Strategic Energy Reallocation: A Policy Driven Tariff Structure for Managing Domestic Electricity Demand in Pakistan

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THESIS ACCEPTANCE CERTIFICATE

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CERTIFICATE OF APPROVAL

This is to certify that the research work presented in this thesis, entitled "Strategic Energy Reallocation: A Policy Driven Tariff Structure for Managing Domestic Electricity Demand in Pakistan" was conducted by Mr Haseeb Ahmad under the supervision of Dr. Kashif Imran. No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Department of Electrical Power Engineering in partial fulfillment of the requirements for the degree of Master of Science in the Field of Electrical Engineering (Power) Department of Electrical Power Engineering, US Pakistan Center for Advanced Studies in Energy (USPCAS-E), National University of Sciences and Technology, Islamabad.

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AUTHOR'S DECLARATION

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DEDICATION

Achieving success necessitates a mixture of enthusiasm, dedication, hard work, and being in the right place at the right time. I want to dedicate this work to my family, especially my mother, who taught me how to read and write. None of this would have been possible without their encouragement and belief in me.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AER	Australian Energy Regulator
AMI	Advanced Metering Infrastructure
CPP	Critical Peak Pricing
CPUC	California Public Utilities Commission
DECC	Department of Energy & Climate Change
DERC	Delhi Electricity Regulatory Commission
DISCOs	Distribution Companies
DSM	Demand-side Management
EIA	Energy Information Administration
ESKOM	Electricity Supply Commission
EV	Electric Vehicle
FY	Fiscal Year
GDP	Gross Domestic Product
GWh	Gigawatt-hour
IEEJ	Institute of Energy Economics, Japan
IESCO	Islamabad Electric Supply Company
IGCEP	Indicative Generation Capacity Expansion Plan
kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
NEPRA	National Electric Power Regulatory Authority
NPMV	Non-Project Missed Volume
NSW	New South Wales
NTDC	National Transmission and Dispatch Company
O&M	Operation and Maintenance
PBS	Pakistan Bureau of Statistics
PG&E	Pacific Gas and Electric Company
PRECON	Pakistan Residential Electricity Consumption
PV	Photovoltaic
RESs	Renewable Energy Sources

RFO	Residual Fuel Oil
RLNG	Re-Gasified Liquefied Natural Gas
ROE	Return On Equity
RTP	Real-Time Pricing
SEC	SAARC Energy Centre
SMAP	Smart Meter Analytics Platform
SVCE	Silicon Valley Clean Energy
TOU	Time-of-Use
UPS	Uninterrupted Power Supply
US DOE	US Department of Energy
VIC	Victoria
VRE	Variable Renewable Energy

ABSTRACT

This paper presents a novel tariff structure designed to manage domestic electricity demand through demand-side management strategies, reallocating the resulting savings to the industrial sector to enhance productivity and stimulate economic growth in Pakistan. In the fiscal year 2022-23, domestic and industrial sectors consumed 43% and 24% of the total generated electricity, respectively, with industrial consumption playing a crucial role in GDP contribution. This research focuses on decreasing domestic energy consumption and reallocating the conserved electricity to the industrial sector, thereby boosting economic performance. Current tariffs do not account for income disparities and inadequately address price elasticity, leading to inefficient energy distribution. The proposed tariff structure aims to optimize electricity consumption among users while fulfilling the essential needs of domestic consumers.

Utilizing datasets from local billing, the PRECON dataset, regulatory notifications from NEPRA, and a newly compiled representative dataset, the study bases its tariff recommendations on consumer income and demand elasticity. The study emphasises the need to allocate energy resources to the industrial sector for economic growth, as well as the industry's substantial contribution to Pakistan's GDP.

The proposed tariff structure endeavours to curtail consumer demand while upholding a minimum critical consumption threshold derived from PRECON data analysis. Linear regression analysis indicates a potential 3.15% reduction (1,000.89 GWh) in national electricity demand, with a 1.25% decrease observed in the representative dataset of 4,765 consumers. A potential increase in consumption was observed in the 101-200 slab due to shifts in consumer behavioural trends supported by historical data analysis. The findings suggest that the proposed tariff can reduce residential electricity demand in Pakistan by 1-3%, facilitating greater electricity availability for industries and promoting economic growth and industrial productivity.

Keywords: Tariff structure, electricity economics, regulatory policy, price elasticity, demand-side management, domestic load reduction.

CHAPTER 1: INTRODUCTION

1.1 Background and Motivation

Pakistan is facing a severe economic crisis, including high inflation rates and declining foreign exchange reserves, while inadequate electricity infrastructure is hindering reliable electricity from being supplied throughout the country [1]. While the government has taken steps to address the issue of reliable energy supply through policy interventions, the reliance on conventional power generation methods, inefficiency in distribution and transmission systems, and lack of demand-side management strategies continue to impede progress. These issues, especially the inadequate electricity infrastructure, have affected the industry's productivity and growth. This unreliable energy supply causes severe losses, particularly in energy-dependent industries including textiles, which reported losses of approximately $70 million during a major blackout in 2023 [2]. One way to provide reliable electricity for industries is to upgrade the entire energy system, which requires significant investment to modernize generation, transmission, and distribution systems [3]. Existing attempts to resolve this issue include the expansion of power generation capacities and investment in renewable energy. However, these efforts have failed to address the underlying inefficiencies in tariff structures and load management. A critical gap in these attempts lies in the insufficient focus on demand-side solutions that could optimize load distribution without needing massive infrastructure investments.

A second way to tackle this problem is to prioritize energy provision to the industrial sector while reducing electricity supply to domestic consumers. This strategy would direct scarce resources to industries critical to economic growth but may have social implications, as residential consumers already face high tariffs and outages. The industrial sector employs millions of people and significantly contributes to the GDP [4]. Figure 1.1 is obtained from [5], [6],[7], [8], [9], [10], [11], [12], [13], [14], and [15], which presents the percentage growth in GDP and the industrial sector, as well as the percentage share of the industrial sector in GDP for the fiscal years 2013 to 2024. Figure 1.1 illustrates the correlation between industrial progression and GDP growth in Pakistan. The industrial sector's percentage share of GDP fluctuates between 18.22% and 21.02%. Despite minor dips, the industrial sector maintains a significant and relatively stable role in Pakistan's economic output, contributing around 20% on average to the GDP. However, many industries have been forced to operate at reduced capacity or shut down entirely due to frequent power outages and an unstable electrical supply, leading to financial losses and increased unemployment [16].

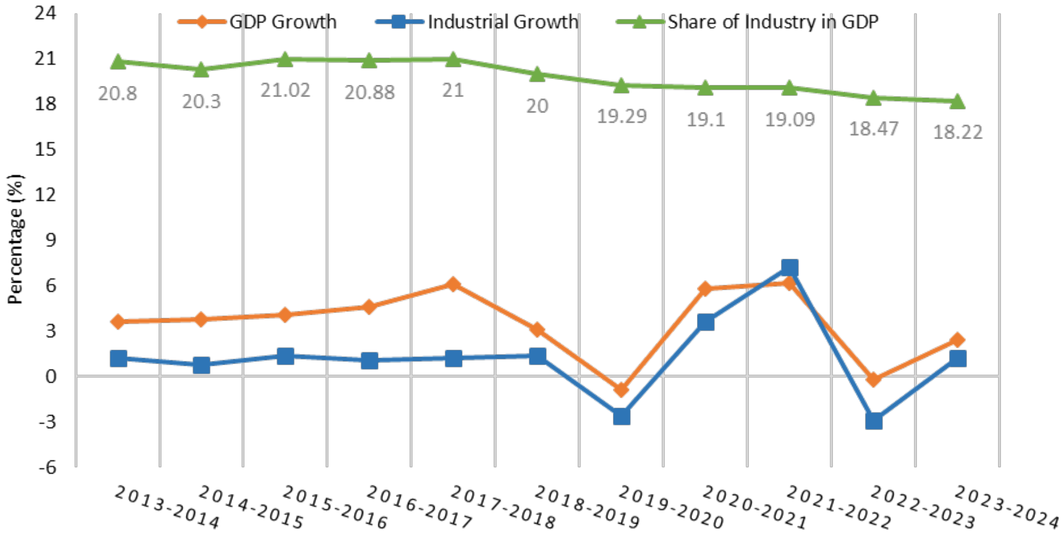


Figure 1.1: GDP and industrial growth, and share of industry in GDP from 2013 to 2024

Pakistan's sales mix predominantly focuses on domestic consumption, and a comparison of FY 2019 to FY 2024 reveals no substantial change over the years. As per the NEPRA State of Industry Report 2023 [17], Industrial Consumption accounted for 24.57% of the entire sales in 2018-19 and 24.21% in 2022-23. As per the same report, the proportion of domestic consumption is the largest in 2018-19, standing at 46.12% and 43.42% in 2022-23. With the country's reliance on 60% imported fuel, supplying electricity to non-productive domestic loads is a critical issue that needs attention. By shifting energy use from the domestic to the industrial sector, Pakistan could improve its trade balance and accelerate economic growth [18]. Figure 1.2 compares electricity consumption in the industrial and domestic sectors across different countries and it is obtained from [19], [20], [21], [22], [23], and [24]. It highlights that the industrial sector consistently consumes more electricity than the domestic sector in these countries. In contrast, the domestic load is the primary electricity consumer in Pakistan, underscoring a vital difference in energy usage patterns.

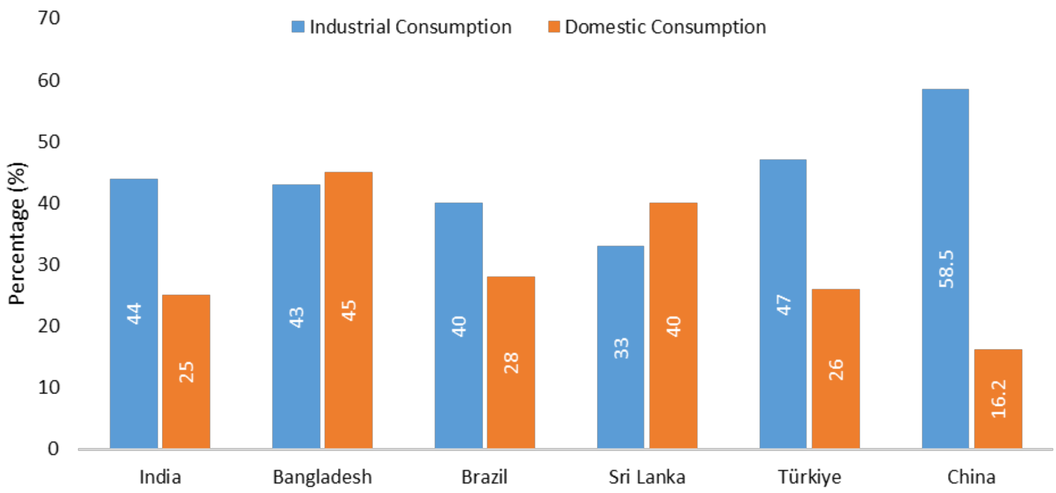


Figure 1.2: Percentage share of industrial and domestic sectors in total electricity consumption

Demand-side management (DSM) is a possible solution for shifting the load of domestic consumers from peak to off-peak hours [25], allowing for meeting the demand of the industrial sector. This study attempts to overcome the existing gaps by proposing a novel tariff structure to implement demand-side management (DSM) for Pakistan's domestic electricity consumption. This tariff formula aims to cut the demand curve and free up capacity for the industrial load by penalizing domestic consumers for excessive use during peak hours. Currently, the Time-of-Use tariff for domestic loads only applies to consumers having three-phase connections [17]. The originality of this study lies in its focus on integrating socioeconomic factors (income and price elasticity) into the tariff-setting process, which Pakistan's energy policy has overlooked. Therefore, considering household income and price elasticity, this study proposes a new tariff structure for all domestic consumers. In terms of contribution, this research provides a framework for implementing DSM more effectively by aligning tariff structures with consumer behaviour. It also highlights the potential for improving industrial productivity through strategic energy allocation, a critical area for economic development in Pakistan.

1.2 Problem Statement

The electricity pricing structure in Pakistan is based on a slab-wise framework. This indicates that within predetermined consumption levels, customers are billed at a set rate for each unit of electricity usage. Customers are billed at a different rate for excess use, for instance, if they use more energy than a certain threshold of kWh. Although this system is simple to set up and easy to use, it does not encourage users to use less energy or energy more wisely, particularly during peak hours when grid demand is at its highest and power generation costs are at their highest. Peak time is usually the evening and nighttime hours when household consumption spikes. This peak demand requires the use of more costly [26] and inefficient power plants, which raises the price of energy and worsens the overall environmental effect due to increased emissions [27]. As a result, Pakistan needs a tariff structure that promotes demand-side flexibility.

It would be necessary for customers to modify their energy consumption habits to better match the total demand on the grid in order to implement tariff structures that support demand-side flexibility. The implementation of Time-of-Use (TOU) tariffs is one such strategy. Higher prices during peak hours will encourage users to move their non-essential energy use to off-peak hours, when power is less expensive, under such a scheme. This unconventional tariff structure can assist in flattening the demand curve. By doing this, the need for expensive peaking power plants will be reduced [28], and it will increase the overall stability and dependability of the electrical grid [29]. They would also promote more sustainable and efficient energy consumption habits.

Pakistan's existing tariff system is straightforward and easy to set up, but it opposes demand-side management and energy efficiency. Suppliers can encourage customers to modify their patterns of energy usage by implementing tariff structures such as TOU tariffs. In addition to potentially saving money for individual customers, this change would also help in lessening the stress on the electrical system, cutting the cost of producing power, and minimising the negative effects on the environment.

1.3 Proposed Methodology

The proposed solution for reducing demand during peak hours is implementing a Time-of-Use (TOU) tariff structure for the domestic electricity consumers of Pakistan. This research work will propose a formula to calculate the tariff during peak hours.

First, information on electrical consumption across different customer tiers will be gathered. This information will be obtained from the National Electric Power Regulatory Authority (NEPRA). The next step will be to publish an online poll to find out how variables like home income affect the amount of power used. To gain a deeper understanding of the processes at work, this survey will yield insightful information on customer behaviour and preferences.

The next stage is to analyse and visualise the data after it has all been gathered and compiled. Our goal in going through this process is to find connections, patterns, and trends that may not be immediately obvious. We will investigate that how the demand for electricity varies in reaction to price fluctuations, while accounting for a parameter like family income. We will be able to comprehend the intricate link between tariff and demand in the power market more effectively due to this investigation.

Apart from analyzing these quantities, qualitative factors will also be considered. For example, the survey results may include information on how consumers feel about using power at different times of the day and if they are open to changing how tariffs are structured. It will be essential to comprehend these viewpoints to create a tariff structure that is both consumer-acceptable and successful.

The data analysis will involve advanced statistical techniques and possibly machine learning algorithms to ensure robust and reliable results. Visualization tools will be used to present the findings in an accessible and understandable manner, which will aid in communicating the insights to stakeholders, policymakers, and the general public.

Ultimately with these understandings a new tariff structure that includes modifications for peak pricing will be suggested. This innovative technique seeks to persuade customers to use less electricity at times of peak demand. This will ease the strain on the system and encourage more sustainable patterns of energy use.

It is anticipated that the introduction of the TOU tariff will lower peak demand improving the system's efficiency and dependability of electricity supply. In the long run this can lower power prices for consumers, save operating costs for utility companies, and benefit the environment by lowering the demand for further fossil fuel-fueled electrical generation. In addition to supporting sustainable energy practices and advancing Pakistan's overall economic and environmental goals, this all-encompassing plan aims to control demand.

1.4 Thesis Layout

The structure of this thesis is organized into the following sections:

Chapter 2: Literature Review: A thorough analysis of various tariff structures and demand-side management (DSM) is provided in this section. Furthermore an analysis is conducted on Pakistan's present tariff structure. The chapter also explores the relationship between price and demand, and the variables influencing energy pricing as well as the effect of prices on demand . The chapter also covers Pakistan's energy landscape, the effects of Time-of-Use (TOU) rates on developing and South Asian nations, and consumer acceptability of TOU tariffs.

Chapter 3: Methodology: This chapter describes the approach used to solve this research. It contains information on how the dataset was gathered and clustered as well as specifics on the data cleaning and collection procedures. This portion of the thesis also outlines the design of the suggested tariff structure.

Chapter 4: Results and Discussion: The findings and results derived from the study are presented and discussed in this section.

Chapter 5: Conclusions and Recommendations: This concluding chapter summarises the key findings of the study and offers recommendations for the future. It explains the overall study, highlighting its significance and potential implications for the field.

CHAPTER 2: LITERATURE REVIEW

This chapter serves as a comprehensive exploration of the existing research and scholarly work. We take a closer look at what other researchers have found out through their studies, the theories they have developed, and the real-life observations they have made. By doing this, we aim to get a better understanding of our topic and to see what has already been discovered. We will explore different ideas and evidence that researchers have gathered over the years, helping us build a strong foundation for our research.

2.1 Demand Side Management (DSM)

The objective of demand-side management (DSM) or energy-side management is to encourage consumers to use less energy during peak hours or to shift their load from peak hours to off-peak hours [30]. DSM is "scientific control of usage and demand of electricity for achieving better load factor and economy, by the licensee or supplier" [31]. "To plan, implement, and monitor activities designed to influence customer uses of electricity in ways that will produce desired changes in the utility's load shape" is the definition of DSM, which came into being during the 1970s [32]. DSM offers advantages to energy producers as well as customers. Customers can actively participate in the process by reshaping the load profile through well-informed decisions to achieve optimal energy consumption. This reduces the demand for peak loads, thereby contributing to the stability of the power system network as a whole [33]. As a result, load management is an essential DSM component.

Demand-side management (DSM) explains the techniques that utilities, grid operators, and energy suppliers use to influence and control how end-users (consumers) use electricity in order to create a more reliable, effective, and affordable energy system. The main goal of DSM is to change or adjust the power consumption in response to shifting grid conditions or to fulfil certain policy objectives [34].

DSM is particularly crucial in light of the growing grid integration of variable renewable energy sources such as solar and wind. These renewable energy sources frequently generate electricity intermittently and with intrinsic weather-dependent changes, which can impact the supply and demand of electricity [35].

The implementation of DSM is only possible when the consumer's side equally participates in it. The two main activities of DSM are load shifting and energy efficiency, or conversion programs. DSM is implemented using different techniques; some are mentioned by [36] and [37] as follows:

- Time of Day Tariff
- Peak Clipping
- Valley Filling
- Load Priority Techniques
- Energy Efficiency Improvement
- Rainwater Harvesting

DSM has many benefits, and a few of them are stated below:

- By reducing demand during peak hours, DSM helps in improving grid stability [38].
- DSM encourages consumers to shift their loads from peak hours to off-peak hours.
- DSM allows better integration of VRE.
- Optimising electricity consumption will eventually lead to cost savings for both the supply and demand sides.

Demand-side management is an essential tool for maximising the use of energy resources, enhancing grid efficiency, and facilitating the integration of renewable energy, all of which contribute to a more robust and sustainable energy system.

2.2 Electricity Tariff

Until now, the importance of DSM has been discussed. Let us see what the electricity tariff is to get a better understanding of a chosen topic. A tariff is defined as the rate at which consumers will purchase electricity per unit. In other words, the tariff is the technique through which consumers will be charged for their used electricity [39].

The tariff structure varies according to the consumer. The tariff includes the price of producing and supplying electricity and a reasonable profit for the supply side.

2.2.1 *Tariff Structures*

Different tariff structures can be used for demand-side flexibility, and some of them are as follows:

In a flat rate tariff structure, a fixed or constant rate is applied to every energy unit used, regardless of use [40]. in increasing block rate tariff consumers are charged block-wise in this structure. Price increases with the increase in the use of electricity in the form of blocks as the step function [41]. For example, if a consumer has used 300 units of electricity, then the rate for the 0-100 units will be different, the rate for 101-200 units will be higher than the last 100 units, and the rate for 201-300 units will be higher than the previous slab. Consumers are charged as decreasing block-wise in decreasing block rate tariff structure. Price decreases with the increase in electricity use [41].

In Time-of-Use (TOU) consumers are charged differently in different time slots of the day; these time slots are called “time bands” [42]. Prices will be higher in peak periods, and during off-peak times, prices will be lowest to encourage consumers to shift their loads in that slot [41]. Sometimes, a high peak occurs over a short period of time. Therefore, according to the critical peak pricing (CPP), this period will have a very high price [43]. In real-time pricing (RTP) structure, the load usage is charged on an hourly or half-hourly basis [44]. In the day-ahead RTP or day of real-time RTP, consumers are informed about the pricing of electricity a day before so that they can make their plan for electricity usage accordingly [45]. This pricing structure requires maximum participation from consumers and energy suppliers.

Table 2.1 shows some tariff structures that are used in different countries. From table 2.1, it is seen that developed countries like the USA, UK, and Germany are using linear tariff structures while developing countries are using increasing block rate tariffs for domestic consumers. Australia is using a decreasing block rate tariff. This might be because of the high penetration of rooftop PV panels from the consumer side. This study will further describe the tariff structure of Pakistan and the proposed

Table 2.1: Tariff structures used in different countries

Flat Rate Tariff	Increasing Block Rate Tariff	Decreasing Block Rate Tariff	Time-of-Use Tariff	Critical Peak Pricing	Real-Time Pricing
Germany, US, Canada, UK, and Turkey (mostly developed countries) [46]	Pakistan, India, Bangladesh, and Iran (mostly developing countries) [46]	Australia [46]	Russia, Nepal, and Thailand [46]	Few states of the USA [48], [49]	Spain [47]

tariff structure for Pakistan. This study further elaborates on regulatory policies for this initiative and different challenges for the implementation of the proposed tariff structure considerations to incentivize demand-side flexibility.

2.3 Current Tariff Structure of Pakistan

In Pakistan, the tariff structure is structured around the block rate tariff method. The current tariff framework in Pakistan for residential users comprises two distinct categories: protected and unprotected consumers [50]. Consumers falling within the protected category are those whose electricity consumption does not exceed 200 units within any consecutive six-month period. Consumers who use more than 200 units are considered unprotected consumers.

Protected consumers have a small electricity usage and are subject to a block rate tariff system, which ensures fair and equitable billing procedures. Meanwhile, unprotected consumers confront a tariff system with varied rates based on their electricity use. Users with a sanctioned load of more than 4 kW are obliged to install a three-phase Time-of-Use (TOU) meter for more precise monitoring and billing. Peak demand for electricity in Pakistan often occurs between 5 p.m. and 10 p.m. Differential tariffs should be used to incentivize off-peak usage to reduce grid strain during peak hours.

This breakdown of tariff structures highlights the comprehensive strategy employed to successfully regulate power usage while guaranteeing affordability and accessibility for all customer categories. The goal of matching tariffs with consumption patterns and raising awareness of peak and off-peak pricing is to develop an energy efficiency and sustainability culture among Pakistan's domestic consumers. Table 2.2 shows the current tariff structure of Pakistan [51].

Table 2.2: Current tariff structure of Pakistan

Slabs (kWh)	Current Tariff (Rs)
Protected Consumers	
Upto 50 Life Line	5.00
51-100 Life Line	16.61
0-100	18.88
101-200	21.06
Unprotected Consumers	
0-100	22.46
101-200	24.85
201-300	25.33
301-400	26.33
401-500	26.82
501-600	27.81
601-700	28.97
Above 700	30.3

2.4 Relation of Demand and Price

The relationship between demand and price, both in general and specifically in the case of electricity, is crucial to understanding market dynamics and consumer behaviour.

2.4.1 General Relationship between Demand and Price

2.4.1.1 Law of Demand

According to the law of demand in economics, the quantity desired for a commodity or service falls as its price rises, and vice versa, all other things being equal [52]. This inverse relationship between price and quantity demanded is a fundamental concept in economics.

2.4.1.2 Price Elasticity of Demand

The amount that good is sought after concerning a price change is measured by the price elasticity of demand. A slight variation in price causes a substantial shift in the quantity sought if the demand is elastic. Elastic demand, on the other hand, shows that the quantity required responds to price changes with minimum variation [53].

2.4.2 Relationship between Electricity Demand and Price

2.4.2.1 Electricity Demand

The demand for electricity is influenced by various factors such as population growth, economic activity, weather conditions, and technological advancements [54]. Consumers require electricity for lighting, heating, cooling, industrial processes, and more.

2.4.2.2 Price Impact on Electricity Demand

Changes in electricity prices can significantly impact demand. Higher prices may lead consumers to reduce their electricity consumption by using energy-efficient appliances, adjusting usage patterns, or investing in renewable energy sources. Conversely, lower prices may encourage higher consumption [55].

2.4.3 Factors Affecting Electricity Prices

Electricity prices are affected by many factors, such as the inflation rate, technological advancements [56], the cost of generating electricity, market competition [57], the expansion of renewable energy [58], changes in fuel prices [59], and policy decisions. A few of these factors are discussed below:

2.4.3.1 Generation Costs

The generation cost plays a crucial role in determining electricity prices [60]. The cost of generating electricity, influenced by fuel prices, maintenance, and infrastructure investments, plays a significant role in determining electricity prices.

2.4.3.2 Market Conditions

Electricity prices are also influenced by market dynamics, including supply and demand fluctuations, transmission constraints, long-term and short-term plans, and regulatory policies [61].

2.4.3.3 Renewable Energy Integration

The increasing share of renewable energy sources like solar and wind power can impact electricity prices due to their intermittent nature and zero marginal cost of generation [62].

The relationship between demand and price is a fundamental economic concept that applies to various goods and services, including electricity. Understanding how changes in price affect demand and vice versa is essential for policymakers, energy providers, and consumers to make informed decisions regarding energy consumption, pricing strategies, and sustainability efforts.

The reduction in electricity consumption is greater in the case where the current price is higher than the previous price than in the case where the current price is lower than the previous price [63]. Table 2.3 provides a detailed snapshot of units sold and average tariffs across fiscal years 2022, 2021, and 2020. Electricity demand is increasing each year, while electricity prices have also increased over the years.

Table 2.3: Units sold and average uniform tariff

Year	Total Units Sold (GWh)	Average Uniform Tariff (Rs)
2022	60409.41	23.34
2021	57855.86	19.64
2020	55132.61	18.13

The price elasticity of demand ε was calculated using equation (1). The variables ε, ΔD, ΔP, D, and P represent elasticity, change in units sold, change in tariff, units sold, and tariff, respectively. Table 2.3 provides the data used for these calculations, with the results presented in Table 2.4.

$$\varepsilon = \frac{\Delta D / D}{\Delta P / P} \tag{2.1}$$

While electricity is undoubtedly a fundamental necessity rather than a luxury [63], reflecting an overall inelastic demand concerning price, our analysis illuminates intriguing nuances when examining specific consumption slabs. Notably, in the ”Average” row of table 2.4, the elasticity value consistently remains below 1, underscoring the prevailing inelastic behaviour of demand across the board.

Table 2.4: Price elasticity in demand for the years 2020 to 2022

Year	D_1 (GWh)	D_2 (GWh)	ΔD (GWh)	P_1 (Rs)	P_2 (Rs)	ΔP (Rs)	$\frac{\Delta D}{D_1}$	$\frac{\Delta P}{P_1}$	ε
For 2022-2021	60,409.41	57,855.86	2,553.55	23.34	19.64	3.7	0.0423	0.1585	0.2669
For 2021-2020	57,855.86	55,132.61	2,723.25	19.64	18.13	1.51	0.0471	0.0769	0.6125
Average	-	-	-	-	-	-	-	-	0.4397

However, a closer examination of the data reveals a more intricate pattern: certain slabs exhibit elasticity in response to price fluctuations. This intriguing finding underscores the significance of our study, which aims to delve into these variations and comprehensively understand the complex dynamics of consumer behaviour within different pricing brackets. For a visual representation, figure 2.1 visually depicts the elasticity of different slabs, offering further insight into the varying degrees of responsiveness within the consumer base. As far as the data for 2022 shows, 60% of consumers are from 0 to 200 slab section [51]. It is seen in figure 2.1 that consumers of 0 to 200 units are highly elastic with price change. Expect 201-300 slab, all other slabs are price-elastic. The reduction in electricity consumption is greater in the case where the current price is higher than the previous price than in the case where the current price is lower than the previous price. 240,339,447 kWh were imported by DISCOs in FY 2022, and the total number of domestic net metering consumers was 33,065 [51]. The total number of licenses issued in 2021 was 8417 [64], whereas in 2022, it was 7032 for all categories of consumers [51]. It is evident that the reduction in demand for higher slabs observed in FY2022 cannot be attributed solely to the installation of solar panels by household consumers, which infers that consumers are price-responsive. By exploring these nuances, we aim to shed a load on potential avenues for optimising pricing strategies and enhancing overall market efficiency in the electricity sector.

2.5 Effect of Time-of-Use (TOU) Tariff in Developing Countries

Time-of-Use (TOU) tariff structure impacts residential consumption patterns similarly in developing countries and developed countries, highlighting the need for effective TOU programs globally [65]. Time-of-Use tariffs incentivize peak demand reduction in residential customers, aiding in peak load management and efficiency, as seen in Japan's post-2011 power shortage [66].

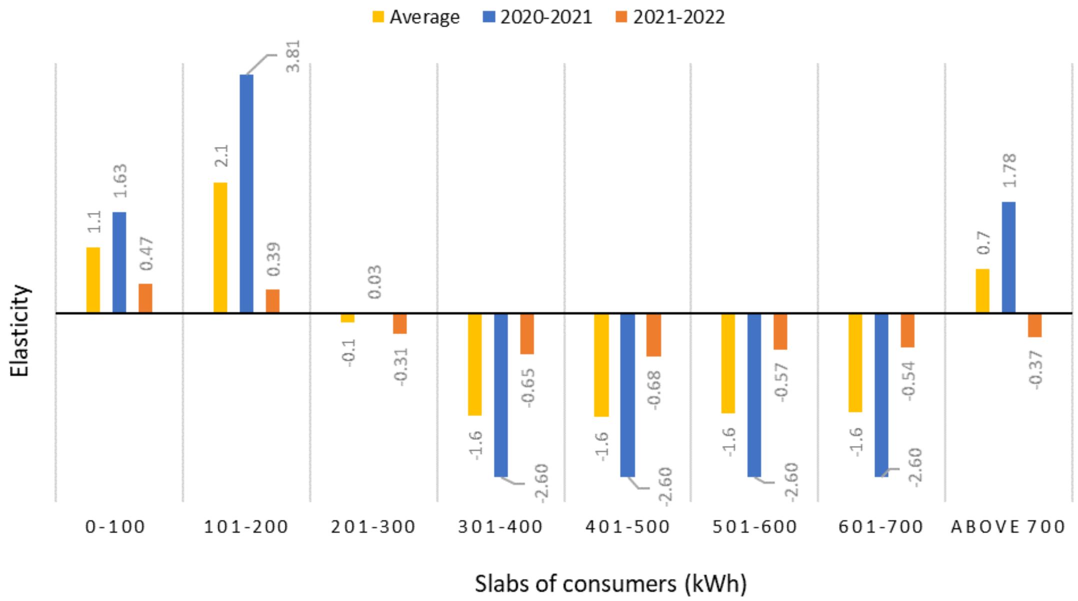


Figure 2.1: Slab-wise price elasticity

For residential and commercial users the Electricity Supply Commission (Eskom) of South Africa has instituted TOU tariff. The outcomes have been mixed but generally favourable, industrial customers in particular have reacted well to the TOU pricing, with many companies moving their activities to off-peak hours in order to reduce their power expenses. This has resulted to a smoother demand curve and also helped Eskom manage its limited producing capacity properly [67].

In Brazil TOU tariffs was introduced to encourage energy conservation, and optimise the use of the country's hydroelectric resources. The implementation of TOU tariffs in São Paulo, saw a reduction in peak demand up to 7% allowing for better resource allocation and reducing the likelhood of blackouts, during periods of high demand [68].

The use of TOU tariffs in developing countries has shown that it can be an effective strategy for controlling energy use and enhancing grid stability. The consumption habits of these nations have altered and their energy systems are now more efficient, and peak loads have decreased. The experiences of South Africa and Brazil are making a strong case for the broader adoption of TOU tariffs in other developing regions.

2.6 Effect of Time-of-Use (TOU) Tariff in South Asian Countries

The implementation of Time-of-Use tariffs in South Asian countries is a crucial step towards increasing energy efficiency and successfully regulating peak demand [69]. These tariff schemes are intentionally designed to persuade users to change their energy usage habits by offering reduced prices during low-demand times and higher rates during peak hours. Time-of-Use tariff incentivize users to shift their energy usage to off-peak hours [70], play an important role in balancing grid demand, lowering strain during peak periods, and optimizing total energy utilization.

Time-of-Use (TOU) tariff has proven to be an effective approach for reducing peak electricity demand in the residential sector around the world, especially in developed countries. The introduction of Time-of-Use tariff is especially important for South Asian countries like India, Pakistan, and Sri Lanka which face the problems of fulfilling rising energy consumption while aiming for sustainability. Research indicates a growing trend to adopt time-of-use tariffs in conjunction with smart metering technologies [71] to give consumers real-time information and empower them to make more informed energy decisions. Customers gain from this combination of smart metering and pricing systems not just by potentially saving money on their power bills but also by lowering total energy use and carbon emissions.

In China, the implementation of TOU tariffs has been widely adopted across several provinces. The results have been promising, with significant reductions in peak electricity demand and an improved load factor. In Jiangsu Province, the introduction of TOU pricing led to a 10% reduction in peak load, enhancing grid stability and reducing the need for costly peaking power plants [72].

In the Indian region of Jharkhand, a mini-grid operator reported that the introduction of a TOU tariff led farmers to use irrigation systems more during the day when the price of electricity was lower [73]. The TOU rates are applicable in Delhi and Maharashtra as well. To manage the rising demand during peak hours, the Delhi Electricity Regulatory Commission (DERC) introduced TOU tariffs. Owing to this promotion, there was an obvious shift in consumer behaviour. Many residential and business clients are changing their consumption patterns to benefit from lower prices during off-peak hours. This modification has produced a more balanced load profile and reduced the strain on the distribution network [74].

Similarly, in Bangladesh, it is proposed by [75] that with the Time-of-Use pricing approach, total electricity costs from the consumer's point of view change slightly, while from the utility's perspective, considerable savings are made, especially when the network operates close to full capacity or has a limited energy supply.

The implementation of Time-of-Use tariffs in South Asian nations may be summed up as a proactive step towards building a more reliable, effective, and sustainable energy infrastructure. The implementation of Time-of-Use tariffs fits in with the global move towards cleaner and more sustainable energy systems. These tariffs assist in optimising the use of renewable energy resources and reducing dependency on fossil fuel-based generation, therefore aiding efforts to mitigate climate change and promote environmental sustainability.

2.7 Acceptance of Time-of-Use Tariff among Residential Consumers

Time-of-Use tariffs have the potential to significantly lower peak energy consumption and save power output. Time-of-Use (TOU) rates are usually accepted by customers; surveys suggest that a considerable proportion of respondents would prefer a TOU tariff over fixed rate choices, which would reduce energy use during peak hours. Around 70% of German customers are open to changing their demand in order to potentially avoid investing in fossil fuel power plants [76].

TOU tariffs have been put into effect in some US states, including Arizona and California. The research conducted by the US Department of Energy revealed considerable variations across utility firms with respect to consumer acceptance and engagement. In June 2021, Silicon Valley Clean Energy (SVCE) [77] and Pacific Gas and Electric Company (PG&E) [78] implemented TOU pricing as required by the California Public Utilities Commission (CPUC) [79] across the state, and more than 75% of Californian customers expressed satisfaction, indicating that high acceptance rates were achieved in an environment where substantial customer education and incentives were offered. In contrast, employing proactive communication techniques resulted in a drop in acceptability [80].

As part of the introduction of smart meters in the UK, TOU rates have been presented. Most of the respondents to the Department of Energy & Climate Change (DECC) research expressed satisfaction with TOU pricing. Customers recognised the possibility of cost savings and modified their consumption habits appropriately. Among homes that were environmentally sensitive and tech-savvy, the acceptance rate was quite high [81].

In regions like Victoria (VIC) and New South Wales (NSW), Australia, the Australian Energy Regulator (AER) widely embraces TOU rates. ABC News conducted research and found that the percentage of consumers adopting TOU is on the rise. Adoption was primarily motivated by cost savings and environmental benefits. However, some criticism was observed among older demographics and low-income households, perhaps because of concerns about understanding and navigating the new pricing structure [82].

Consumer acceptance towards the Time-of-Use (TOU) tariff in Korea is analysed through preferences using conjoint analysis, revealing discrete group preferences and segmented attitudes towards electricity tariffs [83]. Consumers in Italy showed limited but noticeable acceptance of the Time-of-Use tariff, with some shifting consumption to off-peak hours, indicating a change in user behaviour towards the new pricing structure [84].

Japan tried to lower peak demand and improve energy efficiency by implementing TOU tariffs, particularly following the Fukushima accident. A study conducted by UK energy data analytics start-up Smart Meter Analytics Platform (SMAP) Energy and Japanese energy retailer Looop collaborated on the creation of Japan's first smart meter-enabled Time-of-Use (TOU) tariff revealed a high degree of customer acceptability and successful implementation of this program. Strong public awareness efforts and effective benefit explanations were the main drivers of the favourable response [85].

Customised techniques are necessary to cater to different consumer groups, as demonstrated by the possibility of customer preferences for TOU prices changing based on demographic characteristics and attitudes towards the expenses of current home power. The customer's acceptance of TOU tariffs is largely dependent on effective marketing, education, and their perception of the pricing plan's advantages.

The US, Australia, Japan, and the UK are among the countries that have successfully imposed TOU tariffs and have reported high levels of customer satisfaction and preparedness to change consumption patterns. The data described above emphasises the importance of broad consumer outreach and assistance.

2.8 Electricity Landscape of Pakistan

Throughout the years, Pakistan's energy industry has encountered several difficulties, including a persistent mismatch between supply and demand, a heavy reliance on fossil fuels for electricity generation, and inadequate transmission and distribution systems. The consequences of these issues includes frequent blackouts, high generation costs, and significant transmission and distribution losses. To create a more dependable and sustainable energy system the energy industry must keep evolving to meet the demands and preferences of its clients. Policies and tariff structures that are effective must take into account the distinct needs and consumption patterns of different consumer groups.

The electricity demand in Pakistan is driven by a range of sectors each with unique requirements and characteristics. These sectors include the following sectors [86]:

- Agricultural Load
- Industrial Load
- Commercial Load
- Domestic Load
- Public Services

For the agriculture sector the two main uses of electricity are irrigation and operating farm equipment. Seasonal variables impact demand in this sector, with planting and harvesting seasons seeing the highest consumption. To maximise crop yields and ensure overall food security, the agriculture sector needs a steady supply of power. The sector uses energy in a unique way that varies greatly depending on weather and irrigation requirements. Pakistan's farm sector is increasingly generating electricity from renewable sources, including solar and wind power to save costs and reduce greenhouse gas emissions [87].

A major driver of the need for energy is the industrial sector. Reliable electricity is essential for industrial facilities such as manufacturing, processing, production, and others. Pakistan's largest electricity consumers are the chemical, steel, cement, and textile sectors. Efficient energy supply to this sector is critical for economic growth [88] and competitiveness, as any disruption can lead to significant financial losses.

Commercial customers include retail stores, offices, restaurants, and hotels. This industry needs consistent and dependable electricity to guarantee smooth operations and customer satisfaction. The electricity usage of the commercial sector is often more steady, with peak demand occurring during business hours in contrast with the residential sector. The differences in consumption can be seen according to the kind of business and whether or not energy-consuming machinery is present.

Residential customers are the largest category, accounting for a significant portion of total electricity use [89]. There is a broad range of income ranges, demands, and energy consumption patterns among the households in this sector. Residential demand is characterised by daily and seasonal changes. Peak use often occurs in the evenings and summer months due to cooling requirements.

Additional factors that add to the total demand for electricity are public services, including government offices, schools, hospitals, and street lighting. For these services to operate efficiently and deliver services, a stable electrical supply is necessary. The demand in this sector is generally stable but can fluctuate based on specific activities or emergencies such as increased usage in hospitals during health crises.

It takes an extensive strategy to meet the various demands of different consumer groups, one that involves promoting energy-saving practices, implementing sophisticated metering infrastructure and developing appropriate tariff structures. Policymakers may develop policies that optimise power usage, lower costs, and improve the sustainability and dependability of the energy system by taking into account the demand and features of each sector.

The energy sector of Pakistan face numerous challenges, that necessitate a multifaceted and inclusive approach to refrom. An energy system that is more reliable and efficient may be developed by comprehending the unique need of customer in the residential, commercial, industrial, agricultural, and public service sectors. In addition, to addressing the imbalance between supply and demand this entails updating the transmission and distribution network and lowering dependency on fossil fuel. As the sector evolves, continuous efforts to meet the changing needs of consumers will be essential for ensuring sustainable development and economic growth in Pakistan.

Domestic customers make up the vast majority as of June 2022, making up over 87% of all connections countrywide. Nonetheless, domestic customers continue to be highly prevalent when it comes to sanctioned loads, accounting for around 60% of the nation's total sanctioned load capacity. When considering the daily peak load situation, 28,000 MW of electricity units are requested during peak hours, and domestic users account for a substantial 60% of this load. This number assumes even more significance. The distribution of consumers across these categories is further illustrated in Figure 2.2, highlighting the predominance of domestic consumers in the electricity consumption landscape of the country [51]. The significance of having an effective Demand Side Management (DSM) program in meeting the requirements and consumption patterns of distinct consumer categories is emphasized by this information. Tailored plans may be created to optimize energy use, enhance grid stability, and promote sustainable consumption practices for all consumer categories through the implementation of targeted DSM programs. These actions will ultimately result in a more robust and efficient electrical infrastructure.

2.9 Shift towards Industrialization

The country's industrial sector's vitality is closely linked to its economic trajectory. The industrial sector has relatively few customers, but the significant energy demand it creates, as seen in figure 2.2, makes it imperative to give industries first priority when it comes to energy supply. Fostering an environment that promotes innovation, higher productivity, and enhanced global competitiveness is the main goal of this plan. The goal is to propel total economic growth to previously unheard-of levels by assisting in the enhancement of skills, encouraging the creation of jobs, and strengthening participation in the international market by giving industry access to a steady supply of energy.

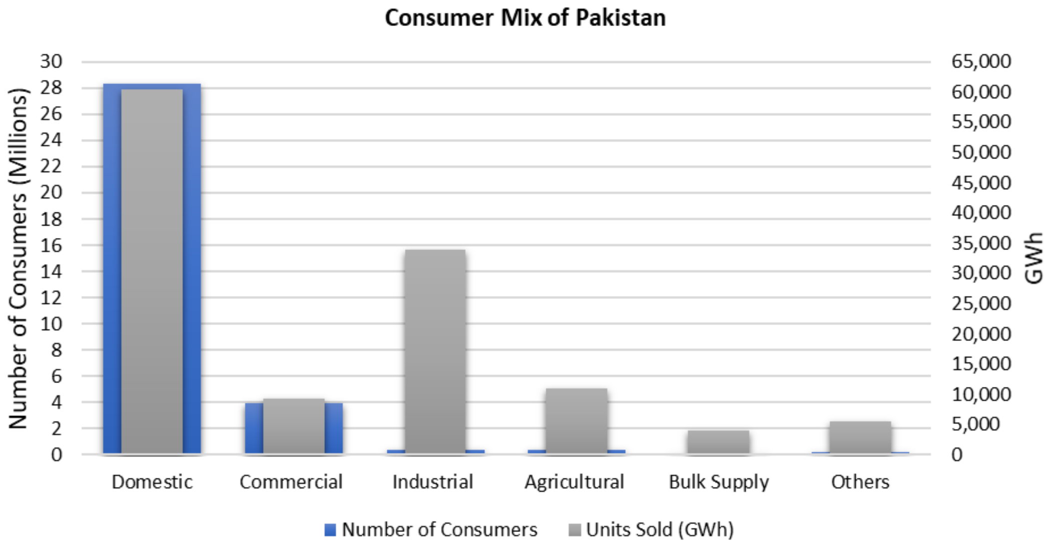


Figure 2.2: Showing the number of consumers per category and unit consumed per category as of June 2022

On the other hand, the agricultural sector's heavy reliance on power frequently impedes economic progress, whereas energy use in the industrial and commercial spheres produces significant benefits. While domestic power consumption is still rather large, its effect on economic growth is usually quite limited [90]. This crucial transformation from an agricultural economy to an industrial one is a transformative stage characterised by resource reallocation and a change in the country's GDP composition. As countries advance along this trajectory, the industrial sector's contribution to GDP starts to rise and finally peaks during the highly industrialised phase [91]. In the meantime, the percentage of agriculture in GDP steadily declines. Concurrently, the services sector experiences a parallel ascent, reflecting the evolving economic landscape of developing nations and the multifaceted dynamics driving their growth trajectory.

A number of factors, such as the availability of excess labour in agriculture, the higher productivity and wages associated with industrial sectors, and the growing demand for services in developing societies, support the shift from agrarian-based economies to industrialization [91]. This shift is seen in Pakistan's GDP, where the proportion of agriculture is falling while the industrial and services sectors are growing at a moderate rate and, most notably, expanding, respectively [91]. However, more research and development in the industrial sector is necessary to promote steady economic growth and reduce unemployment.

Encouraging Pakistan's industrial sector to get a larger portion of the country's power allotment might be extremely beneficial for both long-term sustainability and economic growth. There are multiple strong arguments supporting this strategic focus, all of which contribute to the country's overall economic growth and prosperity.

Maximising production capacity and efficiency is primarily facilitated by providing a steady and plentiful supply of power to the industrial sector. Prosperity and economic growth can be stimulated by increasing the industrial sector's access to power [92]. Uninterrupted electrical power supplies allow firms to run their operations at maximum efficiency, increase output, and satisfy expanding consumer needs by powering industrial machinery and other activities [93]. Not only does this increase in industrial activity promote economic growth, but it also starts a domino effect of favourable effects that spread across the whole economy.

Large-scale employment growth is one of the most obvious advantages of a growing manufacturing sector. The industrial sector in Pakistan has produced almost 2.5 million jobs in just the last three years alone [94], highlighting its critical role in reducing unemployment and promoting socioeconomic development. Moreover, industrial expansion has a multiplier effect that promotes growth in auxiliary industries and raises general prosperity in addition to directly producing jobs [95].

Improving Pakistan's industrial efficiency with a sufficient supply of power increases its competitiveness internationally [96]. The country may lessen its dependency on conventional farming methods and take advantage of the potential for value-added manufacturing by fostering a strong industrial foundation. Industries are positioned as dependable and powerful participants in international commerce when they are able to reliably satisfy demand on a global scale thanks to a stable energy infrastructure [97]. This diversification promotes innovation, attracts international investment, and propels export-led growth for Pakistan while also strengthening its resilience to external shocks [98].

Additionally, putting industrial electricity demands first means funding infrastructural development at the same time [99]. These expenditures go beyond improvements to the electricity grid and include more national infrastructure projects, including communication technology, logistics systems, and transportation networks [99]. In addition to promoting industrial expansion, these infrastructural improvements create the foundation for further socioeconomic advancement and wealth.

Technological innovation and manufacturing process developments are catalysed by the introduction of electricity into the industrial sector [100]. Industries may promote innovation, increase productivity, make the best use of resources, and create innovative technologies that have a positive impact on many different areas of the economy. Economic progress depends heavily on industrial expansion, but attempts are being made to strike a balance between industrial growth and environmental responsibility [101]. Initiatives aimed at promoting energy efficiency, reducing emissions, and investing in sustainable practices ensure that industrial expansion occurs in harmony with environmental conservation efforts, safeguarding natural resources, and mitigating ecological impacts. Industrial companies have the potential to reduce their environmental impact, decrease carbon emissions, and contribute to climate mitigation goals by using energy-efficient technology and integrating renewable energy sources [102]. Aside from being in line with international sustainability imperatives, this transition towards sustainable industry also strengthens national resilience to the effects of climate change and promotes sustainability.

Diversifying the economy by placing greater emphasis on the industrial sector reduces dependency on a narrow range of sectors, enhancing economic resilience and stability over the long term [103]. Pakistan may steer towards long-term economic progress, prosperity, and socio-economic development for its people by embracing industrial expansion and giving energy supply top priority in this vital sector. Moreover, social programs, healthcare projects, and educational attempts may be supported by the money made by a strong industrial sector [101]. Reinvesting in social welfare and human capital improves people's quality of life and promotes equitable development for all societal sectors.

Analyzing the data reveals that the textile industry is a key component of Pakistan's economy and exerts a significant impact for several reasons. To simplify, this industry has a substantial economic impact as it accounts for about 8.5% of our total Gross Domestic Product (GDP) [104]. It also forms a cornerstone of our export industry, accounting for over 60% of the nation's export earnings [104]. Still, its influence goes beyond simple economic data; the textile industry is a powerful employer, supporting over 40% of the labour force, or about 19 million people [104]. This demonstrates the critical role that this industry plays in fostering economic expansion as well as supporting job opportunities and means of subsistence for millions of Pakistanis. As a result, it is clear that the textile business is about more than simply making fabrics; it supports our whole economy and provides a living wage for a large number of people [104]. And it is not just the textile sector; numerous other industries wield similar influence, further solidifying their collective importance in driving the economic engine of Pakistan forward.

According to the statistics for 2022, there is a noticeable balance in the amount of power consumed by the industrial and residential sectors. Half of the units sold were to domestic users, while the remaining 26% went to the industrial sector. Even with this disparity in spending, the income produced reveals otherwise. The income stream was primarily contributed to by domestic customers, who made up Rs. 970,531 million, and industrial consumers, who made up Rs. 793,823 million, were not far behind.

What is interesting here is the discrepancy between consumption volume and revenue generation. Although the industrial sector consumed nearly as much electricity as domestic consumers, their share of revenue billed was slightly lower at 32%, while domestic consumers' contribution stood at 39%. This finding emphasises how important the industrial sector is to distribution businesses' ability to generate income.

The economic landscape depicted in the Pakistan Economic Survey 2022-23 reveals a concerning trend, with a mere 0.29% increase in GDP signalling a significant decline. This downturn is symptomatic of various underlying challenges, including diminished industrial output, limited infrastructure investments, and a noticeable slowdown in commercial activities, as underscored in the State of Industry Report 2023 [17].

The Prime Minister of Pakistan has issued directions via the Task Management

System to all Distribution Companies (DISCOs), directing them to prioritise the supply of energy to commercial and industrial organisations in light of current economic challenges [105]. The acknowledgement of the critical role that the industrial and commercial sectors play in promoting economic growth and stability is highlighted by this strategic change in emphasis.

However, amid efforts to bolster industrial and commercial electricity supply, DISCOs continue to grapple with the pervasive challenge of circular debt, which has ballooned to a staggering Rs. 2,309,997.36 million for the fiscal year 2022-23. This mounting debt load is made worse by structural problems, including low bill recovery and high theft losses, which are mostly seen in the home sector. Given these difficulties, it would be wise to strategically shift the electrical demand from the residential to the commercial sector. This would solve the issue of income generation and maybe lessen the pressure on the financial stability of DISCOs.

It is also important to stress that the welfare of domestic users is not compromised in order to pursue this effort. Instead, it is about allocating energy in a way that results in a harmonic balance and appropriately addresses both industrial progress and public welfare. Large-scale expenditures in contemporary infrastructure, such as improvements to the electric grid and the deployment of renewable energy initiatives, are essential to this resolution. With an eye on protecting the welfare of our population, these investments are designed to effectively satisfy the energy needs of the industrial and residential sectors.

2.10 Problems for Policymakers

The fact that single-phase connections account for roughly 99% of all residential consumer connections [106] presents a substantial challenge to legislators. This is a significant difficulty because Time-of-Use pricing for these connections cannot be implemented due to limitations in the current infrastructure. It is imperative that this issue be addressed, and this study is centred on it.

Moreover, the effectiveness of current Time-of-Use metering systems in influencing load patterns is questionable, particularly given the substantial variability observed in consumption patterns throughout the day and across different seasons. For instance, an analysis of peak loads recorded in June 2023 sheds light on the dynamic nature of consumption behaviours. The findings, detailed in figure 2.3, reveal a significant degree of fluctuation in both the peak load values and the corresponding times at which they occur. Figure 2.3 presents a summary of these findings, highlighting the diverse array of factors that contribute to the fluctuating consumption patterns observed among consumers.

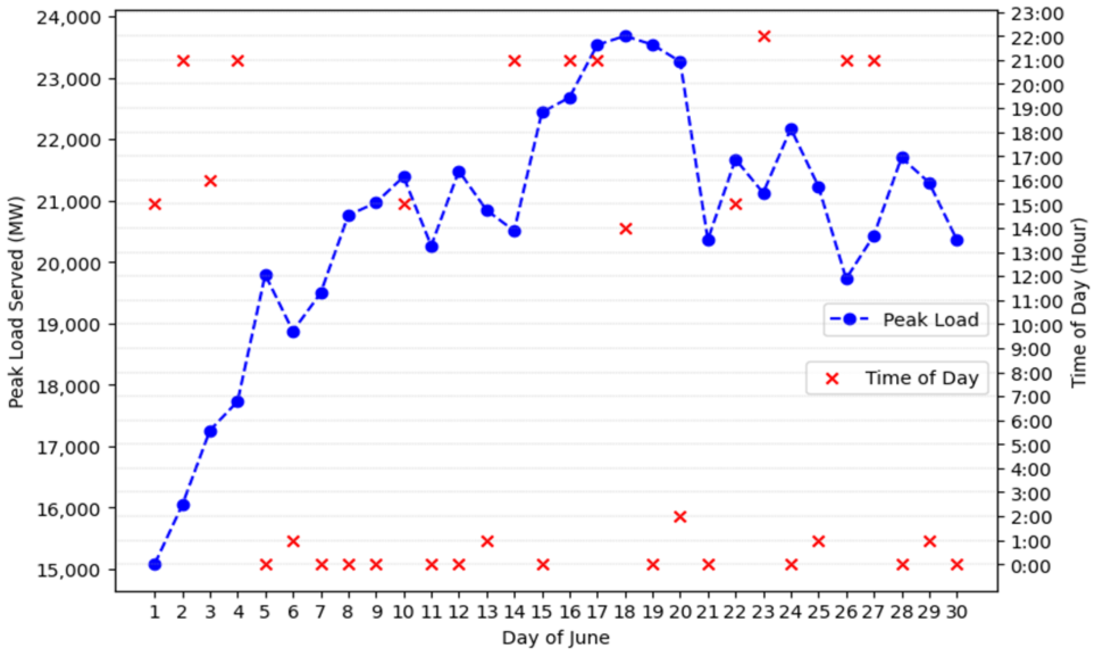


Figure 2.3: Peak demand and time of the day when peak demand hit for June 2023.

Through a thorough examination of peak load dynamics and consumption patterns, this research seeks to offer answers and insights to the current problems associated with the introduction of Time-of-Use tariffs. By carefully analysing these problems, decision-makers and interested parties may come up with plans that not only get around the present problems but also open the door for more fair and successful energy management techniques in the domestic sector.

CHAPTER 3: METHODOLOGY

The current tariff policy does not encourage consumers to use electricity efficiently. Therefore, there is a need for a tariff scheme that will motivate consumers to do demand-side management. The proposed tariff structure is a Time-of-Use (TOU) for the domestic consumers of Pakistan. This tariff model charges consumers differently in different time slots of the day. The proposed tariff structure is for peak hours of the day, generally assumed from 5 p.m. to 10 p.m. in Pakistan. The aim of this proposed approach is to reduce demand during peak hours, thereby minimizing the need to operate high-cost generators. During off-peak hours, more economical generators may not be fully utilized due to low demand. By reducing demand during peak hours, the goal is to redistribute the load to off-peak hours. This will allow the full utilization of more cost-effective generators.

Figure 3.1 summarises the research methodology in the form of a block diagram. The details of the research methodology adopted for this study are mentioned in the coming paragraphs. The main steps carried out to perform this research include data collection, data cleaning, data analysis, clustering the dataset, designing the tariff formula based on income and price elasticity, and checking the effect of the proposed tariff using a machine learning prediction algorithm.

3.1 Data Acquisition and Cleaning Process

I began gathering data for this study in its early stages. The National Electric Power Regulatory Authority (NEPRA) provided a dataset that includes data for the 2020, 2021, and 2022 fiscal years. This data needed to be carefully cleaned and analysed in order for me to identify the important metrics. These comprised how many consumers were in each consumption slab, how much energy was consumed in each slab, and the tariff rates that corresponded to each slab.

Following this initial data collection, I turned my attention to the PRECON dataset [107]. The PRECON dataset offers detailed information on home power usage trends annually. This dataset turned out to be yet another important component. By carefully examining the data, I was able to determine the crucial minimum con-

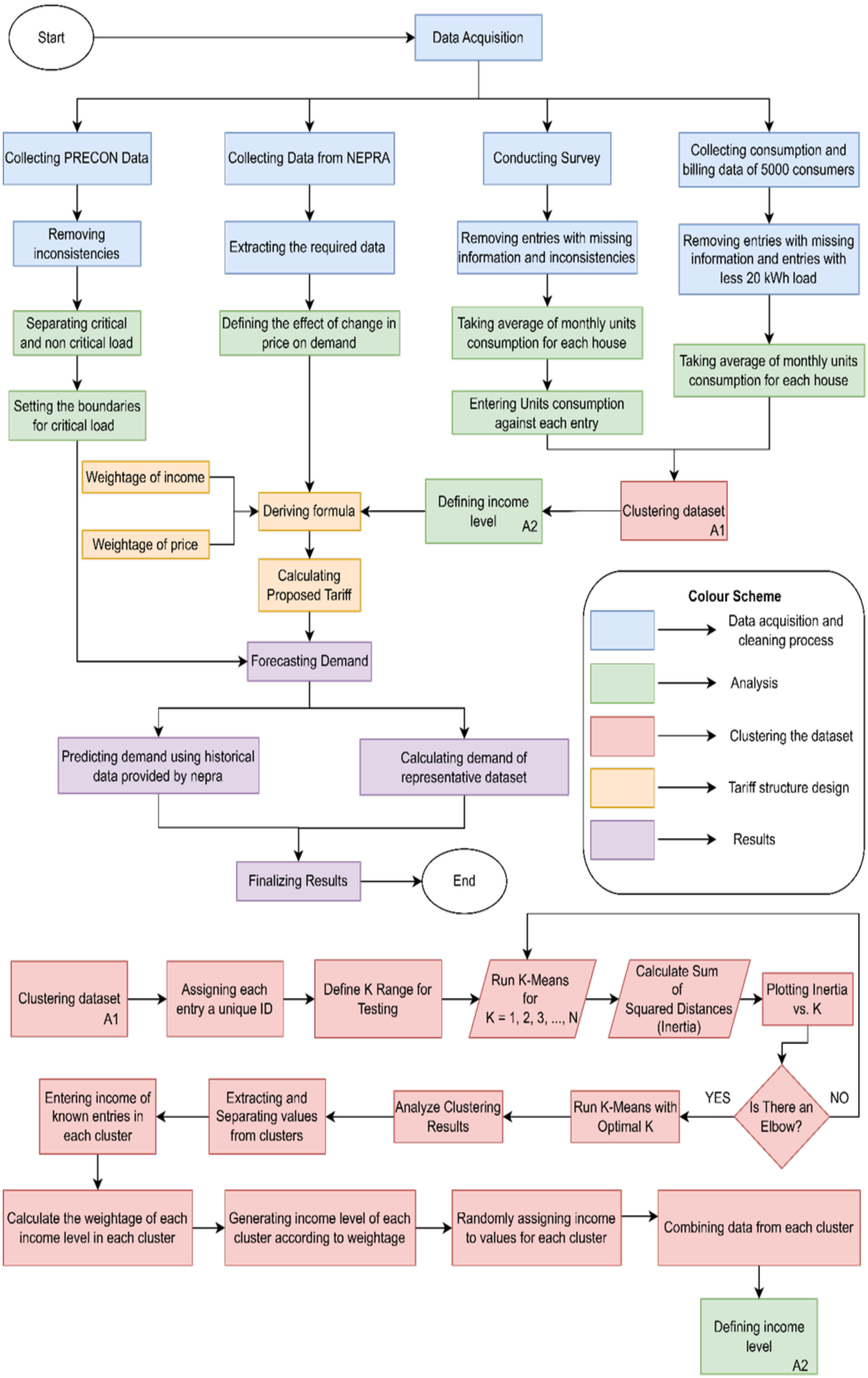


Figure 3.1: Flowchart of the methodology used for research

sumption limit. This cap denotes the minimal amount of electricity that is considered needed for the average home. We can create a baseline for each household's minimal consumption criterion by examining this dataset. This cutoff point is critical to comprehending the basic electrical requirements of homes, and it is especially pertinent when considering the maintenance of a steady power supply. In order to establish the minimum critical load, the average load of the uninterrupted power supply (UPS) for each household using this dataset was analysed and computed. This process entails a great deal of analysis and computation in order to accurately represent the typical consumption patterns of households. After computing the average load for each household, the overall average of these values was computed, which functions as the minimum critical limit of the load and offers important insights into the essential electricity requirements of households.

Following these procedures, a survey method was used in this study to investigate the connection between different income ranges and certain patterns of energy usage. There were thirteen questions in the survey, all of which were intended to provide thorough insights into different facets of the topic. The survey questions were obtained from these sources: [108], [109], [110], [111], [112], [113], [114], and [115]. Our dataset started out with 140 items. Using [116], the sample size was 139, where the population is 28,298,657, the margin of error is 7% and the confidence level is 90%, which shows that 140 entries are enough to carry out this study. However, the ideal scenario would have involved a larger, more representative sample; due to limited resources and time constraints, the survey was limited to 140 respondents. We aimed to increase the size of our dataset in recognition of this restriction and in an effort to strengthen the validity of our conclusions. In order to do this, we added 5,000 additional data points from a local distribution company. This addition greatly strengthened our dataset, yielding a combined dataset of 5140 items. Table 3.1 is a detailed overview of the survey questions.

Subsequently, the data was cleaned to ensure its integrity and reliability. This involved removing entries with missing electricity bill images, excluding those with monthly consumption below 20 kWh, and removing duplicate entries. Following the data cleaning procedures, out of the 5140 entries, only 4,765 were retained as cleaned

Table 3.1: Survey questions

Questions	Options
What is your monthly household income (in PKR)?	Less than 40,000 40,000 to 70,000 70,000 to 100,000 100,000 to 150,000 150,000 to 200,000 More than 200,000
Which region your house is located in:	Urban/Rural
Total members of your house	(open-ended)
How many rooms do you have?	(open-ended)
How many ACs do you have in the house?	(open-ended)
How many TVs do you have in the house?	(open-ended)
How many microwave ovens do you have in the house?	(open-ended)
What were your electricity units consumed last month?	(open-ended)
Does an increase in the price of electricity reduce your electricity consumption?	Yes/ No/ Not Sure
Do you have an idea of high pricing time (5 pm to 10 pm generally)?	Yes/ No
Do you reduce your consumption in high pricing time?	Yes/ No
What is the highest education level in your household?	No formal education Primary school Secondary school High school Bachelor's degree or Higher
Kindly upload a picture of your electricity bill	(open-ended)

data for further analysis. These 4,765 entries were used to represent the domestic consumers, and this data is named "Representative Dataset of Domestic Consumers of Pakistan", shortened to the term "representative dataset" in this paper.

We wanted to be sure that our study would produce precise and trustworthy insights into the relationship between customer energy usage habits and income ranges; therefore, we took great care in gathering and cleaning our data.

3.2 Clustering Dataset

The principal objective of this stage was to apply clustering algorithms to enhance the dataset that was supplied by Engr. Kashif Janjua, which was deficient in important income-level information. Finding discrete groupings within a dataset that have comparable traits or patterns is possible through the use of cluster analysis [117].

Different clustering techniques have been created over time by researchers, each with unique uses and capabilities [118]. Because of its ease of use and computational effectiveness, K-means clustering is a well-liked option among these techniques [119]. To get valuable insights into patterns of consumer activity, we decided to cluster the combined dataset in this research project using the K-means method. K-means clustering is one of the most frequently used machine learning algorithms due to its simplicity and computational efficiency, making it a popular method of solving clustering difficulties in psychological and other fields [120]. This algorithm splits the data into identical clusters based on their feature similarities [121].

We divided similar feature-wise quality into homogeneous groups by similarity in characteristics using the K-means technique. We classified customers based on income-related patterns that gave us insights into customer behaviour. In the Python environment, we used the K-means clustering method where all these resources are provided by Scikit-learn [122]. In order to gain a better understanding of cluster outcomes we also used Matplotlib packages [123] for data visualization.

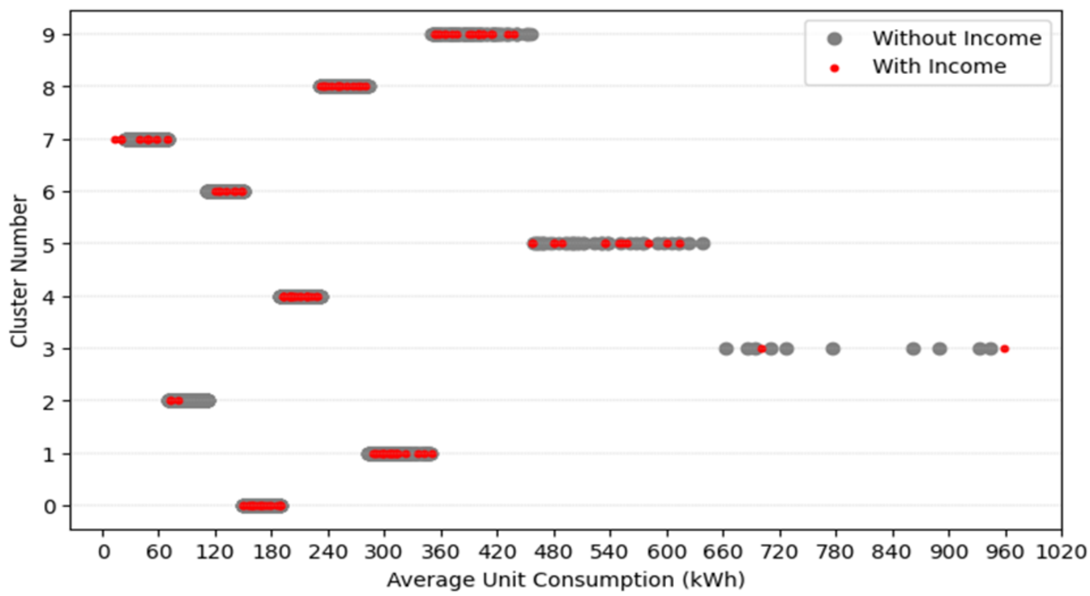


Figure 3.2: Clustering output

Figure 3.2 illustrates the output of the K-means clustering process. Data points from the local bills dataset (which does not contain income information) are represented by grey dots in this image. The remaining entries indicate entries with income-level information. We were successfully able to divide the data points into ten groups with 2 or more income-range information data points per cluster utilizing our clustering technique.

Remember too that many entries in every cluster had no income range information. We got around that issue by using a slightly more sophisticated method to infer income ranges among these entries. More specifically, we used the proportion of observed income range categories within a specific cluster to construct a probability distribution from which we stochastically assigned income ranges. Considering that our dataset is a long-term one and thus we should maintain its representativeness for the sake of any future research, this method was used to enhance the generalizability after testing our findings. This is how the income ranges are allocated:

$$NS_{unknown\ income} = W_{known\ income} \times N_{unknown\ income} \tag{3.1}$$

$$W_{known\ income} = \frac{N_S}{N_{known\ income}} \tag{3.2}$$

$NS_{unknown\ income}$ denotes the number of entries corresponding to a specific income range within the cluster of unknown income entries, while $W_{known\ income}$ signifies the weightage assigned to known specific income ranges within the same cluster. Additionally, $N_{unknown\ income}$ stands for the total count of entries pertaining to unknown income ranges in the cluster, and $N_{known\ income}$ represents the total number of entries associated with known income ranges within the cluster. Lastly, N_S represents the total count of entries for a specific income range within the known income ranges in the cluster.

For instance, let's consider cluster label 9, which comprises a total of 44 entries, out of which 11 contain income range information, distributed as follows:

- 6 entries fall within the income bracket of 40,000 to 70,000
- 3 entries lie within the income range of 70,000 to 100,000
- 2 entries are categorized under the income bracket of 150,000 to 200,000.

It is clear from this data analysis that the weights assigned to each income category are derived from the percentage of entries in each cluster. For example, the weighting of the income range of 40,000 to 70,000 is computed as follows: 6 divided by 11 yields a weighting of around 0.5454. Similarly, the weightage for the 70,000 to 100,000 bracket is computed as 3 divided by 11, yielding a weightage of approximately 0.2727. Likewise, the weightage for the 150,000 to 200,000 income range is determined as 2 divided by 11, resulting in a weightage of approximately 0.1818.

Utilising these weightages, the allocation of income ranges for the remaining 33 entries within cluster label 9 is facilitated. Out of these 33 entries lacking income information, 18 entries are randomly assigned to the 40,000 to 70,000 income bracket, 9 entries are allocated to the 70,000 to 100,000 bracket, and 6 entries are designated for the 150,000 to 200,000 income range.

This method enhances the data transparency and provides more confidence on the dataset accuracy for further analysis and decision making through fair income range representation with in the cluster. In these datasets I have sourced a lot of information, and by working through them I have set myself up to go further. Information from NEPRA data, accompanied by the important minimum consumption limit determined by means of the PRECON dataset contrasted to info on consumer income from a survey will form the starting point for this sequent stage of the elucidation.

3.3 Proposed Solution

Customers are not encouraged to use electricity effectively by the present tariff policy, which emphasizes the need for a more successful program that encourages demand-side management. Time-of-Use (TOU), a new tariff structure for Pakistani domestic users, is suggested as a solution to this problem. This strategy, which tries to divert consumption from peak hours, bills customers at varying rates based on the time of day, as explained in the introduction. The new rate specifically targets Pakistan's peak hours, which are often from 5 to 10 p.m. Reducing demand during these periods of high consumption is the goal in order to lessen the need for costly generators.

During off-peak hours, when demand is lower, more economical generators are often underutilized. By incentivizing consumers to shift their electricity use to these periods, the proposed tariff structure aims to optimize the use of cost-effective generators, reducing overall generation costs. This approach makes the energy system more reliable and efficient, in addition to aiding in load balancing more successfully. Encouraging off-peak use can result in a more even distribution of the demand for power throughout the day, which can reduce grid stress during peak hours and improve supply dependability.

Furthermore, there may be wider economic advantages to this tariff regime. Reduced operational dependency on expensive generators might result in large cost savings that could be transferred to customers, promoting a more sustainable and financially feasible energy market. It also conforms to international energy management best practices, where demand control and increased energy efficiency have been achieved via the effective application of dynamic pricing models. A positive step towards modernizing Pakistan's electrical industry, encouraging energy savings, and guaranteeing that customers take a more active role in controlling their electricity use is the move to a TOU rate structure. By reducing demand spikes and building a more flexible and robust energy system, this strategy can also aid in the integration of renewable energy sources.

The current tariff structure includes variable and fixed costs of generation, transmission charges, distribution charges, and market operator fees. These components are calculated by the National Electric Power Regulatory Authority (NEPRA) to ensure that the electricity providers can cover their expenses and achieve a reasonable return on their investments. The proposed tariff consists of two parts, where the first part is the current tariff and the second is the additional tariff termed X factor. The main objective of this study is to find this X factor, which will be integral to achieving a more efficient and equitable tariff system.

In addition to these fundamental costs, the X factor is introduced as a dynamic element designed to incentivize more efficient electricity consumption patterns among consumers. The purpose of the X factor is to reflect the marginal cost of supplying electricity during peak demand periods, thereby encouraging consumers to shift their usage to off-peak times. This not only helps in reducing the overall demand during peak hours but also maximizes the utilization of more economical generators during off-peak periods.

During peak hours, which typically run from 5:00 p.m. to 10:00 p.m., the rate will add this X factor on top of the standard residential electricity cost. It is designed to curb consumption while the grid is under the highest demand, as a way of reducing pressure on the electricity supply system and hence cutting costs by avoiding the activation of expensive peak-time generators.

The proposed model endeavours to create a more flexible and responsive pricing structure using the X factor that can respond according to the high-distorted electricity market demand. This in return fits the objectives of demand-side management, leading to a fairer and healthier electricity consumption behaviour. Additionally, it aligns with global best practices in energy management, where similar dynamic pricing models have been effectively implemented to manage peak demand and improve overall grid stability.

The introduction of the X factor not only supports efficient energy use but also contributes to broader economic objectives by potentially lowering operational costs and enhancing the financial viability of electricity providers. This dual-component tariff structure represents a significant step forward in modernizing Pakistan's electricity market, fostering greater consumer engagement, and ensuring a more reliable and cost-effective energy supply. The proposed tariff formula is defined by the equation 3.

$$New\ Tariff = Current\ Tariff + X\ factor \tag{3.3}$$

A correlation between the price and demand of power has been established through historical data analysis in order to identify the X factor. As was previously said, the fundamental principle is that demand is often negatively correlated with price. On the other hand, this connection is marginally inelastic in the context of total power use, meaning that changes in price lead to very tiny changes in demand. Because power is a necessary good, customers' ability to modify their consumption in reaction to price variations is limited, making the inelasticity in the electricity market especially noticeable.

Research findings from sources [124] and [125] have demonstrated that in developing countries, the dynamics of electricity consumption are significantly more influenced by fluctuations in income over an extended period than by variations in price. To be more precise, there is a direct correlation between rising income ranges and rising power consumption while falling income ranges tend to result in falling electricity demand. This correlation demonstrates how important income is in dictating consumption habits.

Further supporting this perspective, an article [111] provides a detailed analysis, presenting coefficients of 0.8 and 0.17 for income and price, respectively. According to these coefficients, income has a greater impact on electricity consumption than price fluctuations. This indicates that price changes do have an impact on demand, but it is far less important than income variations. There is a strong positive correlation between income and electricity demand, meaning that there is a significant rise in power consumption for the increase in income. In contrast, the coefficient of 0.17 for the price implies a much weaker negative correlation, indicating that price changes have a relatively minor impact on consumption behaviour.

In light of this, household income is included as a critical component in the suggested tariff model. To better represent the factors influencing energy usage, the model takes income into account in addition to price. This method suggests that, although price elasticity plays a significant role, income elasticity has a higher influence on the formation of long-term spending patterns.

Taking income into consideration while creating the tariff allows for a more complex and effective pricing approach. By keeping the tariff structure adjusted for both past and future variations in electricity prices, which affect consumer behaviour, it ensures compatibility. The inclusion of income and price elasticity in the tariff model makes it more equitable and realistic in its representation of the variables that genuinely influence consumption. It provides an excellent basis for determining the X factor as well.

The end result of this Tariff design incorporating ideas from these findings will in the interest to ensure consistent efficient energy use practice while respecting the economic burden struggling households face. By judiciously linking the tariff structure with income data, this creates a just and efficient tariff system that both incentivises sustainable electricity use and provides overall economic stability. The X factor is now divided into the following two additional parts:

$$X\ factor = \mathcal{F}_i + \mathcal{F}_p \tag{3.4}$$

The factors influencing the demand in equation 4 are represented by $\mathcal{F}_i$ for income and $\mathcal{F}_p$ for price. Electricity consumption tends to grow when household income rises and vice versa, as indicated by the income factor $\mathcal{F}_i$, which measures the impact of changes in income ranges on demand. Alternatively, the price factor $\mathcal{F}_p$ gauges how sensitive demand is to fluctuations in electricity rates, illustrating the idea that, while to a lesser extent than changes in income, higher costs usually translate into lower consumption. By including these variables in the formula, demand dynamics may be thoroughly examined, leading to a more realistic and accurate model for estimating electricity consumption depending on the state of the economy.

According to the Household Integrated Economic Survey by the Pakistan Bureau of Statistics [126], households on average spend 13.6% of their income on electricity. The income ranges relevant to this expenditure are detailed in table 3.2.

Table 3.2: Categorization of average monthly income into different ranges

Sr. No	**Income Ranges (Rs)**	**income range i, (Rs)**	**13.6% of i (Rs)**	**20% of i (Rs)**
1	Less than or Equal to Rs 40,000	40,000	5,440	8,000
2	Rs 40,000 to Rs 70,000	55,000	7,480	11,000
3	Rs 70,000 to Rs 100,000	85,000	11,560	**17,000**
4	Rs 100,000 to Rs 150,000	125,000	**17,000**	25,000
5	Rs 150,000 to Rs 200,000	175,000	23,800	35,000

Households regularly set aside 13.6% of their monthly income for power costs, according to historical statistics. Expanding on this knowledge, it makes sense to believe that customers will not spend more than this amount. A 20% income barrier is suggested, which is a value judged outside the affordable range of customers, in order to set peak-hour power costs that exceed their financial restrictions. The reason for choosing this 20% benchmark is that it roughly corresponds to 13.6% of the income group above it. For example, 20% of Rs 85,000 and 13.6% of Rs 125,000 represent Rs 17,000, as shown in Table 3.2. Since, historically, consumers do not spend more than 13.6% of their income on electricity, setting the electricity cost at this level is expected to push consumers towards reduced consumption during peak hours. Equation 5, which captures the affordability principle in the construction of the tariff system, formalizes this idea.

$$\alpha = \frac{Current\ Tariff}{13.6\%\ of\ income} \times 20\%\ of\ income \tag{3.5}$$

In equation 5, α will tell that how much a tariff should be for consumers to spend 20% of their income. Let ω_i be the weightage of the income affecting demand. The equation for the income factor affecting demand is mentioned in equation 6.

$$\mathcal{F}_i = \omega_i \times (\alpha - Current\ Tariff) \tag{3.6}$$

From the data notified by NEPRA, an average percentage change in tariff and demand is computed by equations (7) and (8), respectively.

$$\begin{gathered} average\ percentage\ change\ in\ tariff = \\ \frac{\left(\frac{\pi_{2022} - \pi_{2021}}{(\pi_{2022} + \pi_{2021})/2} \times 100 + \frac{\pi_{2021} - \pi_{2020}}{(\pi_{2021} + \pi_{2020})/2} \times 100 \right)}{2} \end{gathered} \tag{3.7}$$

$$\begin{gathered} average\ percentage\ change\ in\ demand = \\ \frac{\left(\frac{D_{2022} - D_{2021}}{(D_{2022} + D_{2021})/2} \times 100 \right) + \left(\frac{D_{2021} - D_{2020}}{(D_{2021} + D_{2020})/2} \times 100 \right)}{2} \end{gathered} \tag{3.8}$$

π_i and D_i are uniform electricity prices and demands for ith year, where i is 2020, 2021, and 2022. Let β be the percentage change in tariff for each slab reducing 1% of demand defined by equation (9) and represents the second column in Table **??** named “Tariff Increment”.

$$\beta = \frac{average\ percentage\ change\ in\ tariff}{average\ percentage\ change\ in\ demand} \tag{3.9}$$

For $\mathcal{F}_p$, let us assume that ω_p is the weightage of the electricity prices affecting demand, and β is the factor of price for each slab that is affecting demand. Therefore, the equation for the price factor affecting demand is mentioned in equation 10.

$$\mathcal{F}_p = \left[\omega_p \times \left((1 + \frac{\beta}{100}) + Current\ Tariff\right)\right] \tag{3.10}$$

The variable β, representing the increment in price, is concisely summarised in table 4.2, with the second column explicitly denoting its variations.

Substituting equations 6 and 10 in equation 4 results in the equation 11:

$$\begin{aligned} X\ factor = {} & [\omega_i \times (\alpha - Current\ Tariff)] \\ & + \left[\omega_p \times \left((1 + \frac{\beta}{100}) + Current\ Tariff\right)\right] \end{aligned} \tag{3.11}$$

Substituting equation 11 in equation 3:

$$\begin{aligned} New\ Tariff = {} & Current\ Tariff + [\omega_i \times (\alpha - Current\ Tariff)] \\ & + \left[\omega_p \times \left((1 + \frac{\beta}{100}) + Current\ Tariff\right)\right] \end{aligned} \tag{3.12}$$

Equation 12 is the final proposed equation that will be used to calculate the tariff during peak hours.

3.4 Hypothetical Case Study

Let us demonstrate the usefulness of the suggested equation with a real-world scenario. Let us consider a home that typically uses 215 kWh of power and has an income between 100,000 and 150,000 PKR. As of right now, the unit rate for this amount of use is Rs. 25.33 [51]. Let us now designate particular values for our variables:

ω_i = 0.8, α = Rs. 37.25, ω_p = 0.17, and β = 4.8.

Equation 12 is substituted with these values, and a new tariff of Rs. 39.38 is calculated. This revised tariff structure will apply to the consumer between the hours of 5 and 10 p.m. (peak hours) and Rs. 25.33 (off-peak hours). The example above demonstrates the practical application of our proposed pricing model, which seeks to align consumer spending with income ranges during peak power use. By striking a balance between revenue production and customer affordability, we want to establish a stable and equitable energy market in Pakistan through targeted rate increases.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Assigning Boundaries of Electricity Consumption against income ranges

From the survey data, the consumption of different income ranges and their density is plotted in figure 4.1.

Using figure 4.1, brackets of consumption are set for each income range, which is mentioned in table 4.1:

Table 4.1: Monthly assigned consumption against each income range

Monthly Income Range (Rs)	Monthly Consumption Boundaries	
	Min (kWh)	Max (kWh)
Less than or Equal to Rs 40,000	0.0	147.0
Rs 40,000 to Rs 70,000	147.0	171.0
Rs 70,000 to Rs 100,000	171.0	182.5
Rs 100,000 to Rs 150,000	182.5	223.0
Rs 150,000 to Rs 200,000	223.0	959.0

From figure 4.1, it can be seen that there is mostly no defined boundary for each income range. To obtain table 4.1, equation 1 is used.

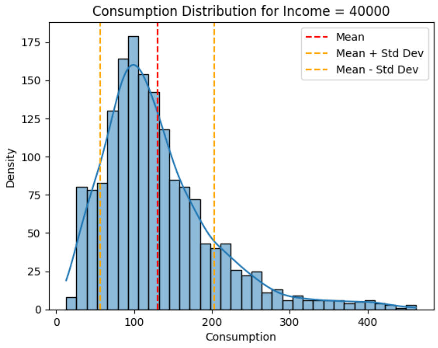
$$Mid_i = \frac{\mu_i + \mu_{i+1}}{2} \tag{4.1}$$

μ_i represents the mean consumption for the i^{th} income range, and μ_{i+1} represents the mean consumption for the $(i+1)^{\text{th}}$ income range. Mid_i represents the midpoint between the mean consumption of the i^{th} and $(i+1)^{\text{th}}$ income ranges. This midpoint serves as the upper limit for μ_i (lower-end income range) and the lower limit for μ_{i+1} (higher-end income range).

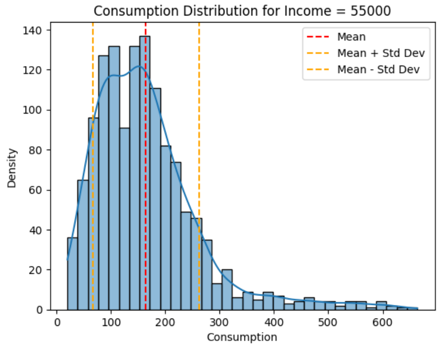
For example, for the income range less than or equal to Rs. 40,000, the mean point is 130.1663 kWh, and for Rs. 40,000 to Rs. 70,000, the mean point is 164.5183 kWh.

Therefore, μ_i = 130.1663 and μ_{i+1} = 164.5183. Putting these values into the equation 1.

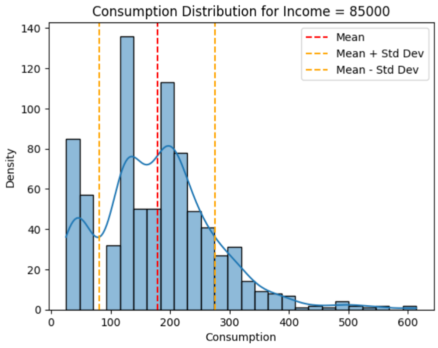
$$Mid_i = \frac{(130.1663)+(164.5183)}{2} = \frac{294.6846}{2} = 147.3423$$



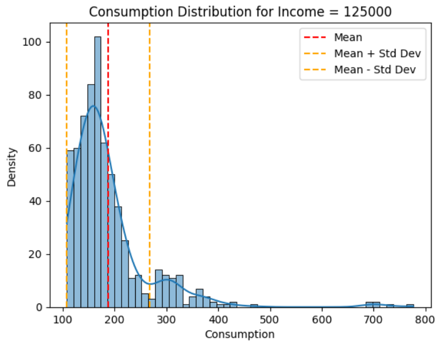
(a) Electricity consumption of users having monthly income of less than or equal to Rs. 40,000



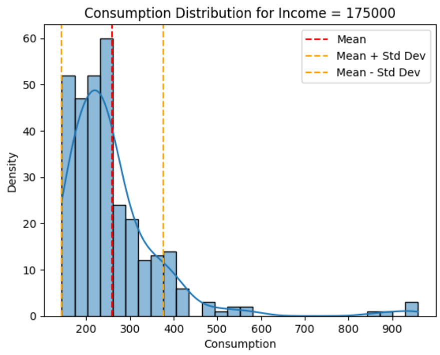
(b) Electricity consumption of users having monthly income of Rs. 40,000 to Rs. 70,000



(c) Electricity consumption of users having monthly income of Rs. 70,000 to Rs. 100,000



(d) Electricity consumption of users having monthly income of Rs. 100,000 to Rs. 1500,000



(e) Electricity consumption of users having monthly income of Rs. 150,000 to Rs. 200,000

Figure 4.1: Frequency graph of electricity consumption for users having a monthly income range of a) less than or equal to Rs 40,000. b) Rs 40,000 to Rs 70,000. c) Rs 70,000 to Rs 100,000. d) Rs 100,000 to Rs 150,000. e) Rs 150,000 to Rs 200,000

The midpoint is 147.3423 kWh, or approximately 147 kWh. This is the upper limit of lower-end income that is equal to or less than Rs. 40,000 and the lower limit of Rs. 40,000 and Rs. 70,000. The remaining income ranges go through the same process in a similar manner.

4.2 Relationship between Demand and Price according to NEPRA Data

The analysis of the historical data obtained from the NEPRA table 4.2 is created. In table 4.2, it can be seen that the price of every slab is affecting demand.

Table 4.2: Percentage reduction in demand by increasing price

Slabs (kWh)	**Demand Reduction (%)**	**Tariff Increment, β (%)**
Under 50	1%	13.0%
0-100	1%	1.18%
101-200	1%	1.23%
201-300	1%	1.48%
301-400	1%	1.77%
401-500	1%	1.77%
501-600	1%	1.77%
601-700	1%	1.77%
Above 700	1%	3.83%

Table 4.2 reveals that the required price increase varies significantly depending on the consumption level. A significant price increase of 13% is required for low-use slabs (less than 50 kWh) in order to persuade customers to cut their usage by just 1%. This implies that these users may require electricity to run basic appliances that are hard to reduce.

A similar pattern emerges in the 101-200 kWh and 201-300 kWh slabs. Here, price increases of 1.2% and 4.8%, respectively, are required for a 1% demand reduction.

On the other hand, the slabs with 301–700 kWh and 700 kWh and above show a lower price rise (around 1.8%) for the same 1% decrease in demand. This may point to a slightly more price-sensitive population, even if they are still inelastic. These customers could be able to purchase energy-saving products or utilize power for more discretionary purposes.

4.3 Proposed Tariff Rates for Each Slab

After getting table 4.1 and table 4.2, values are substituted in the proposed tariff equation 12. The new tariff, as derived from the proposed formula, is outlined in table 4.3. It is divided by the same slabs that are implemented now. Two tariffs are set for each consumption slab: a lower charge for non-peak hours and a higher rate for peak hours. Prices during off-peak hours start at Rs. 22.46/kWh for the lowest consumption tier (0-100 kWh) and go up to Rs. 30.3/kWh for usage exceeding 700 kWh. Prices are higher during peak hours; for instance, they go from Rs. 34.93/kWh to Rs. 47.51/kWh across the relevant use categories. This dual-tier tariff structure aims to promote energy conservation during peak hours by charging a lower rate during off-peak hours.

Table 4.3: Proposed tariff for peak hours

Slabs (kWh)	Current Tariff (Rs/kWh) For All Hours	Proposed Tariff (Rs/kWh)	
		Off-Peak Hours	Peak Hours
000-100	22.46	22.46	34.78
101-200	24.85	24.85	38.48
201-300	25.33	25.33	39.38
301-400	26.33	26.33	40.80
401-500	26.82	26.82	41.56
501-600	27.81	27.81	43.09
601-700	28.97	28.97	44.89
Above 700	30.30	30.30	47.06

4.4 Expected Results of Proposed Model

Analysis of the data shows that when the new tariff structure was put into place, there were significant declines in consumer demand. The first monthly usage figure for all 4765 users was 782043.6154 kWh. On the other hand, the anticipated monthly total consumption for the same customer base will drop to 770889.7493 kWh under the new pricing. It is imperative to take into account the critical load limit determined by the PRECON dataset [107], which is approximately equivalent to 106 kWh. This critical limit signifies the threshold below which consumers are unlikely to reduce their consumption further. The revised anticipated total monthly consumption for the 4765 users is therefore modified to 772271.1526 kWh in order to account for this restriction. The little predicted drop beyond the critical load limit is taken into account by this change. The difference in demand between the two cases is 9772.462825 kWh, which suggests a considerable decrease in total consumption. Each household is expected to reduce its monthly energy use by around 2.053038409 kWh on average. The household with a monthly usage of 959 kWh shows the largest drop, with a predicted decline to 938.139035 kWh, or a 20.86096504 kWh decrease. These results demonstrate the effectiveness of the new pricing structure in encouraging customers to use less energy, even if the impact varies depending on the consumption group.

A dataset covering unit consumption and tariff details for each slab, covering the years FY 2022, FY 2021, and FY 2020, was subjected to a linear regression analysis. The available data was used to train this model, which allowed for the prediction of new consumption levels based on the suggested tariff structure. Table 4.4 presents a summary of the analysis's conclusions.

Table 4.4: Predicted overall load of all slabs

Slabs (kWh)	Demand in 2022 (GWh) A	Predicted Demand (GWh) B	Reduction in Demand (GWh) C = A-B	Percentage Reduction (%) D = (C/A)x100
000-100	5,199.89	5,199.89	0	0
101-200	6,768.72	7,221.60	-452.89	-6.69
201-300	11,150.62	10,651.82	498.80	4.47
301-400	4,316.86	3,811.24	505.62	11.71
401-500	1,932.82	1,696.92	236.53	12.24
501-600	1,045.10	935.88	109.21	10.45
601-700	547.14	491.87	55.27	10.10
Above 700	780.01	731.67	48.33	6.20
Total	**31,741.16**	**30,740.26**	**1,000.89**	**3.15**

The objective of this investigation was to evaluate how well the suggested tariff structure will affect customer demand and maximise energy sector income collection. Policymakers may make educated judgements about tariff adjustments to achieve desired results in terms of revenue stability and consumption control by employing predictive modelling and extrapolating from past data.

Consumption inside the 101-200 slab deviated from predicted patterns and exhibited an unexpected increase. This abnormality demands more investigation to determine the underlying causes of this change. A potential reason may be a shift in the customer base from higher usage tiers to this range, which might be impacted by modifications made to the price structure. This theory is further supported by the study of historical data, which points to a relationship between price adjustments and customer behaviour. Historical data also shows that a decrease in customers has been seen in high-end slabs, whereas a rise in users has been seen in this slab. Table 4.5 provides the number of customers for each slab for the years FY2020, FY2021, and FY2022.

Table 4.5: Percentage of number of consumers for different slabs

Slabs (kWh)	Percentage of Consumers		
	FY 2020 (%)	FY 2021 (%)	FY 2022 (%)
000-100	7.09	7.34	8.61
101-200	9.25	9.98	11.21
201-300	22.65	21.61	18.46
301-400	10.43	9.19	7.15
401-500	10.43	4.20	3.20
501-600	2.53	2.23	1.73
601-700	1.34	1.18	0.91
Above 700	1.67	1.55	1.29

It can be clearly seen in table 4.5 that an increase in the number of consumers is observed in the slabs of 0-100 and 101-200; the rest of the slabs are experiencing a reduction. It can be inferred from this information that some high-end consumers have reduced their consumption over time due to an increase in electricity prices.

Nevertheless, except for this one observation, the entire study shows a promising direction. Although there is an exception in the 101-200 slab, the overall trend points to a positive outlook. Forecasts indicate a consistent yearly decline in load of 3.15%, which translates into a significant reduction in energy usage of 1000.89 GWh. This encouraging pattern highlights how well the suggested pricing structure works to encourage demand control and energy savings.

Looking ahead, it is essential to delve deeper into the specific drivers behind the observed increase in consumption within the 101-200 slab. By understanding these dynamics more comprehensively, policymakers and stakeholders can refine strategies to optimise the tariff structure further and enhance its efficacy in achieving energy efficiency goals.

The proposed price structure seeks to encourage customers to modify their usage patterns in order to achieve this goal, especially by moving activities to off-peak hours. The purpose of this project is also to make money in order to fund important projects related to the production of energy. The tariff structure aims to achieve equilibrium between the objectives of sustainable energy management and customer interests by harmonizing these two goals.

As a result, even if there is an unexpected rise in consumption within the 101–

200 slab, the general trend indicates that efforts to meet energy efficiency objectives are making progress. This emphasizes how crucial it is to keep an eye on the tariff structure and make necessary adjustments to guarantee that it continues to encourage the use of renewable energy sources.

4.5 Regulatory Policy Recommendations

Developing a comprehensive regulatory framework, which will be called the ”National Demand-Side Management program,” is a prerequisite for formulating a policy at the national level to support demand-side management. The main objective of this policy is to reduce energy consumption during peak hours and improve grid stability. It is specifically designed to encourage and reward demand-side management measures among customers. Some of the essential elements of the regulatory policy are outlined below:

During off-peak hours, the current tariff calculation standards will be followed, guaranteeing uniformity and openness in pricing procedures. The determination of electricity tariffs is based on a range of factors, including but not limited to market circumstances, regulatory regulations, and generation costs.

Equation 2 will be used to calculate electricity tariffs during on-peak hours, guaranteeing that the pricing appropriately reflects supply and demand dynamics during these times of increased use.

$$\begin{aligned} New\ Tariff &= Current\ Tariff + [\omega_i \times (\alpha - Current\ Tariff)] \\ &+ \left[\omega_p \times \left((1 + \frac{\beta}{100}) + Current\ Tariff\right)\right] \end{aligned} \tag{4.2}$$

This method, which takes into account a number of variables, including market dynamics, generating costs, and patterns of peak demand, aims to balance the needs of energy providers in terms of income generation with those of customers. Through the use of a customised formula for peak hours, the price structure is made more adaptable to actual variations in energy consumption, which in turn encourages resource efficiency and improves grid stability. A dedication to accuracy and equity in tariff computation is further demonstrated by the establishment of a specific formula, which promotes accountability and transparency throughout the ecosystem of the electrical market.

In order to enable efficient tracking and control of energy usage trends, Time-of-Use meters will be installed everywhere, regardless of the type of consumer. Integration of applications to inform consumers about current tariff rates and provide alerts for load reduction during peak demand periods. Utilization of these applications to streamline load management processes and engage with appliance manufacturers to incorporate demand-side management features.

A specialized committee will be formed to supervise the program's execution and advancement. Both customer involvement and program efficacy will be guaranteed by this committee. Customers who actively contribute to the creation and success of demand-side management programs will get financial rewards. Conducting a comprehensive public awareness campaign to educate and encourage consumers to actively participate in demand-side management practices, thereby fostering program success and sustainability. Developing a strategy that takes into account both the country's current and future energy demands is essential, since reasonable, long-term energy plans are essential to a nation's well-being [127]. With the help of this strategy, long-term energy security and economic stability are intended to be supported within a sustainable framework.

In order to tackle Pakistan's current energy usage and grid stability issues, the "National Demand-Side Management Program" was created. By putting these policies into practice, the program hopes to build a more sustainable and effective energy ecosystem, guaranteeing that the nation can satisfy its energy demands while fostering environmental sustainability and economic progress. The achievement of energy efficiency and sustainability as a shared aim by a number of stakeholders, including consumers, regulatory agencies, and business leaders, will be essential to the success of the program.

4.6 Deployment Challenges

There are several obstacles to overcome in Pakistan while implementing the suggested pricing framework, particularly given that the country is still in the process of developing. The following challenges are anticipated during the implementation of this model:

4.6.1 Consumer Education

Educating consumers is pivotal for the success of demand-side management. It will be extremely difficult to inform customers about the significance of demand-side management and how they can actively participate, as its efficacy depends on consumer behaviour. Pakistan's varied population and varying educational attainment levels make this effort much more difficult, calling for extensive and easily accessible teaching initiatives.

4.6.2 Lack of Advanced Energy meters

Currently, the TOU metering required for the proposed tariff is only available for 3-phase meters, whereas, the single-phase meters do not have the TOU metering. Upgrading to advanced energy meters is important because traditional energy meters cannot deliver the required level of data granularity. For a developing country with limited resources, this upgrading is a major challenge since it demands a huge time commitment, financial expenditure, and logistical preparation.

4.6.3 Advanced Data Storage Systems

Deploying the model demands for a sophisticated system that can collect, store and analyze electricity consumption data on an hourly basis. One thing in addition to a large fiscal outlay that might be keeping this sort of system from being developed and maintained is the lack infrastructure or expertise. The issue is further complicated by the requirement that data be secure and reliable.

4.6.4 *Financial Constraints*

The cost of upgrading the metering infrastructure, deploying state of the art data storage solutions and launching widespread consumer education programs is not insignificant. This will require responsible fiscal planning based on the broke economic budgetary inability nation like Pakistan which may also need outside support in looking for needed finance.

4.6.5 *Regulatory and Institutional Barriers*

Setting up a new tariff structure will require regulators to plunge into labyrinthine bureaucratic processes. Coordination across different regulatory and governmental agencies will be necessary, not to mention the development of new guidelines and standards. In addition, overcoming institutional reluctance to change or even political barriers would make the process more complicated.

4.6.6 *Technical Expertise and Capacity Building*

Since this is a very high technology system so the technical expertise for its implementation may not be available right now in Pakistan. Workforce development training and capacity-building programs will be needed to prepare the workforce with the skills to operate and maintain this new infrastructure. It will require the participation of international experts and money for education and training.

4.6.7 *Consumer Acceptance and Compliance*

The new pricing system may be difficult for consumers to understand and comply with, even with adequate education. If customers feel that the new rates will be expensive, they may be reluctant to accept adjustments to their invoicing and usage habits. To gain customer acceptance, it will be crucial to establish trust and highlight the advantages of the new system.

4.6.8 *Pilot Testing and Scaling*

Before full-scale implementation, pilot projects will be necessary to test the feasibility and effectiveness of the new tariff structure. Before the model is implemented nationally, these pilots must be carefully planned and closely watched, and the lessons acquired must be used to enhance the model. Overcoming operational and logistical obstacles is necessary to scale up pilot programs to full execution.

Although the above bullets highlight some of the main issues, they are by no means all-inclusive. There is no question that putting the proposed tariff system into effect would bring additional, unanticipated difficulties that the implementing bodies would need to deal with. These difficulties underline the necessity of a comprehensive, well-coordinated strategy involving a variety of stakeholders to guarantee the program's effective implementation and the accomplishment of its goals in encouraging sustainable energy consumption patterns in Pakistan.

In order to guarantee the program's successful implementation and achieve its goals of encouraging sustainable energy consumption practices in Pakistan, it will be imperative to successfully address these obstacles. Despite its difficulty, this project has the potential to change the nation's energy environment by increasing energy efficiency, lowering dependency on expensive energy sources, and eventually creating a more robust and sustainable energy system.

4.7 Policy Targets

The main objectives of this project are to improve the effective and efficient use of installed variable renewable energy (VRE) sources in conjunction with the tactical use of demand-side management strategies to optimize patterns of energy consumption. Overall energy stress is expected to be significantly reduced by carefully easing the burden on grid stations, especially during times of peak demand. Through the prevention of outages and enhancement of the power grid's overall performance, this strategy guarantees a more steady and dependable electricity supply. Moreover, the increased integration of renewable energy sources is expected to reduce peak load requirements, which will reduce reliance on fossil fuel importation. Transitioning away from fossil fuels not only reduces greenhouse gas emissions but also corresponds with the national goal of a 50% reduction by 2030. Furthermore, the seamless integration of VRE sources is expected to draw international investment into Pakistan's burgeoning power industry, accelerating economic growth and supporting the country's energy resilience and sustainability efforts.

Variable Renewable Energy (VRE) electricity has the potential to provide several secondary advantages in addition to its core goals, supporting Pakistan's socioeconomic landscape and total energy infrastructure. As more rural areas choose VRE, electrification projects will grow, and the country's installed capacity will undoubtedly increase. This will create the foundation for better electricity availability and dependability in previously underserved areas. By supporting the supply of vital services like healthcare, education, and commerce, this expansion would not only improve the standard of living for those living in rural areas but also promote all-encompassing regional development.

Due to the necessity for both skilled and unskilled labour in these locations, the implementation of VRE projects in rural communities offers a special chance to promote local economic growth. The expansion of work options promotes increased economic stability and prosperity at the local level, which helps to reduce poverty and empower people on a socioeconomic basis. The program can assist in creating a competent labour force that can support the long-term sustainability of renewable energy solutions by offering jobs in the installation, upkeep, and operation of VRE systems. Additionally, the implementation of VRE will enable competitive energy rates to be introduced, and this, together with possible changes in consumer behaviour towards more sustainable energy habits, might improve the overall sustainability and efficiency of Pakistan's energy sector. By leveraging the transformative potential of VRE deployment beyond its immediate energy benefits, Pakistan can pave the way for a more inclusive, prosperous, and sustainable energy future for all its citizens.

Apart from the economic and environmental advantages, it is anticipated that the extensive implementation of VRE will spur technological advancements and infrastructural enhancements throughout the energy industry. In addition to increasing its ability to produce and control renewable energy, the country will provide the technological foundation needed to enable further developments. As a result, a more sophisticated and robust energy system that can include different renewable energy sources and adjust to fluctuating energy needs may be built. When these initiatives are combined, they would not only improve energy security but also establish Pakistan as a pioneer in renewable energy in the area, serving as an example for other developing countries to aspire to.

The ultimate goal of the suggested project is to build Pakistan's energy ecosystem to be more robust and sustainable. It seeks to maintain the nation's long-term energy security, encourage economic growth, and lessen dependency on fossil fuels by striking a balance between the demands of industrial and household customers. The study emphasizes how crucial thorough planning, strong regulations, and stakeholder involvement are to achieving these goals and facilitating the effective use of the suggested tariff scheme. With the help of this all-encompassing strategy, the advantages of renewable energy will be optimized, offering sustained benefits to Pakistan's environment, economy, and society at large.

4.8 Expected Outcomes of the Proposed Program

The proposed tariff structure will have a major positive impact, especially in terms of peak shaving and improving grid stability during peak hours. It is possible to lessen the strain on the national grid at times of peak demand by providing incentives for users to modify their patterns of energy consumption. This would increase grid stability. In [128], authors have shown that the different off-peak and on-peak prices have an impact on unit consumption and are not that much affected by rooftop solar panels. The program has important indirect effects as well. In [129], it is stated that dynamic tariffs have improved economic efficiency. Furthermore, [130] mentioned that the dynamic tariff can increase the adaptation of RESs more than the constant tariff, which can further help in reducing peak load. Dynamic tariff is also encouraged by [131]; their results reveal that the dynamic tariff is effective in improving the profitability of the retailer. Reducing reliance on fossil fuels is a corollary of employing variable renewable energy (VRE) sources to meet energy demand. This is in line with national emissions reduction and environmental sustainability goals. By switching to greener energy sources, hazardous fuel emissions are also decreased, supporting national emission reduction objectives and encouraging environmental conservation efforts.

However, as customers are essential to the program's success, the initiative's success depends on good consumer participation and education. Customers must be made aware of the significance and ramifications of demand-side management for this program to be implemented successfully since it transfers some of the risks related to peak demand management to them. [132] showed that using demand-side management incentives with market regulations can lead to additional reductions in individual electricity consumption, heightened retail profitability, and decreased electricity expenditures for consumers.

In addition to encouraging more flexibility in energy use, this dynamic tariff system emphasises how crucial it is to include renewable energy sources in the national energy grid in order to improve sustainability and resilience. Therefore, the policy will ensure that higher VRE is utilised even during times of low demand. Furthermore, as electric vehicles (EVs) gain popularity at an increasing rate, officials must ensure that EVs are smoothly incorporated into the energy grid. Complex obstacles are presented by this shift, such as the threat of impending grid congestion, which is discussed in [133]. Tariff structure design becomes even more important since it has a significant impact on system voltage dynamics, which is essential for maintaining the grid's safety and effectiveness. Tariff frameworks are essential for controlling power use and preventing possible grid disturbances brought on by the rising number of electric vehicles (EVs) since consumer behaviour has become more sensitive to price systems [134]. Thus, policymakers must adopt a proactive stance, incorporating provisions for EV integration within their policy frameworks to foster a harmonious convergence of transportation and energy sectors, advancing the sustainability agenda while safeguarding grid reliability.

CHAPTER 5: CONCLUSIONS AND FUTURE RECOMMENDATIONS

5.1 Conclusion

An advanced, efficient, and fair tariff structure is essential for optimising electricity use, incentivizing demand-side management, and driving consumer behavioural changes. This paper examines various tariff structures, including flat rate, block rate, Time-of-Use (TOU), real-time pricing, and two-part real-time pricing tariffs. Given that 80% of the electricity load in Pakistan is domestic, this sector is the primary focus of the proposed tariff model.

The goal of the suggested approach is to rectify the shortcomings in the present tariff structure, which insufficiently motivates customers to efficiently control their power use. The approach charges customers different rates at different times of the day by introducing Time-of-Use pricing, with a focus on peak hours from 5 p.m. to 10 p.m. By redistributing demand, this strategy aims to minimise the need to run expensive generators during peak hours and enable the usage of less expensive generators during off-peak hours. Because they account for a significant portion of the total electrical load, domestic users are the focus of demand-side control efforts.

The paper introduces a novel electricity tariff structure tailored for domestic consumers in Pakistan, aiming to optimise revenue generation while ensuring affordability and energy efficiency. Based on consumer income and the price elasticity of demand, the suggested approach determines tariffs using information from NEPRA, the PRECON dataset, and an extensive survey. The study highlights the substantial contributions of industries, notably the textile industry, to Pakistan's GDP, exports, and employment and stresses the need to give the industrial sector the first priority when allocating energy to promote economic growth.

The Time-of-Use (TOU) model in the proposed tariff structure charges customers different rates at different times of the day in order to solve the inefficiencies in the present system. With a special focus on the hours of 5 p.m. to 10 p.m., this plan seeks to reallocate demand and lessen the need to run expensive generators during these times. The model optimises overall system efficiency by allowing the use of more cost-effective generators by moving a portion of the load to off-peak hours.

Furthermore, the study underscores that while industrial growth is crucial for economic advancement, it should not come at the expense of domestic consumers. To properly support all sectors, a balanced approach to energy allocation is recommended. In addition to improving grid efficiency and stability, the suggested tariff offers a means to use energy sustainably, promoting consumer welfare, and economic growth.

50% of the electrical units sold in 2022 went to domestic users, bringing in Rs. 970,531 million in income. The remaining 26% of the units sold went to the industrial sector, which brought in Rs. 793,823 million. The study emphasises that, despite the emphasis on industrial expansion, household welfare should not suffer in favour of industrial growth. Instead, it calls for a balanced approach to energy allocation that benefits both sectors. Based on the PRECON dataset, the suggested pricing structure seeks to lower customer demand while maintaining a minimal critical consumption limit.

Although customer behaviour adjustments in reaction to increased pricing may result in increased consumption in the 101-200 slab, which is also observed in the historical data that high consumption users tend to move to lower slabs because of high prices, linear regression analysis indicates an annual load decrease of 3.15% across various consumption slabs. This strategy makes sure that household users' basic requirements are satisfied even as they are urged to use power more wisely. In the end, the suggested strategy would benefit Pakistan's consumers and economy by encouraging sustainable energy behaviours in addition to improving overall grid reliability.

Developing sophisticated data storage systems, installing modern metering infrastructure, and educating customers are key obstacles that must be overcome to implement the suggested pricing structure. These obstacles are substantial for a growing nation such as Pakistan, and their resolution calls for careful preparation and calculated moves.

A thorough regulatory policy is outlined in the study to help with program execution. In order to guarantee that the suggested tariff structure is successfully adopted, this policy outlines both major and secondary aims. By tackling these fundamental problems, the policy hopes to foster an atmosphere that will support the new tariff structure and, in the end, result in a framework for the more fair and efficient distribution of power that is advantageous to all parties involved.

The study also covers the wider economic ramifications of the suggested tariff regime. The concept tries to raise industrial production by moving the focus to the industrial sector, which can result in more employment opportunities and accelerated GDP growth. The goal of the suggested model is to eliminate inefficiencies in the present tariff structure that prevent users from being encouraged to use power efficiently.

The suggested approach charges customers different fees at different times of the day by introducing a Time-of-Use (TOU) tariff, with a focus on peak hours from 5 p.m. to 10 p.m. The goal of this strategy is to reallocate demand so that less expensive generators may be used during off-peak hours and more expensive generators can be used during peak hours. The proposed TOU tariff structure is designed not only to optimise energy usage but also to ensure affordability and efficiency, ultimately leading to a more balanced and sustainable energy consumption pattern.

The proposed tariff structure not only aims to reduce the peak load on the national grid but also promotes energy conservation and financial savings for consumers. It improves grid stability and facilitates the efficient use of energy resources by promoting demand-side flexibility. The model also supports the creation of a regulatory framework to handle potential obstacles and enable a seamless transition, ensuring the long-term application of the suggested tariff structure.

The regulatory structure calls for creating sophisticated data storage solutions, guaranteeing the construction of modern metering infrastructure, and educating customers about the advantages of the new pricing system. The framework facilitates a gradual transition towards more efficient energy consumption habits by surmounting these obstacles. This all-encompassing policy aims to ensure long-term prosperity and stability by fostering a sustainable and balanced energy strategy that is advantageous to the environment and the economy alike.

The ultimate goal of the suggested remedy is to build Pakistan's energy environment to be more robust and sustainable. It seeks to maintain the nation's long-term energy security, encourage economic growth, and lessen dependency on fossil fuels by striking a balance between the demands of industrial and household customers. The study emphasizes how crucial thorough planning, strong regulations, and stakeholder involvement are to achieving these goals and facilitating the effective use of the suggested tariff.

Achieving these goals requires addressing significant challenges, including consumer education, advanced metering infrastructure installation, and sophisticated data storage solutions. The proposed tariff structure, particularly its Time-of-Use model, charges different rates during various times of the day to redistribute demand and minimise peak load pressures. This strategy supports a more reliable and efficient grid system by encouraging users to save money in addition to using energy more efficiently.

For the proposed model to be successful, a well-considered regulatory framework that resolves potential roadblocks and facilitates a smooth transition is necessary. This framework must ensure the continued participation of stakeholders, such as lawmakers, corporate executives, and consumers, in order to adjust to shifting market conditions and energy demands. The concept aims to create a robust energy infrastructure that protects Pakistan's energy future, fosters economic and environmental benefits, and promotes innovation and teamwork.

In summary, there are many potential benefits to efficient demand-side management, despite the associated difficulties. Pakistan can steer towards a more sustainable, egalitarian, and efficient energy environment and ensure a better future for future generations by working together with utilities, customers, and politicians. Pakistan may lead the way towards a more sustainable and affluent future by adopting cutting-edge pricing structures and encouraging proactive consumer engagement.

5.2 Recommendations

A national survey can provide more information about the relative effects of price dynamics and income on the amount of electricity used. Comprehensive research of this kind will help policymakers understand consumer behaviour better and create demand-side management plans that cater to a wide range of demographic groupings. By understanding how different income ranges and price changes influence electricity consumption, more effective and equitable tariff structures can be developed.

Additionally, there is a good probability that demand-side control initiatives would increase if initiatives like IESCO's pilot project for installing Advanced Metering Infrastructure (AMI) in Rawalpindi [135] were launched nationwide. The nationwide adoption of AMI technology would not only offer a plethora of data for assessing consumption patterns, but it would also lay the groundwork for focused initiatives meant to promote sustainability and energy efficiency in general. AMI can provide real-time data on electricity usage, allowing for more precise monitoring and management of energy consumption.

Investing money in renewable energy sources is also crucial. Hydropower, wind, and solar energy all have enormous promise in Pakistan. Enhancing energy security, lowering greenhouse gas emissions, and reducing reliance on fossil fuels can be achieved by increasing the proportion of renewable energy in the energy mix. Government policies should support the development and integration of renewable energy projects through subsidies, tax incentives, and streamlined regulatory processes.

Improving energy storage capacity is yet another essential area that needs to be improved. Batteries and other energy storage devices have the ability to store extra energy produced during off-peak hours and release it during periods of high demand. This can facilitate the incorporation of variable renewable energy sources, lessen the need for peaking power plants, and assist in balancing supply and demand.

Finally, promoting energy efficiency across all sectors is crucial. Implementing energy efficiency standards for buildings, appliances, and industrial processes can significantly reduce overall energy consumption. Public awareness campaigns and incentives for the adoption of energy-efficient technologies can further encourage consumers to reduce their energy usage. By implementing these suggestions, Pakistan can build a more resilient, sustainable, and effective energy sector that serves the needs of all of its customers while fostering environmental sustainability and economic progress.

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