times.

Figure 18: Households having Sanctioned Load 5 kWh and above



Source: Authors' illustration based on a primary survey of Karachi.

Impact of Recent Increase in Tariff

Table 12 below provides the impact of the recent increase in electricity tariff rates on household expenditures. Table 2 shows that by the end of 2021, the government has again revised the tariff rates for all consumption slabs except the lifeline tariff slab. For each three consumption slabs, from 1 to 300 kWh units, tariff rates were increased at a flat rate of Rs. 1.61, while for all the higher slabs tariff was revised at a flat rate of Rs. 3.33.

Table 12: Electricity Expenditure Before and After the Tariff Increase

Slabs category	Electricity Units Expenditures (Before Tariff Increase)	Electricity Units Expenditures (After Tariff Increase)	Percentage Change
Up to 50 Units	135.35	135.35	00
Up to 100 Units	587.31	699.38	19.08
101-200 Units	1331.38	1581.60	18.79
201-300 Units	2724.99	3107.18	14.03
301-700 Units	6117.94	7022.17	14.78
Above 700 Units	21790.36	25572.70	17.36
On-Peak & Off-Peak	13201.52	15769.42	19.45

Source: Authors' calculations based on primary data of Karachi.

In Table 12, the percentage increase in electricity expenditures is calculated by keeping the units consumed constant and applying new rates to calculate the expenditures after the increase in tariffs. It shows that expenditures increased by more than 14 per cent for all the slabs. The highest percentage increase was recorded for households having sanctioned load of 5 or above. The impact of the recent tariff revision was also substantial on lower consumption households.

Impact of Tariff Variation on Household Welfare

In this section, we empirically explore the impact of the average electricity tariff on households' welfare. Household welfare was measured by households' monthly expenditures on various commodities, namely food and beverages, health, education, clothing, transport, furniture, communication, and recreational activities.

Furthermore, the analysis is based on the OLS regression model, given in Equation 14, using primary data from Karachi, consisting of a sample of 467 households. Regression results are reported in Table 13.

Table 13: Impact of Tariff on Household Expenditure

Expenditure Item	Electricity Tariff
Food & Beverages	- 0.005***
Health	-0.004
Education	0.002
Clothing	-0.005**
Transport	- 0.006***
Recreational Activities	-0.009*
Furniture	0.002
Communication	-0.005**

Note: *** indicates significant at 1%, ** at 5%, and * at 10%
Source: Authors' calculations based on a primary survey of Karachi.

Table 13 reports the estimates of electricity tariff, resulting from the determinants of the log of household's monthly expenditures.[9] The estimates show that increased tariffs reduced household welfare, measured in terms of reduction in expenditures on other commodity items, such as food and beverages, clothing, transport, recreational activities, and communication. The negative and statistically significant estimate of electricity tariffs on households' food expenditures reveals that one rupee increase in electricity tariff, on average, led to a decrease in households' monthly food expenditures by 0.5%. Similarly, the effect of the tariff increase on households' monthly expenditures on clothing, transport, communication, and recreation was a decline of 0.5%, 0.6%, 0.9%, and 0.5%, respectively.

The empirical findings of the impact of electricity tariffs on households' expenditures of other items reveal the crowding out effect, which can be observed from the reduction in expenditures on other items in the household consumption basket as a result of the tariff increase.

Energy Literacy and Behavior

Considering all the above issues in electricity management and affordability, it is imperative to educate the general public about sustainable energy consumption habits. Considering it an essential instrument, this study included these important modules in the energy survey that we carried out for this study to understand the cognitive and behavioural aspects of household energy use. Including these aspects in the policy design will enable individuals to make appropriate choices in energy use as well.

Various indices were calculated from the literacy, behaviour, and satisfaction modules in the energy questionnaire. Each index was calculated by linear combinations of various indicators[10] .

Table 14: Energy Literacy Index

Town	Mean
Baldia	0.300
Bin Qasim	0.244
Gadab	0.397
Gulberg	0.325
Gulshan-e-Iqbal	0.413
Jamshed	0.455
Kaemari	0.211
Korangi	0.314
Landhi	0.260
Liaqatabad	0.461
Lyari	0.328
Malir	0.425
New Karachi	0.294
North Nazimabad	0.381
Orangi	0.167

[9] Detailed and comprehensive regression results with all the covariates and income dummies are given in Annexure A5.

[10] The list of the indicators for each index is provided in Annexure A8

Saddar	0.411
Site	0.210
Shah Faisal	0.382

Source: Authors' calculations based on Primary data from Karachi

Table 14 shows the energy literacy index computed by employing various energy literacy indicators, given in the questionnaire. The index given below measures the extent to which households in Karachi are energy literate. The values of the index range from 0 (energy illiterate) to 1 (energy literate).

Table 14 shows that residents of not a single town in Karachi were literate enough in the tariff structure, tariff rates, and other aspects of energy. However, residents of Liaquatabad, Jamshed town, Malir town, Gulshan-e-Iqbal town and Saddar town were relatively more informed.

Table 15: Energy Behavioral Index

Town	Mean
Baldia	0.375
Bin Qasim	0.05
Gadab	0.538
Gulberg	0.405
Gulshan-e-Iqbal	0.406
Jamshed	0.223
Kaemari	0.434
Korangi	0.077
Landhi	0.117
Liaqatabad	0.147
Lyari	0.500
Malir	0.675
New Karachi	0.419
North Nazimabad	0.369
Orangi	0.414
Saddar	0.342
Site	0.348
Shah Faisal	0.441

Source: Authors' calculations based on primary data from Karachi

Table 15 shows the index that measures the households' behaviour or habits regarding the use of electricity in their daily lives. The index value ranges from 0 to 1, where 0 indicates households having irresponsible behaviour regarding energy utilisation and the index value of 1 indicates good habits of households.

The table shows that the households' behaviour regarding electricity use was moderate (indicated by the dark blue colour) in Malir, Lyari, and Gadab. Index values show that citizens' behaviour towards energy use could be improved by educating them. This could help the policy maker in achieving the aim of efficient energy use and conservation of energy resources.

Table 16: Satisfaction Index

Town	Mean
Baldia	0.523
Bin Qasim	0.440
Gadab	0.530
Gulberg	0.536
Gulshan-e-Iqbal	0.534
Jamshed	0.502
Kaemari	0.524
Korangi	0.538
Landhi	0.533
Liaqatabad	0.484
Lyari	0.423
Malir	0.477
New Karachi	0.500
North Nazimabad	0.512
Orangi	0.434
Saddar	0.518
Site	0.559
Shah Faisal	0.515

Source: Authors' calculations based on primary data from Karachi

Table 16 shows the satisfaction index that measures households' level of satisfaction with K-Electric services. The index was measured using indicators based on power outages asked in the questionnaire. The average value of the index for each town ranges from 0 (extremely unsatisfied) to 1 (totally satisfied). The darker shade in the table shows a relatively higher level of satisfaction compared to the lighter shade which represents lower levels of satisfaction. The index value for each town is around 0.5, which shows a moderate level of satisfaction across households.

5. CONCLUSION AND POLICY IMPLICATION

Over the past few years, the Government of Pakistan has initiated electricity tariff reforms that directly impact household welfare in the country. As a result of these reforms, the government has started curtailing the electricity subsidies, gradually increasing end-consumer electricity prices. However, changing the policy to raise the subsidised electricity tariff decreases the affordability for a consumer and impacts the overall welfare of a household, which is believed to increase energy poverty in Pakistan.

This study aimed to analyse the impact of a rise in electricity tariffs on the welfare of households. The foremost analysis of the study was divided into three broader objectives. The first objective attempted to find the crowding-out effect of increased electricity tariffs on households' budgetary allocation of resources at various income levels. In the second section, the study attempted to find the proportion of households dragged below the poverty line because of the rise in electricity prices. The study also measured the compensation required by the households to mitigate the income effect of rising electricity tariffs on household welfare. The first and second parts of the analysis were based on HIES datasets. However, because of limitations in using secondary datasets, the study also conducted a primary survey in Karachi as a case study for obtaining in-depth information on the energy situation.

The conditional demand function was estimated to achieve the study's first objective. Results of this section show statistically significant differences in expenditure allocations for most of the expenditure categories between low and high tariff periods. It was found that after an increase in tariff, low-income households, on average, allocated less budget for health, transport, communication, recreation, education, housing and fuel. A more or less similar pattern was observed for middle-income households. This shows that purchasing power of consumers has been depleted over the years. As far as the crowding-out effect of electricity expenditure is concerned, a heterogeneous effect for various income groups was revealed. An increase in the outlay of electricity leads to the fall in budget shares devoted to food, tobacco, recreation and restaurant for low-income households. The crowding-out effect of electricity expenditure on middle-income households was the most significant. This section shows how frequent tariff increases in the energy sector might burden limited household resources and impede prosperity.

Results reported in the second section showed that the proportion of the population below the energy poverty threshold in 2015-16 decreased in 2018-19, despite the increase in tariff. Around 38% of the population of Karachi city was below the international poverty threshold of $ 1.25 per day per adult. It was found that if the compensation (equivalent to the rise in electricity price) had been provided to the poor households, the poverty estimates would decline, and about 4.7 per cent of the poor population would be pulled above the international poverty threshold. These estimates, however, indicate the impact of electricity tariff increase in inflating income poverty in Karachi city, on the one hand, while describing the significance of compensatory mechanisms in reducing poverty, on the other.

To safeguard the poorest, it is recommended to estimate social impacts regularly before the scheduled price hike to provide targeted financial and social support programs. In this regard, existing programs like BISP or EHSAaS support programmes could be scaled up, or new ones could also be initiated for ensuring food security and other necessities of life, such as health care, clothing, education, etc. It has also been learned from the experience of other countries that successful implementation of reforms was accompanied by compensation packages for the poor and increased service quality and reliability for households paying higher prices.

As mentioned earlier, a primary survey titled "Karachi: The City of Lights" was also conducted for this study. This section provided a descriptive analysis of consumption, expenditures, and changes in the recent increase in electricity tariff on household welfare. The first important conclusion drawn from this section was that the government charges and other charges, such as the TVL fees, fuel adjustment charges, etc., constituted a significant proportion of total electricity bills. Secondly, the fuel adjustment charges for the lifeline slab were more than the total amount spent on units consumed, whereas government charges also constituted a significant proportion. Results revealed that households bore an extra burden in the form of these charges. The third important finding was related to the households having sanctioned load of 5 kWh or above. It was found that households consuming less than 300 kWh units, on average, were worse off under the ToU tariff structure. This finding shows that although electricity charges are still subsidised for low-consumption households, the proportion of additional costs should also be curtailed to diminish the adverse effects on the poor.

The empirical estimation from primary data substantiated the earlier section's findings that the tariff's impact had reduced household welfare. An increase in electricity tariff reduced households' expenditures on other commodity items, including food and beverages, clothing, transport, recreational activities, and communication.

This study considers that educating the general public about sustainable energy consumption habits is imperative. Considering this as an essential instrument, this study encompassed these crucial modules in the energy survey to understand households' cognitive and behavioural aspects of energy use. Including these aspects in policy design will enable individuals to make appropriate choices in energy use. Results show that the general public of Karachi was not informed about the current electricity sector reforms. Similarly, efficiency in end-use also needs to be improved. In this regard, literacy programs at high- school levels or through advertisements on social media could be initiated. In the past, public service messages for saving electricity were communicated through television advertisements. The same policy should be continued to make individuals energy literate. Energy-efficient appliances should also be promoted to improve electricity affordability, particularly among middle and high-income households. Without any government interference, households can respond to a rise in price either by switching towards more energy-efficient appliances or adopting habits of efficient electricity utilization. These kinds of efficiency programmes will bring sustainable changes in society. These measures are believed to provide a buffer against the adverse impact of price increases, particularly on middle- and higher-income households. The existing literature on Pakistan also points toward the importance of institutional and end-use efficiencies, including efficiency in production, distribution, and consumption.

Analysis of this study shows that the government is determined to gradually phase out electricity subsidies at a high pace. In this regard, it is recommended to publicise the upcoming rise in price among the general public as not all the individuals in the country are literate enough to anticipate the impact. However, unexpected rises in price aggravate anger among individuals and could obstruct these reform processes' smooth implementation and completion.

REFERENCES

Atamanov, A., Jellema, J., & Serajuddin, U. (2015). *Energy subsidies reform in Jordan*. Retrieved from https://elibrary.worldbank.org/doi/abs/10.1596/1813-9450-7313

Banks, J., Blundell, R., & Lewbel, A. (1997). Quadratic engel curves and consumer demand. *Review of Economics and Statistics*, *79*(4), 527-539.

Clements, B., Coady, D., Fabrizio, S., Gupta, S., & Shang, B. (2014). Energy subsidies: How large are they and how can they be reformed? *Economics of Energy & Environmental Policy*, *3*(1), 1-18.

Conti, J., Holtberg, P., Diefenderfer, J., LaRose, A., Turnure, J. T., & Westfall, L. (2016). *International energy outlook 2016 with projections to 2040*. Washington, D.C.: Energy Information Administration (EIA).

Del Granado, F. J. A., Coady, D., & Gillingham, R. (2012). The unequal benefits of fuel subsidies: A review of evidence for developing countries. *World Development*, *40*(11), 2234-2248.

Do, Y. K., & Bautista, M. A. (2015). Tobacco use and household expenditures on food, education, and healthcare in low-and middle-income countries: a multilevel analysis. *BMC Public Health*, *15*(1), 1-11.

Freund, C. L., & Wallich, C. (1995). *Raising household energy prices in Poland: who gains? who loses?*. Washington, D.C.: World Bank.

Government of Pakistan. (2016). *National poverty report 2015-16*. Islamabad: Ministry of Planning, Development & Special Initiatives.

Hagenaars, A. J. M., de Vos, K., Zaidi, M. A. and Statistical Office of the European Communities. (1994) *Poverty statistics in the late 1980s: research based on micro data, Eurostat*. Luxembourg: Office for Official Publications of the European Communities.

Husain, M. J., Datta, B. K., Virk-Baker, M. K., Parascandola, M., & Khondker, B. H. (2018). The crowding-out effect of tobacco expenditure on household spending patterns in Bangladesh. *PloS one*, *13*(10), e0205120.

Ikhsan, M., & Purbasari, D. (2012, July). *Determination of electricity tariffs in Indonesia: Integrating efficiency and poverty reduction goals*. Paper presented at The Plenary Session of the Indonesian Economist Association.

John, R. M. (2008). Crowding out effect of tobacco expenditure and its implications on household resource allocation in India. *Social science & medicine*, *66*(6), 1356-1367.

John, R. M. (2012). Crowding-out effect of tobacco expenditure and its implications on intra-household resource allocation in India. *Social Science Medicine, 66*(6), 1356-1367.

Joskow, P. L. (2008). Incentive regulation and its application to electricity networks. *Review of Network Economics*, *7*(4).

Lampietti, J. A. (Ed.). (2004). *Power's promise: Electricity reforms in Eastern Europe and Central Asia* (Vol. 1). Washington, D.C.:World Bank.

Makmun., & Abdurrahman. (2003). Dampak Kenaikan Tarif Dasar Listrik Terhadap Konsumsi Listrik dan Pendapatan Masyarakat (Impact of Electricity Tariff Increase on Electricity Consumption and Community Income). *Jurnal Keuangan Dan Moneter, 6*(2), 63-83

Moshiri, S. (2015). The effects of the energy price reform on households' consumption in Iran. *Energy Policy*, *79*, 177-188.

Moss, T., Bazilian, M., Blimpo, M., Culver, L., Kincer, J., Mahadavan, M. & Webber, M. (2020). *The Modern energy minimum: The case for a new global electricity consumption threshold*. Retrieved from https://www.rockefellerfoundation.org/wp-content/uploads/2020/12/Modern-Energy-Minimum-Sept30.pdf

Nguyen, N. M., & Nguyen, A. (2020). Crowding-out effect of tobacco expenditure in Vietnam. *Tobacco Control*, *29*(Suppl 5), s326-s330.

Pollak, R. A. (1969). Conditional demand functions and consumption theory. *The Quarterly Journal of Economics*, *83*(1), 60-78.

Walker, T., Sahin, S., Saqib, M., & Mayer, K. (2014). Reforming electricity subsidies in Pakistan: measures to protect the poor. Washington, D.C.:World Bank.

World Bank. (2017). *Residential electricity subsidies in Pakistan: Targeting, welfare impacts, and options for reform*. Washington, D.C.:World Bank.

Zhang, F. (2019). *In the dark: how much do power sector distortions cost south Asia?* Washington, D.C.:World Bank.

PART II

ENERGY ISSUES

Policy Briefs

A TECHNO-ECONOMIC ANALYSIS OF WIDESPREAD MICROGRID/MINIGRID (MG) DEPLOYMENT IN PAKISTAN'S ELECTRICAL POWER SECTOR

Danial Saleem and Salis Usman

INTRODUCTION

In the recent past, the Government of Pakistan has undertaken certain appreciable initiatives in the electrical power sector, which is undergoing extensive reform and restructuring process, particularly in the areas of de-carbonisation and deregulation. Although Pakistan is blessed with abundant natural energy resources, a significant percentage of the population remains without electricity access since the expansion of the centralised grid is uneconomical due to certain reasons including but not limited to limited financial resources and scattered populations. In this regard, micro/mini-grid (MG) deployment offers an excellent opportunity to address this problem, improve the life quality of the people of Pakistan, and help the economy.

According to this study's findings, in comparison to fossil-fuel-based MGs, the renewable energy dominated MGs offer a lucrative investment opportunity/financial viability and also contribute to reducing adverse effects on the environment. Even though MGs present a cost-effective solution for the remote unelectrified areas of Pakistan, they may suffer technical issues if not properly designed. Direct current MGs and the application of MGs for irrigation purposes present interesting cases with respect to reducing the overall cost of energy. Some of the important factors to be considered to evaluate the feasibility of MGs are the electricity demand pattern, supply reliability requirement, discount rate, project lifetime, etc.

There is an urgent need for a comprehensive policy and regulatory framework since the existing one is insufficient to effectively upscale MG deployment in Pakistan. While assessing electricity provision options for remote unelectrified areas of Pakistan, the electricity planners must consider and evaluate MGs before proposing huge investments for transmission and distribution infrastructure. One of the important considerations is to align the design of MGs with the affordability of the customers in each specific geographical area, to create a win-win situation for all the stakeholders.

METHODOLOGY

The study is predominately based on simulation and analysis-based research methods. The answers to the research questions were found through a mathematical model that represents the structure and dynamics of technical and economic processes of MG deployment. Based on qualitative analysis and literature review, three possible scenarios were developed and modelled using the HOMER-Pro hybrid optimisation tool. Furthermore, techno-economic analysis was performed keeping in view technical and commercial aspects and also MGs' impacts on Pakistan's power grid and prospective customers of MGs.

Textual and content analysis of existing policy and regulatory framework precisely ARE Policy 2019, National Electricity Policy 2021, and NEPRA Microgrid Regulations 2021 (draft) was carried out. The relevant case studies, policy instruments, and regulatory documents were analysed to find coherence in their objectives, identify gaps, and point out missing links while comparing them with international best practices.

Moreover, the existing business models currently being implemented for setting up and operating MGs in Pakistan were also considered for analysis.

Interviews were conducted with concerned personnel from Pakhtunkhwa Electricity Development Organization (PEDO) and Punjab Power Development Board (PPDB), the executing agencies for MGs in the provinces of KPK and Punjab, and with the authors of the draft MG regulations from NEPRA. Based on results from the techno-economic analyses of three scenarios and interactions with the public-sector executing agencies and the regulator, certain business models were also proposed in this study.

FINDINGS

- A comparison of different applicable MG scenarios is tabulated below:

Table 1: A Comparison of Scenarios: Summary

Parameter	Scenario1	Scenario2	Scenario3
LCOE ($/kWh)	0.111	0.0981	0.0929
Net PresentCost ($)	64,120	78,068	118,903
CAPEX ($)	27,836	34,213	16,048
OPEX ($)	1,587	1,918	4,499
Fuel Consumption Savings (Litre/year)	15,216	16,151	0
CO2 Emissions Savings as comparedto DieselGenerator (kg/Year)	39,831	42,276	15,479
IRR (%)	79.5	66.1	20
PaybackPeriod (Year)	1.34	1.57	5.22

*Notes: *Scenario 1: Off-grid MG application for rural villages/areas having solar PV and wind potential.*
**Scenario 2: Off-grid MGs application for rural villages/areas having solar PV and micro-hydro potential.*
**Scenario 3: Grid-connected MGs application for Housing Societies or Commercial Centers in Urban Areas having utility electricity access.*

- As shown in Table 1, MG deployment is financially very viable and presents a lucrative investment opportunity. The upscaling of MGs, therefore, needs to be acknowledged as a business opportunity by the private sector.

- Fuel-based MG results in CO2 emissions which are detrimental to the environment. Renewable energy (RE) based MGs save significant emissions and are, thus, environment-friendly.

- RE-dominated MGs present much more financial feasibility as compared to fossil-fuel-based MGs.

- Due to the increasing trend of electricity prices, the MG deployment has become a cost-effective solution as compared to the conventional integrated grid for particular scenarios/ applications.

- Although MG is a better option than the conventional integrated grid for the above specific scenarios/applications, it is not an optimal solution under all situations. The feasibility will change significantly depending on various factors like no or lesser renewable energy (RE) potential, consumer requirement of 0% allowed capacity shortage, change in cost trends of REs vs fossil fuels, etc.

- Technical issues associated with the operations of MGs are stability, safety, protective relaying, harmonics, voltage unbalance, etc. Although MGs present a cost-effective solution for remote unelectrified areas of Pakistan, they may face technical issues if not properly designed. The Owners of MG must be cognisant of these issues.

- Existing policy and regulatory framework are insufficient to effectively upscale MGs' deployment in Pakistan.

- DC MGs have become a reality in many countries in recent years. DC MG shows a promising 12% decrease in the cost of energy as compared to similar AC MG, i.e., from 0.111 $/kWh to 0.098 $/kWh.

- The application of MGs for irrigation purposes presents an interesting case. Hybrid MGs having an irrigation application have more economic viability as compared to similar normal rural MGs since these show a promising 18 % decrease in the cost of energy, i.e., from 0.119 $/kWh to 0.0976 $/kWh.

- Allowed capacity shortage is an important factor to be considered for MG development since the cost of energy decreases exponentially with the increase in the allowed percentage capacity shortage.

- Discount rate and project lifetime are important factors to be considered to evaluate the feasibility of MGs. The cost of energy (CoE) increases linearly with the discount rate and decreases exponentially with the project's lifetime.

- Allowed percentage capacity shortage significantly affects the energy mix decisions.

With the consumer requirement of percentage allowed capacity shortage from 0% up to 0.4%, the inclusion of conventional generators in the optimal energy mix is essential, and cannot be achieved exclusively with renewables and storage systems.

- The demand profile significantly affects the CoE of the MG system. In case the demand profile is changed from 24 hours to 12 hours (day-only load), it shows a promising 40% decrease in CoE, from 0.111 $/kWh to 0.0677 $/kWh.

POLICY RECOMMENDATIONS

- For the upscaling of MG development in Pakistan, a comprehensive policy is surely required to address the long-term uncertainty of market development, financial support schemes, and risks associated with the presence of the centralized grid. Furthermore, a regulatory framework is required to address various regulatory requirements, sustainable operation, and cost-recovery mechanisms.

- DC MGs should be included in the regulations for microgrids, to be launched by NEPRA. Similarly, MGs should also be allowed to operate in grid-connected mode. For this purpose, the draft regulatory framework may be customised. Moreover, a mechanism for dealing with the technical issues such as stability, safety, protective relaying, harmonics, voltage unbalance, etc., associated with MGs should be addressed in the final regulations for microgrids.

- Coordinated efforts by the stakeholder entities are required to be channelised for utilising the applicability of MGs for irrigation purposes in remote rural areas.

- While assessing electricity provision for remote unelectrified areas of Pakistan, the system planner must consider and evaluate the MG deployment before proposing huge investments for transmission and distribution infrastructure.

- Based on the study's findings, MGs are an optimal solution when they have a major share of renewable energy resources. Therefore, renewables-based MGs should be promoted in the upcoming policy and regulations. Furthermore, CO_2 emissions should be compensated through a carbon-credit mechanism for fossil fuel-based MGs, to be provided in the upcoming regulatory framework.

- Given an inverse relationship between CoE and the allowed capacity shortage, the design of MGs should be aligned with the affordability of the customers in a specific geographical area to create a win-win situation for all the stakeholders.

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

Naveed Arshad

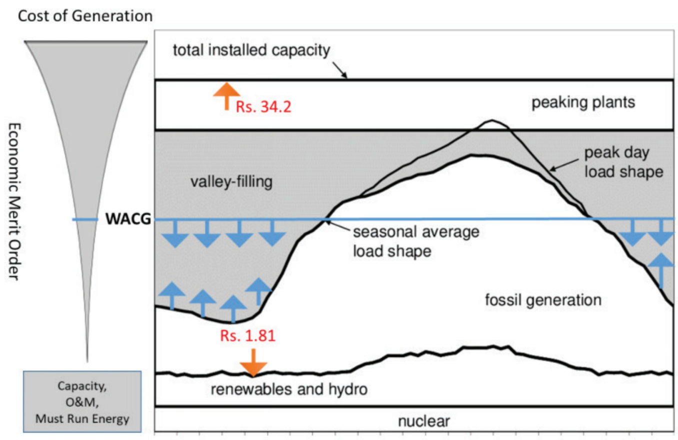
INTRODUCTION

Pakistan has been accumulating substantial circular debt in various sectors. This includes 2300 billion of circular debt in the power sector, 1,300 billion of circular debt in the petroleum sector, and 320 billion of circular debt in the RLNG sector. This colossal cumulative circular debt is paralysing the economic prosperity of the country. Since the power sector depends on petroleum and the RLNG sector for its fuel requirements, it indirectly impacts the circular debt in these two sectors.

One of the significant reasons for circular debt in the power sector is the surplus generation capacity. This surplus generation capacity results in capacity payments that are due whether the electricity is generated or not. Moreover, Pakistan has significant daily and seasonal variations in demand, accounting for a vast surplus capacity during off-peak times. For example, the country's peak load touches 24,500 MW in summers only for a few hours but comes down to less than 8,000 MW in winters. The average load in 2020 was around 17,000 MW against an installed capacity of 36,000 MW. Due to this significant variation in peak loads and the addition of many new generation plants, the annual weighted average cost of generation (WACG) has increased drastically over the last few years. For example, in 2015, the WACG was Rs 7.2, which climbed to Rs 12.3 in 2020. It is important to note that the WACG is generation cost only and does not include transmission, distribution, cross-subsidy, taxes, and other surcharges that a consumer pays.

Figure 1 shows electricity load variation across time. Electricity cannot be stored on a large scale; it has to be consumed the moment it is produced. Therefore, many power plants together fulfil the load requirements. Must-run plants such as nuclear, wind, solar and run-of-river hydro are the first ones to meet the load requirements. If the load increases, fossil fuel-based plants or reservoir-based hydel generation with low marginal cost and high dispatchability are operated next. As the load increases, more plants add to the mix based on their economic merit order, which is also a factor in marginal cost. In Figure 1, the first fossil-fuel-based plant can produce a unit of electricity at Rs 1.81 per kWh, while the last available plant costs almost Rs 34.2 per kWh. The average of all plants' operational costs determines the WACG.. One of the important considerations is to align the design of MGs with the affordability of the customers in each specific geographical area, to create a win-win situation for all the stakeholders.

Figure 1: A Typical Day Load Profile and Cost of Generation based on Economic Merit Order



To reduce the WACG, electric utilities strive to reduce their peak loads as much as possible because not only does it results in higher generation costs but it also creates a situation where unutilised capacity adds a further financial burden. In Figure 1, the more the grey area the more the WACG. For easier understanding, we call the load hours above the WACG line peak hours and those below the WACG line off-peak hours. Any new load that is added to off-peak hours reduces the WACG. Similarly, any new load in the peak hours increases the WACG.

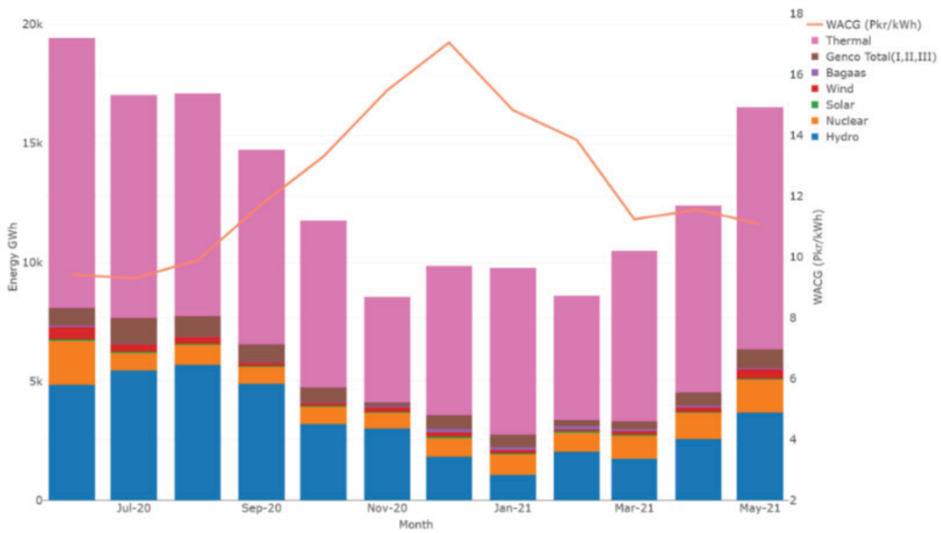
In Pakistan, we follow a 'take-or-pay' regime in our generation sector. In this regime, a fixed capacity payment is due whether the electricity is generated or not. Due to the energising of many new generation plants, the capacity payment component in generation cost has increased from Rs. 2.7 in 2015 to Rs. 6.3 in 2020. Therefore, for Pakistan's electricity sector to become sustainable, we need to shape our energy load as flat as possible.

In this policy brief, we present a technical and financial analysis of the impact of shifting loads from peak hours to off-peak hours. In our analysis, we gathered authentic data from various sources like NEPRA[1], CPPA[2], NTDC[3], NPCC[4], PITC[5], and other relevant stakeholders. We developed a software tool that automatically performed the financial calculations based on the generation plants and their marginal costs. We have shared our findings with the Ministry of Energy (Power Division) and the Board of Directors of CPPA.

KEY FINDINGS

- The WACG in the power sector is highly dependent on the season and nature of the fuel used in the generation plants. For example, while we have a high load in summer, the WACG is low because of cheaper hydro and other renewable resources. However, in winter the WACG is much high because of dependency on imported fuel base sources of generation. For instance, in July 2020 the WACG was Rs 8.86, while in January 2021 the WACG was 14.46. Figure 2 shows the variation in WACG across the year 2020-21.

Figure 2: Monthly Energy Consumption and variation in respective monthly WACG



- By shifting only 5% of the load from peak to off-peak hours the country can save around Rs 6.5 billion with 2020-21 fuel costs. Of course, the savings will amplify with the high fuel prices. Not only do we have these direct savings, but we may also be able to retire many expensive generation plants that may not be needed due to a reduction in peak load. Moreover, all these savings will also save foreign exchange. Finally, as these plants are also the most polluting, we will reduce the overall emissions from the power sector.
- The water reservoirs of Tarbela, Mangla, and others are a source of cheaper energy and provide many other critical benefits. These reservoirs provide stability in the electric grid because of their extremely fast ramping time. With more solar and wind resources, their role will amplify as they require backup power sources due to their variability and intermittency.
- Until now, our power sector has been using fixed tariffs with some time-of-use (ToU) tariffs based

[1] National Electric Power Regulatory Authority
[2] Central Power Purchasing Agency
[3] National Transmission and Despatch Company
[4] National Power Control Centre
[5] Power Information Technology Company

on fixed peak and off-peak hours. However, the electricity load patterns are changing due to distributed generation, electric vehicles, and other disruptive technologies. Therefore, it is critical to reassess the tariff design and create a win-win situation for the power sector and consumers.

- The tariff and other financial calculations of the power sector in Pakistan are based on monthly figures. However, we can do fine-tuned financial calculations based on hourly information availability. This provides much better optimisation and will improve the bottom line of the power sector. Pakistan is opening its electricity market in 2022. With high granularity of information, the market will open many more opportunities for prospective investors and consumers.

RECOMMENDATIONS

Based on the findings of this study, literature review, the collected data, and analyses, we have come up with the following recommendations put forward to improve the financial bottom line of the power sector:

- **Smart Metering**

To regulate peak load and for many similar interventions, smart metres must be placed for demand side management and to monitor the load at any given time interval. Smart meters keep a real-time record of electricity consumption and communicate the electricity usage information to the distribution company. PITC already has developed a smart metering platform that any DISCO can use. Although the cost of smart meter is a bit high ($100-300) but for bulk and large consumers this may not be a challenge. For smaller consumers the load flexibility may determine if the DISCO should invest in installing smart meter. For flexible loads like water pumping, tubewells and some commercial and industrial loads the resulting benefits will outweight the cost of smart meters.

During peak periods like summers, higher tariffs may be offered to the consumers to recuce their demand in lieu of lower tariff in off-peak hours. These price signals will minimize electricity generation costs by lowering the peak demand at selected time intervals. Around fifty thousand smart meters are installed at MEPCO and PESCO. These smart meters may be used for any pilot project.

- **Incentivized Tariff**

Once the smart meters are installed, several tariff-based interventions are possible. For example, in 2021, the Government of Pakistan offered winter electricity package with lower tariffs to improve the load factor through utilizing idle generation capacity. However, we believe that this may not be the most optimal strategy as if the load adds to the peak load then WACG will increase due to higher imported fuel-based generation. Instead, tariffs based on peak and off-peak hours may provide much better financial savings for both the power sector and the consumers. As peak and off-peak hours change almost monthly, one needs a careful analysis of when to offer an incentive. Using our tariff modeling tool one may perform as many scenarios as possible to evaluate the impact of a given load pattern.

- **New Flexible Loads**

After incorporating major industrial and bulk consumers, a range of newly identified flexible loads can be further added to the new tariff schemes. This effort will include the addition of flexible municipal loads such as tube wells, water pumps, etc. Through the usage of smart meters, flexible loads will get dynamic tariff rates via communication protocols of smart meters. The introduction of such tariffs will help both municipalities and DISCOs by lowering their peak demand and increasing their load factor.

HOUSEHOLD ENERGY POVERTY IN PAKISTAN

Fouzia Sohail and Ambreen Fatima

INTRODUCTION

The Government of Pakistan has initiated significant energy sector reforms, including electricity tariff reform, that directly impact the household welfare of the country. As a result of these reforms, the government has started curtailing the electricity subsidies, gradually increasing end-consumer electricity prices. However, changing the policy to raise the subsidised electricity tariff is not easy as tariff reforms have a profound economic and social impact, especially on poor households.

This policy brief, which is based on a study titled “Household Energy Poverty in Pakistan,” discusses the impact of subsidised tariff changes of electricity on the welfare of households. The study attempted to find the crowding-out effect of increased electricity tariffs on the household budgetary allocation of resources at various income levels. It also aimed to measure the compensation required by households to mitigate the income effect of rising electricity tariffs on households' welfare. Because of the limitations of the existing secondary datasets, the study conducted a primary survey of Karachi city as a case study to obtain in-depth information on the energy situation.

METHODOLOGY

Crowding out Effect of Electricity Expenditure and Its Implications on Household Resource Allocation in Pakistan

The first specific objective of the study was to estimate the crowding-out effect of increased electricity expenditure and its impact on intra-household resource allocation through the estimation of the conditional demand function. More specifically, the study endeavoured to analyse the difference in the affordability of electricity between the periods of low and high tariff rates. For achieving these objectives, the study used HIES 2013-14 and 2018-19, assuming that electricity tariffs were relatively lower in 2013-14 as compared to 2018-19.

For explaining the crowding-out effect of electricity expenditure and its impact on intra-household resource allocation, the conditional demand function, as suggested by Pollak (1969), was estimated. The crowding out effect of electricity expenditure entails reduced consumption of goods and services because of the increasing cost of electricity consumption.

Electricity Tariff Reforms and Household Welfare Analysis for Karachi City

The second objective was achieved by following a sequence of steps that begin by understanding the slab and tariff structure applied to residential electricity consumption and eventually lead to the welfare impact. As a first step, electricity units consumed by each household were estimated, which were based on the electricity expenditures of households. To estimate the compensation for the additional income that a household spent on electricity consumption, current and previous tariff structures were used. Assuming the household consumption patterns remain consistent, the compensation was measured for individual households according to the slab they ended up consuming in. Once the compensation was estimated, poverty headcount before and after compensation was measured using both national and international thresholds. Finally, the welfare effect of rising electricity tariffs was reflected by the difference in the two head counts. It mentions those who move below the poverty line because of increased electricity prices.

Karachi: A City of Light

There are certain limitations in the use of HIES data. Hence, considering these limitations, the study conducted a primary survey of Karachi – the "City of Lights" – as a case study for obtaining in-depth information on the energy situation. This study, thus, aims to form a rigorous analytical basis for energy policy-making in Pakistan.

KEY FINDINGS

Crowding out Effect of Increased Electricity Tariff and its Implications on Household Resource Allocation

The results reveal statistically significant differences in expenditure allocations for most of the expenditure categories. For instance, after the increase in tariff, low-income households, on average allocated less on health, transport, communication, recreation, education, housing, and fuel. A more or less similar pattern was observed for middle-income households. High-income households also altered their budgets except for transport and restaurants. These results show a nontrivial difference in the composition of budgetary expenditures of households during the low tariff period compared to the high tariff period. On the one hand, the indirect effects of increased electricity prices compelled poor households to cut their spending on commodities other than necessities. On the other hand, it raised the cost of different food and non-food items, which increased the expenditure of poor households on essentials.

Results show that for low-income households, a Rs. 1,000 increase in electricity expenditure was accompanied by a 1.24 percentage point decrease in food expenditure. For the middle-income group, electricity expenditure crowded out most of the expenditure categories but by a relatively lower percentage. For the high-income class, a Rs. 1000 increase in electricity expenditure led to 0.28 and 0.33 percentage points decrease in health and transport expenditures, respectively. Health expenditures were crowded out at all income levels. The most important point found is that the size of crowding in and crowding out effects was greater for poor households.

Findings reveal that the displacements due to electricity expenditure occurred for commodities that constitute human capital investments, like food and nutrition, health, etc., having severe implications for households' well-being. The crowding out of food and beverage consumption might have implications for children's physical and intellectual growth and nutritional deficiency in mothers, notably, in lower-income households. Electricity tariff reforms, with the nonexistence of adequate health compensation, insurance or other public provision of finances, could lead to welfare loss, particularly among poor households. Hence, inadequate measures by the Government could adversely affect human capital investments crucial for long-term prosperity.

Electricity Tariff Reforms and Household Welfare Analysis for Karachi City

Given the energy threshold and electricity units' estimates, energy poverty for 2015-16 and 2018-19 was calculated. Interestingly, the results show that the population below the energy poverty threshold in 2015-16 was 29.3 per cent, while it decreased to 23.5 per cent in 2018-19, despite the increase in tariff.

Table 1 shows the estimated proportion of the poorest households living below the poverty line by employing standard thresholds and equivalency scales.

Table 1: Percentage of income Poor Population in Karachi

	National Equivalency Scale	OECD Equivalency Scale
	HC international Poverty Line $ 1.25= Rs 170.11	
Uncompensated HH Income	37.74	3.82
Compensated HH Income	33.08	3.20
Change in Poverty	4.67	0.63
	HC national Poverty Line Rs 125.87	
Uncompensated HH Income	14.52	1.14
Compensated HH Income	12.49	0.92
Change in Poverty	2.03	0.22

Source: Authors' estimations using HIES 2018-19

We estimate that if the compensation had been provided to the poor households, all the poverty estimates reported in the third and seventh row of Table 1 would have declined. Considering only the national equalisation scale, about 4.7 per cent of the poor population would be pulled above the international poverty threshold. In contrast, around 2 per cent of the poor population would be able to escape poverty if we consider the national CBN poverty threshold. These estimates, however, indicate the impact of electricity tariff increase in inflating income poverty in Karachi city, on the one hand, while describing the significance of compensatory mechanisms in reducing poverty, on the other. It is, thus, concluded that whatever threshold is being used as a policy tool, the impact of electricity reforms could be mitigated only through a more comprehensive and long-lasting compensatory mechanism.

Findings of Survey, "Karachi: The City of Light"

The findings of the survey are as follows:

- Most of the households consumed in the middle slabs, i.e. 32 per cent in the 5th slab (301-700), 26 per cent of households in the 4th slab (201-300), and 19 per cent in the third slab.
- The lifeline tariff slab is nearly ineffective in Pakistan as a meagre 2.57 per cent of households consumed in the lifeline slab.
- The highest proportion of the households of Karachi, i.e. 32 per cent, on average, consumed only 425 units of electricity per month. This is followed by an average consumption of 256 units by 26% of households.
- On average, households that consumed more than 700 kWh per month paid about three times more than the households that ended up consuming just below 700 kWh.
- Another significant feature is that the government and other charges like TVL fees, fuel adjustment charges, etc., constituted a significant proportion of total bills.
- The most significant finding is that the fuel adjustment charges for the lifeline slab weres more than the total amount spent on units consumed, whereas government charges also constituted a significant proportion. This information reveals that, on one hand, the lifeline slab is believed to be the most protected and subsidised but, on the other hand, various additional charges significantly increase the total electricity bill.
- Results reveal that households consuming less than 300 kWh units, on average, were worse off due to the ToU tariff structure. Such households were bound to pay more than two times the previous amount.
- Empirical estimation shows the negative and statistically significant impact of electricity tariffs on households' food expenditures. It was found that one rupee increase in electricity tariff, on average, led to a decrease in households' monthly food expenditures by 0.5%.
- The energy literacy index estimates show that residents of not a single town in Karachi were literate enough about tariff structure, tariff rates, and other aspects of electricity.
- Index values show that citizens' behaviour towards energy use could be improved by educating them.
- In contrast, the satisfaction index value found for each town was around 0.5 which shows a moderate level of satisfaction towards K-Electric services.

POLICY IMPLICATIONS

Based on the findings of the study, various policy options could be considered. For instance, to safeguard the poorest, it is recommended to estimate socio-economic impacts regularly before the scheduled price hike so that targeted financial and social support programmes could be designed. In this regard, existing programmes such as BISP or EHSAS support programmes could be scaled up, or new ones could also be initiated for ensuring food security and other necessities of life, such as healthcare, clothing, education, etc. It has also been learned from the experience of other countries that successful implementation of reforms is accompanied by compensation packages for the poor and increased service quality and reliability for households paying higher prices.

Based on the findings of the primary survey " Karachi: The City of Light," it is recommended that although electricity charges are still subsidised for low-consumption households, the proportion of additional costs should also be curtailed to diminish the adverse effects on the poor.

The empirical estimation from primary data substantiated the earlier section's findings that the tariff's impact has reduced household welfare. An increase in electricity tariff reduces the households' expenditures on other commodities, including food and beverages, clothing, transport, recreational activities, and communication.

This study suggests that educating the general public about sustainable energy consumption habits is imperative. Considering this as an essential instrument, this study included these crucial modules in the energy survey to understand households' cognitive and behavioural aspects of energy use. Including these aspects in policy design will enable individuals to make appropriate choices in energy use. Results show that the general public of Karachi was not informed about the current electricity sector reforms. Similarly, efficiency in end-use also needs to be improved. In this regard, literacy programs at high-school levels or through advertisements on social media could be initiated. In the past, public service messages for saving electricity were communicated through television advertisements. The same policy should be continued to make individuals energy literate. Energy-efficient appliances should also be promoted to improve electricity affordability, particularly among middle- and high-income households. Without any government interference, households can respond to a rise in price either by switching towards more energy-efficient appliances or adopting habits of efficient electricity utilisation. These kinds of efficiency programs would bring sustainable change in society. These measures are believed to provide a buffer against the adverse impact of price increases, particularly on middle- and higher-income households.

Analysis of this study shows that the government is determined to gradually phase out electricity subsidies at a high pace. In this regard, it is recommended to publicise the upcoming rise in price among the general public as not all the individuals in the country are literate enough to anticipate the impact. However, unexpected rises in price aggravate anger among individuals and could obstruct these reform processes' smooth implementation and completion.

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