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for Equitable Development

RURAL ELECTRIFICATION IN BALOCHISTAN

Challenges to meet Nushki district's electricity demand

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Executive Summary

The problems of energy and specifically lack of electricity access or unreliable grid supply in the rural areas of Pakistan have worsened over the years. Six underserved rural areas in the Nushki district of Balochistan were selected to conduct an on-field survey to gauge the real-time situation of rural areas in Pakistan. The survey provided detailed information on households' basic energy demand, the socioeconomic characteristics of the regions, and their reliance on traditional fuel such as wood and animal waste. The results revealed that the area was facing a severe energy crisis. While approximately 90percent of the households are electrified, they receive an unreliable electricity supply, with an average of two to three hours of electricity supply daily. This study utilizes the Low-range Energy Alternatives Planning (LEAP) model to perform a scenario-based analysis of the basic household existing demand patterns and future demand projections of the region. The scenarios include business as usual, China Pakistan Economic Corridor (CPEC) development, and optimistic scenarios, and highlight the need for decentralized energy systems, clean cooking solutions, and infrastructural development. The demand projections of these scenarios necessitate immediate strategic investments in the region combined with tailored policy reforms, particularly for Nushki.

Survey Insights:

1. Demographics and Socioeconomic Characteristics:

» The average household size is approximately 10 individuals. (That includes an average of 4 women and 5 children per household.)

» Most households fall into low-income brackets, with 72.3percent categorized as having limited financial stability.

» The primary sources of income include farming (33percent) and daily wage labor (12percent).

» Educational access remains limited, with 30percent of children not attending school.

2. Energy Usage Patterns:

» Households reported low voltage levels (<220V), forcing many to supplement their energy needs with solar (photovoltaic) PV systems.

» Traditional biomass fuels dominate, with 84percent of households relying on wood for cooking, contributing to significant Scope 1 emissions.

» The use of modern appliances such as refrigerators and electric stoves remains limited due to financial and infrastructural constraints.

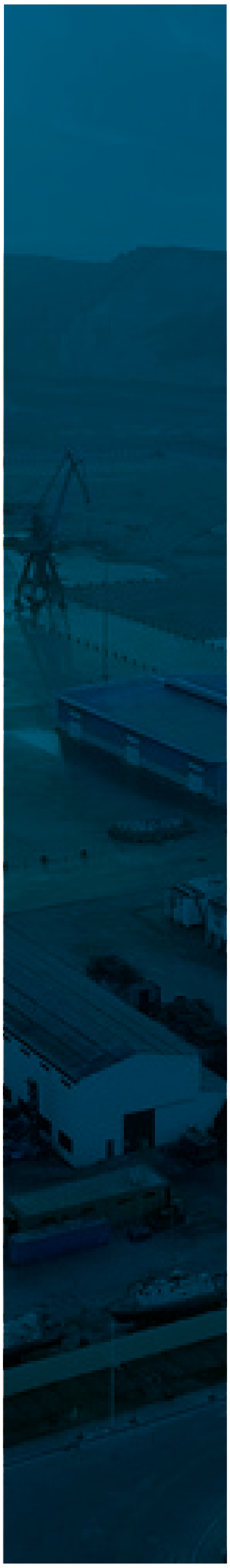
3. Electricity Demand and Supply:

» Urban extension feeders account for only 37.6percent of electricity connections, with rural feeders supplying the majority.

» Electricity consumption patterns reflect inefficiencies, such as high cooling loads due to outdated appliances.

Scenario analysis using the LEAP model

Three scenarios were developed to project future energy demand and assess the impacts of various policy and infrastructure developments:



Business-as-Usual (BAU)

- Limited policy and infrastructural improvements result in continued reliance on traditional fuels and minimal adoption of modern appliances.
- Total electricity demand is projected to rise by 67.8percent by 2035, driven by increasing population and growing cooling loads.
- Emissions are expected to increase by 28percent, reaching 253.1 metric tonnes of CO2 equivalent (CO2e) by 2035, due to persistent reliance on biomass fuels.

CPEC Scenario

- Assumes regional development spurred by China-Pakistan Economic Corridor (CPEC) projects for economic zones and infrastructure improvements.
- For a 4percent household growth rate by 2035 Electricity demand increases by 85percent, reaching 422,700 kWh for 1250 households by 2035, as income levels improve and adoption of efficient appliances rises.
- Under the CPEC scenario[1], several infrastructure development projects are planned, that include road infrastructure, hospitals, and clean water facilities. Gwadar Airport[2] is one of the most important development projects under CPEC.
- Biomass fuel usage for cooking decreases to 60percent, leading to reduced emissions growth (226.5 metric tonnes CO2e by 2035).

Optimistic Scenario

- Aligns with the government's renewable energy targets under the National Electricity Plan 2023 and Alternative Renewable Energy Policy 2019.
- Significant electrification reduces reliance on traditional fuels, with electricity demand increasing by 177percent by 2035.
- Emissions decrease from 197.6 metric tonnes CO2e to 149.6 metric tonnes CO2e by 2035, highlighting the benefits of transitioning to cleaner energy solutions.

1 https://cpec.gov.pk/gwadar

2 https://cpec.gov.pk/project-details/33

Chapter no. 1

Introduction

Sustainable Development Goal (SDG) 7.1 which seeks to ensure access to affordable, reliable, sustainable, and modern energy for all, is particularly relevant to Pakistan. The country's ongoing electricity crisis has severely impacted its economy, contributing to financial instability and debt accumulation. At the heart of this issue lies ineffective demand forecasting, which exacerbates challenges like line losses, nationwide blackouts, and frequent load-shedding. Despite some progress, 56 million[3] people still reside in off-grid areas of Pakistan without access to electricity, while many more live in weak-grid regions.

The energy sector's restructuring efforts have largely focused on short-term financial solutions rather than investing in long-term sustainability of the sector such as addressing the outdated grid infrastructure. This infrastructure issue is a critical barrier to integrating cheaper renewable energy (RE) sources into the grid. Despite having vast potential in solar, wind, and bioenergy, Pakistan lags behind many regional peers in renewable energy adoption - standing at merely 5percent[4] in 2023-24 - and generates a large share of its energy from imported fossil fuels. This dependency on imported fossil fuels is further compounded by stark energy disparities, particularly between urban and rural areas. While 11percent[5] of the population has access to air conditioning, the majority lack even basic electric appliances. The resulting energy poverty is further aggravated by regular power outages, which disrupt daily life, and perpetuate inequitable access to energy. According to the National Transmission and Dispatch Company (NTDC), Pakistan faced three major outages in the fiscal year 2021-22, with an Energy Not Supplied (ENS) amounting to 4.62 million kilowatt (kWh)[6], highlighting the scale of the crisis. ENS refers to the amount of electricity energy that customers are unable to receive due to faults or failures in the electricity supply system. The widening supply and demand gap and energy insecurity underscore the need for reforms focused on underserved regions, particularly rural and remote areas. Rural electrification becomes a vital step in bridging the energy divide and ensuring that marginalized and off-grid communities are not left behind. For these people, the lack of reliable electricity access is not just an inconvenience but an impediment to their economic uplift, healthcare access, and education—all of which depend on an affordable, reliable, and sustainable supply of electricity.

3 https://www.sciencedirect.com/science/article/pii/S2667095X23000235

4 https://app.powerbi.com/view?r=eyJrIjoiNWFjZDAxMWEtYTNiNy00MDIxLTk0YmEtZjk4OTExYTQzMTE0IiwidCI6IjdjMjY4YT-dhLTZiZWEtNGUwOS1iZjM1LWZjNDFlMGY5ODU3YiIsImMiOjl9

5 https://www.clasp.ngo/wp-content/uploads/2023/12/Cooling-Needs-Assessment-2022.pdf

6 file:///C:/Users/LENOVO/Downloads/Performance%20Evaluation%20Report%20of%20Transmission%20Companies%202023-24%20(1).pdf

Pakistan's rural areas, especially in provinces like Balochistan, and Khyber Pakhtunkhwa (KPK), face severe challenges in energy accessibility and affordability. In Balochistan, for instance, 43percent of households are unelectrified, with some relying on self-sustainable solar PV systems while others remain in off-grid areas. Only 57percent receive electricity through the grid. Additionally, 70percent[7] of households depend on firewood for cooking, exposing them to indoor air pollution and its associated long-term health risks. Even though Balochistan is rich in solar and wind potential, much of this renewable resource remains untapped due to inadequate infrastructure and limited policy support. These marginalized communities confront the dual burden of geographical remoteness and insufficient energy infrastructure, making their inclusion in the broader economy and energy transition even more critical.

Addressing these challenges requires a strategic shift toward demand-side management (DSM), renewable energy integration, and the development of micro-grids to enhance energy accessibility in these underserved regions. Globally, the transition from fossil fuels to renewable energy has demonstrated significant benefits, with 521 million dollars saved in 2022 alone, due to increased adoption of renewables. Micro-grids, in particular, hold immense potential for supporting off-grid communities, as evidenced by successful rural electrification efforts in countries like Nigeria, where 75 mini-grids are operational serving about 160,000 people.[8]

However, overcoming barriers such as intermittency, storage, and accessibility in marginalized regions will require advanced energy storage technologies and inclusive policy reforms. As the number of publications and research on electricity demand forecasting grows[9], so does the emphasis on the importance of demand-side management (DSM) and integrating renewable energy into the grid to solve these long-standing challenges. This research utilizes primary data collected through surveys to analyze existing energy demand in an underserved region and employs LEAP modeling tool to forecast future demand scenarios. The insights gained from this analysis aim to inform policy development and guide the implementation of targeted development projects.

7 https://www.pbs.gov.pk/sites/default/files/population/2023/tables/balochistan/pcr/table_22.pdf

8 https://www.get-transform.eu/nigeria-case-study-financing-instruments-for-the-mini-grid-market/

9 https://www.mdpi.com/2071-1050/12/15/5931#B3-sustainability-12-05931

Chapter no. 2

Integration of solar and wind energy: Opportunities for utility-scale VRE projects in Balochistan

The integration of Variable Renewable Energy (VRE), sources of energy whose electricity generation fluctuates due to environmental conditions, particularly solar and wind energy, into Pakistan's grid presents a viable solution to the country's ongoing energy crisis. The country faces a range of energy-related issues, such as surplus capacity, unreasonably high capacity payments, hefty imported fuel costs, obsolete grid infrastructure and an ever-worsening supply-demand gap. Furthermore, the environmental and livelihood costs of current energy production methods, especially from fossil fuels, impose additional burdens on indigenous communities. While intermittency and storage concerns are often cited as barriers to VRE integration, advancements in energy storage technologies, such as Li-ion batteries, demonstrate that these challenges can be effectively addressed. Li-ion batteries are comparatively low maintenance, and do not require scheduled cycling to maintain their battery life. The problem of intermittency can be overcome through the commercialization of efficient storage devices and additional solutions for VRE integration. These include demand-side management to align consumption patterns with generation patterns, grid modernization for seamless VRE integration, regional power pooling to balance supply and demand, hybrid renewable systems to ensure steady baseload power, advanced forecasting techniques for optimized grid operations, and decentralized energy solutions like micro-grids and community solar projects to localize energy production effectively.

Pakistan possesses significant potential for both solar and wind energy, particularly in regions like Balochistan. As of 2023, the estimates show that Pakistan has a solar potential of 40 GW[10] and a wind potential of 50 GW[11]. Despite this, Pakistan lags behind global standards when it comes to integrating VRE into the grid. Balochistan, in particular, holds vast promise due to its high levels of Direct Normal Irradiance (DNI) or beam radiation, making it the most solar-rich region in Pakistan, while also offering excellent conditions for wind energy generation. As a result, Balochistan is seen as a key area for VRE integration.

A recent VRE locational study[12] outlines three integration scenarios, outlining the capacity for VRE in the grid up to the year 2030. In the short-term scenario for 2023, interconnection-ready sites[13] allow Balochistan to contribute 1,850 MW. By the medium-term scenario for 2025, these figures increase to 1,150 MW for Balochistan, while at

10 https://tribune.com.pk/story/2420254/can-pakistan-capitalise-on-solar-as-it-becomes-popular

11 https://dailytimes.com.pk/1132262/harnessing-pakistans-wind-power-potential/#:~:text=According%20to%20the%20Alternate%20Energy,in%20developing%20its%20wind%20sector.

12 World Bank. 2021. Variable Renewable Energy Locational Study. Pakistan Sustainable Energy Series. Washington, DC: World Bank.

13 Interconnection ready sites*: locations which do not require any grid reinforcement for the additional feed-in from new power plants

the moment the existing solar and wind capacity in Balochistan is zero, reflecting that potential has not been explored, and any projects that were planned in Balochistan in the past decade have not been realized at all. In the long-term scenario for 2030, Balochistan (QESCO area) is expected to add 6,150 MW of VRE to the grid, making it the primary region to scale up renewable energy integration.

To facilitate the integration, transmission infrastructure is critical. One of the key proposals is the construction of an High Voltage Direct Current (HVDC) transmission line that would connect Balochistan to Punjab. This line, initially designed for 4 GW and later expandable to 6 GW, would be a ±800 kV bipole HVDC line connecting Chaghi in western Balochistan to Muzaffargarh in western Punjab. The projected annual power transportation capacity of this line is 22,700 GWh, with a per-unit transportation cost of US$0.13/kWh, which is highly cost-effective. The lifetime of this infrastructure is estimated to be 50 years. Furthermore, as per the VRE locational study, there are 29 interconnection-ready sites all across Pakistan to integrate solar and wind projects, 9 of which are located in Balochistan. This offers an immediate opportunity for the province to lead the integration of VRE into the grid.

Balochistan also holds strategic importance in VRE integration at off-grid level, because of its abundant renewable energy potential and low population density. In terms of the availability of land as well, Balochistan presents opportunities for installation of large utility scale solar and wind projects. The province also offers hybrid locations suitable for both solar and wind generation, particularly in remote regions.

According to a recent World Bank study on opportunities for utility scale sites[14], Balochistan stands out as a key region for integrating utility-scale VRE projects, citing its vast potential for solar and wind energy. Figure 1 presents the proposed utility scale sites in this study. The proposed HVDC line will efficiently transport renewable energy from Balochistan to major underserved load centers.

14 http://documents1.worldbank.org/curated/en/099062824120532780/pdf/P1693131b87ed40ae19fee1d3a5a6d0db68.pdf

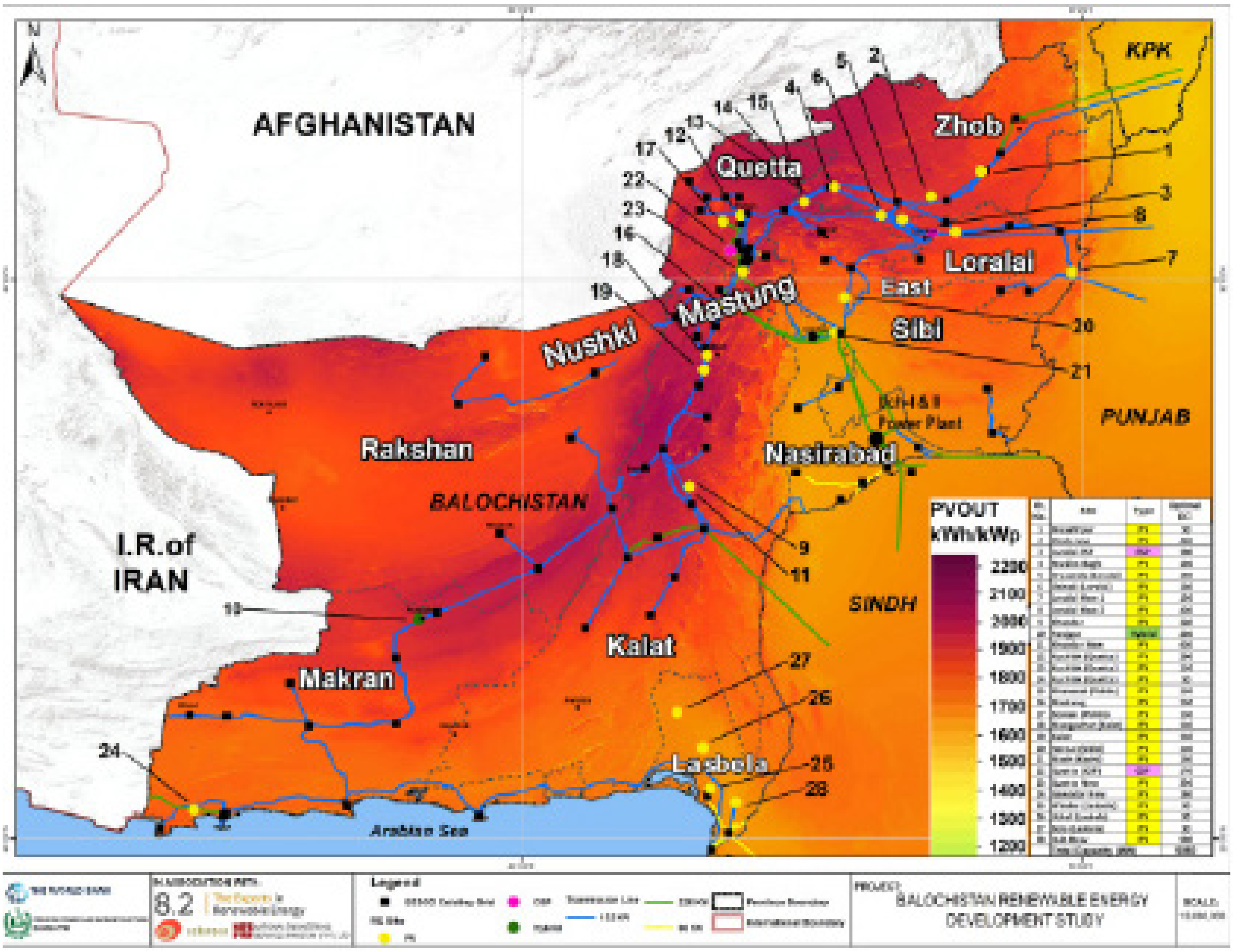


Figure 1:T&D network in Balochistan and proposed utility scale project sites for 2028[15]

The proposed HVDC transmission line from Balochistan to Punjab will play a vital role in transporting renewable energy to major load centers efficiently. This infrastructure, combined with the potential for large-scale solar and wind energy development in Balochistan, makes the province a crucial part of Pakistan's renewable energy future.

Looking ahead, Pakistan's roadmap for integrating VRE involves maximizing interconnection-ready sites in the short term, reinforcing the grid by 2025 and investing in transmission infrastructure and energy storage solutions by 2030.

15 http://documents1.worldbank.org/curated/en/099062824120532780/pdf/P1693131b87ed40ae19fee1d3a5a6d0db68.pdf

Chapter no. 3

Methodology

Figure 2 shows a flow chart illustrating the overall process followed in this study. Starting from desk research, to identifying the area of study, to LEAP modeling, and ending with recommendations based on the analysis done in the study.

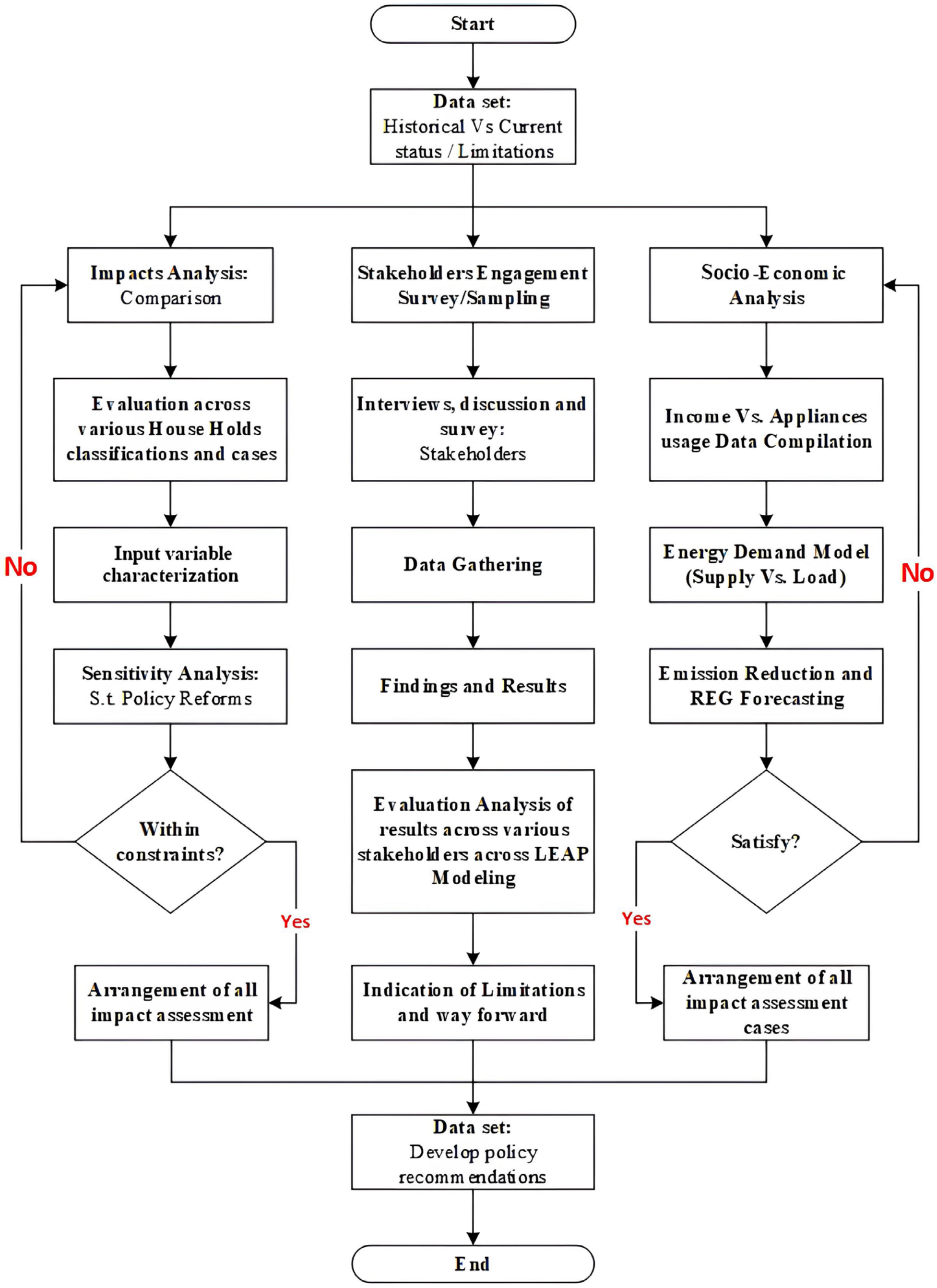


Figure 2:Visual Representation of the Research Methodology

Chapter no. 4

Area of Study

A sensitivity analysis was conducted using the basic household data from Pakistan Bureau of Statistic Census 2023[16] to observe the fuel used by households for lighting and cooking. The results are shown in figure 2 and figure 3. As per the analysis, an approximate of 43percent households are either unelectrified or are located in off-grid areas. 25percent of households are self-sustainable, relying on solar PV to meet their electricity needs. Others use gas and kerosene lamps for lighting.

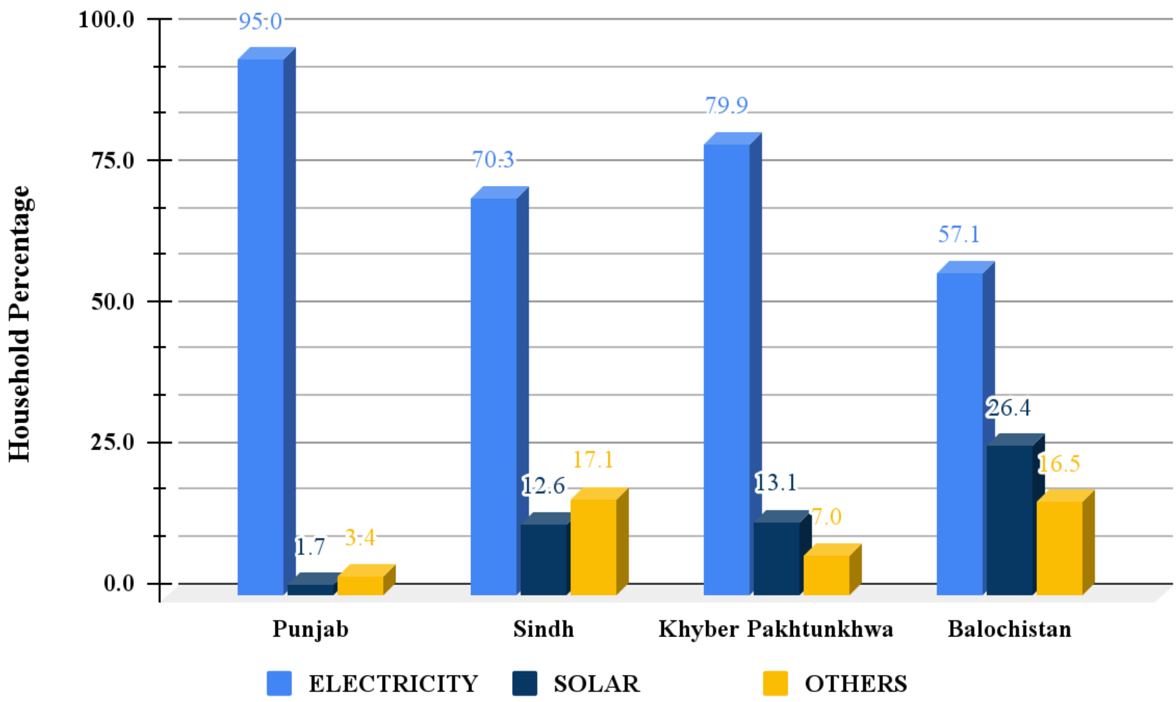


Figure 3: Percentage of households by fuel type for lighting across all provinces (Data Source: PBS census 2023)

Balochistan being the largest province by land i.e. 350,000 square kilometers[17]- has abundant solar potential. Approximately, 40percent of its land receives direct solar insolation with an energy potential of more than 6 kWh per square meter per day, while the rest receives direct solar radiation with an energy potential of 4.5 kWh per square meter per day[18]. Despite this immense potential, this is unutilized and there is not a single operational VRE power plant in the province. Many households rely on small-scale solar panels to meet basic energy needs due to either a complete lack of electricity access or unreliable grid supply. Balochistan has five major thermal power plants with a combined capacity of 3742 MW[19], but the province has the lowest percentage of households with access to grid electricity in the country.

16 https://www.pbs.gov.pk/digital-census/detailed-results

17 Journal of Positive School Psychology http://journalppw.com 2022, Vol. 6, No. 10, 1126-1132 Overview Of Balochistan As A Place Of Global Interest

18 https://documents1.worldbank.org/curated/zh/352401468145176136/pdf/ACS22580WP0v500art020Energy0Sector.pdf

19 https://www.ppib.gov.pk/commisioned_ipps.html

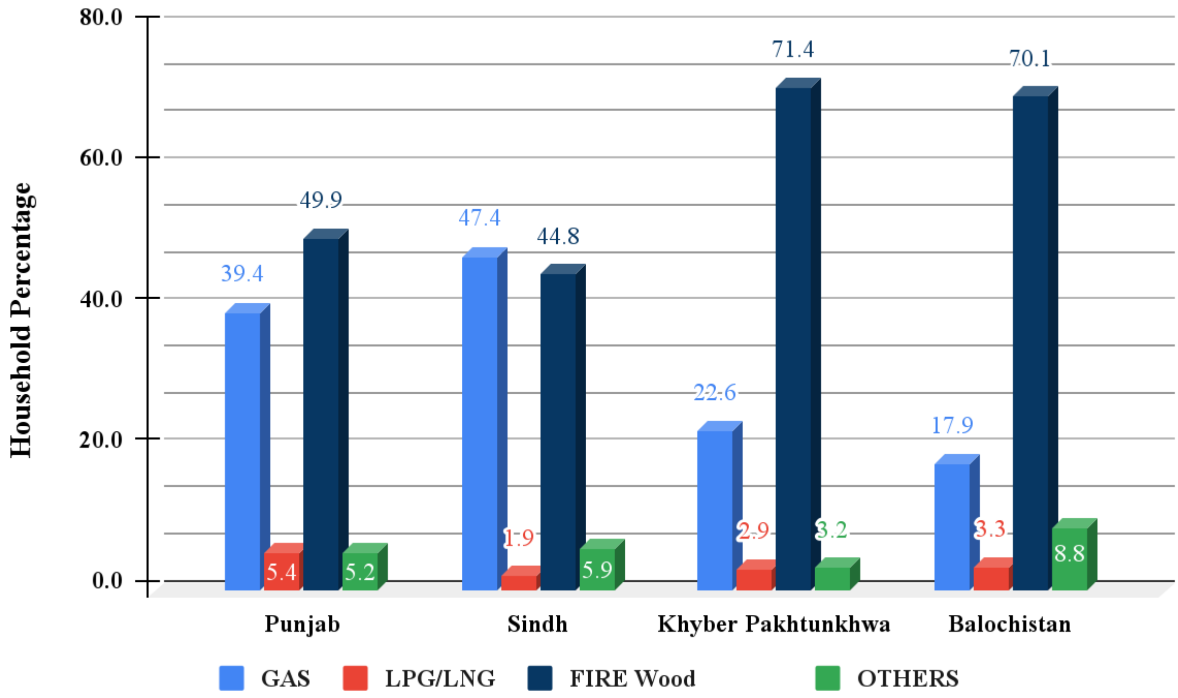


Figure 4: Percentage of households by fuel type for cooking across all provinces (Data Source: PBS census 2023)

Figure.3 is another indication of Balochistan's status as the least privileged, facing severe clean energy access challenges. Despite being the hub of natural gas resource, less than 20percent of households in Balochistan have access to natural gas, significantly lower than in the other provinces[20]. Approximately, 70percent of the households in the region use fire wood for cooking, while others resort to alternate fuels such as organic waste and animal waste. These conditions expose residents to indoor air pollution[21] leading to significant long term health impacts. In order to fully understand and meet the energy demand of people in Balochistan which can be utilized for their cooking, heating, and other basic electricity needs, it is important to do a formal analysis. However, due to limited resources, we had to narrow down to one district to carry out this analysis.

4.1: Demand data collected for Nushki district

Nushki district was selected as the study area for this research. The location of the district was mapped out based on its geographical proximity to one of the highest potential wind corridors of Pakistan, Chagai[22]. Nushki is located at the western end of the country's border with Afghanistan. Its geographical location lies between 65° 07 '42''- 66° 18' 45'' East longitudes and 29° 01 '51''-29° 52' 37''North latitudes. The eastern boundary of this district is covered by the Sarlath hill range and Mastung District. Kalat and Kharan district are to the south and it is bounded by the Chagai district on the west[23]. The district has an area of 5,797 square kilometers with a population density of 35.85 per square kilometer[24].

20 https://www.adb.org/sites/default/files/evaluation-document/35067/files/ie36_6.pdf

21 https://www.mdpi.com/2411-9660/4/4/46

22 https://www.sciencedirect.com/science/article/pii/S2352484722026488

23 Rehman, Tehmoor & Panezai, Sanaullah & Ainuddin,. (2019). Drought perceptions and coping strategies of drought-prone rural households: a case study of Nushki District, Balochistan. 1. 44-56.

24 https://www.pbs.gov.pk/census-2017-district-wise/results/121

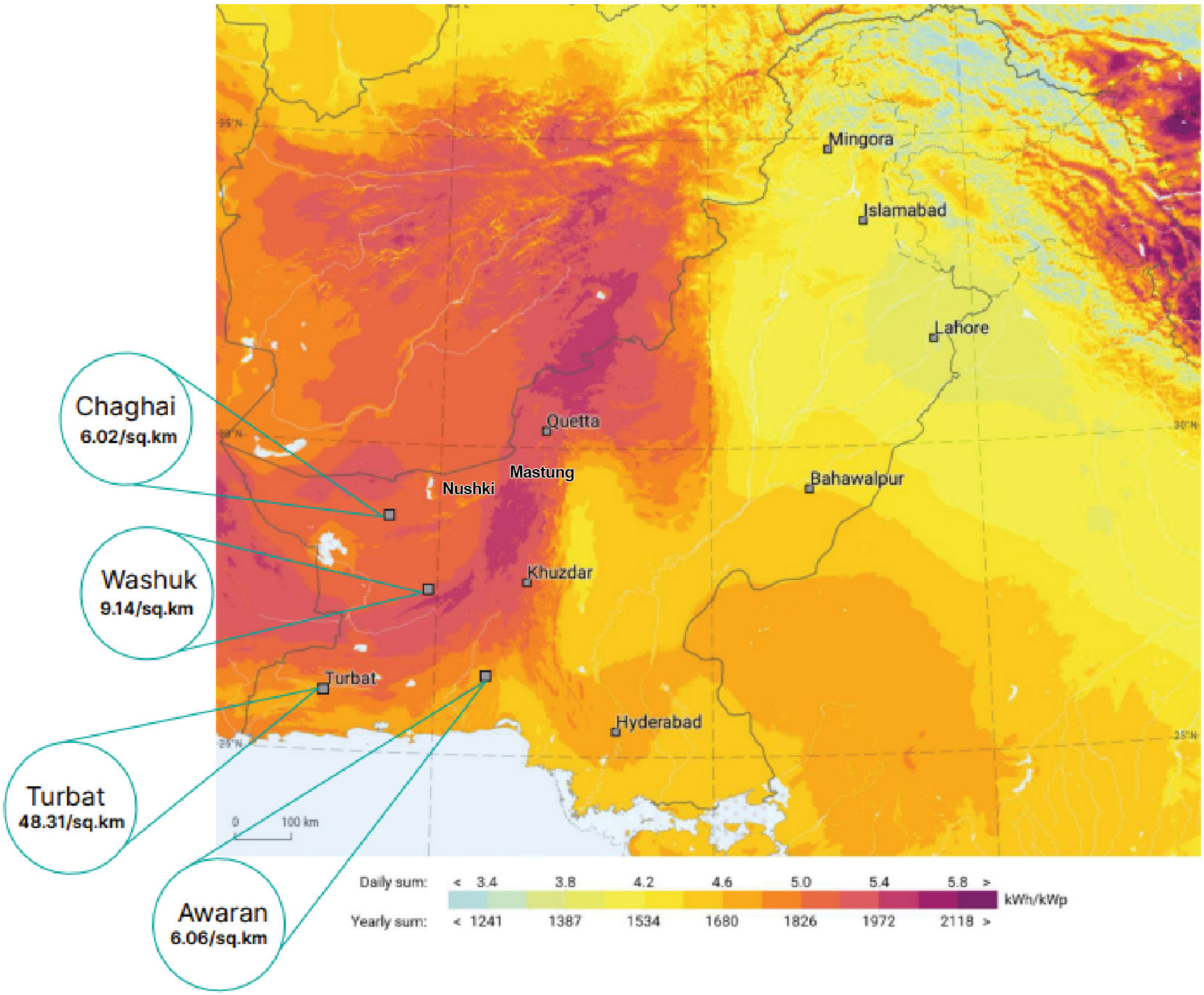


Figure 5: The Global Average Photovoltaic power potential in Pakistan and Population Densities of Wind corridors and high Solar potential areas Balochistan (Source: Global Solar Atlas and PBS census 2023)

Turbat[25] and Chagai[26] are the regions with immense wind potential and Awaran and Washuk have huge solar potential which can be observed in Figure.4. According to the PBS census 2023, the population densities for these districts were among the lowest, making them a viable option for the development of VRE projects. The population density of Turbat in comparison to other three regions makes it less feasible for large utility scale projects for power generation. Therefore, out of the three districts, Chagai stood out as the most feasible location as Nushki and Chagai are located adjacent to each other. Chagai's favorable wind energy conditions make it an ideal candidate for large-scale VRE generation. Decentralized micro-grids connected to these utility-scale projects could offer a reliable power supply to nearby regions. Furthermore, Chagai's proximity to Nushki presents an opportunity to minimize transmission costs by strategically connecting the two districts. This approach would reduce the need for extensive transmission infrastructure, allowing for localized and efficient energy distribution.

While Chagai is the most feasible location for utility-scale VRE projects, the choice between extending the central grid to Nushki and implementing off-grid solutions depends on a careful evaluation of both economic feasibility and the specific energy demand in the region. Decentralized solutions may provide more practical and cost-effec-

25 https://www.researchgate.net/publication/366866286_Assessment_of_Wind_Speed_and_Power_Density_Using_Weibull_and_Rayleigh_Distributions_at_Turbat_Balochistan_Pakistan

26 https://www.sciencedirect.com/science/article/pii/S2352484722026488

tive alternatives to meet Nushki's energy needs, ensuring reliable access to power without relying on costly grid extensions.

4.2: Energy demand assessment tool selection

Energy sector modeling requires the use of sophisticated tools which are considerate of the interconnected nature of energy variables yet are able to find optimized solutions. For this research study, we had to assess tools including MARKAL/TIMES, LEAP, and HOMER, in order to find the tool most suitable to our need of effective demand projection for the district of Nushki, Balochistan. This section discusses these tools, their characteristics, and reason for adoption of LEAP and HOMER software for demand analysis.

MARKAL/TIMES

The market allocation (MARKAL) model is an integrated MARKAL/EFOM system that is largely used for integrated energy system modeling. This technique can be used to effectively analyze energy, economic and environmental issues at national and international levels. TIMES[27] model is based on a bottom up modeling approach that uses linear modeling to develop a least-cost energy system, optimized on given variables and constraints for medium- and long-term planning. This model caters all the processes of the supply chain i.e. from primary sources till the end consumer energy demand. After all the inputs are provided, and the constraints and scenarios are set, the model develops an energy system that is both least-cost and meets the energy demand over the entire time horizon. The only limitation of this software is that it does not account for strategic or policy related constraints, and focuses only on the least-cost optimization. In a nutshell, TIMES is used for the exploration of possible energy futures based on contrasted scenarios.

LEAP

Low Emission Analysis Platform (LEAP)[28] is an integrated energy modelling tool for cities, states, countries, regions and the globe. The tool can track energy production, transformation, consumption, and resource utilization and extraction in all sectors of energy and economy. It can effectively calculate the environmental emissions of each sector with respect to energy extraction, transformation and usage. It is a scenario-based modelling tool and scenarios are designed based on comprehensive accounting of energy, variation in transformation techniques or emission abatement technique. It can holistically cover any demand and supply management exercise. LEAP optimization is also used for the least-cost power generation. However, its use is more accessible as it is an open source software — which makes it more suitable for developing countries. This research is solely focused on household basic energy demand, therefore LEAP is the most suitable tool to determine the existing and future energy demand of the region under consideration in this research. In short, LEAP is like a smart calculator that helps plan a cleaner energy future by showing what happens if there is a change in how energy is used and produced.

HOMER

The Hybrid Optimization Model for Electric Renewables (HOMER)[29] is a general-purpose hybrid system sizing and optimization tool. It can do both grids connected and isolated system power simulation and optimization. It can perform sensitivity analysis and predict system performance. HOMER performs simulations based on hour-

27 https://ndcpartnership.org/knowledge-portal/climate-toolbox/integrated-markal-efom-system-times-model

28 https://leap.sei.org/default.asp?action=introduction

29 S. Bahramara, M. Parsa Moghaddam, M.R. Haghifam, Optimal planning of hybrid renewable energy systems using HOMER: A review, Renewable and Sustainable Energy Reviews, Volume 62, 2016, Pages 609-620, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2016.05.039. (https://www.sciencedirect.com/science/article/pii/S1364032116301496) ly load profiles to identify the best system for supplying electricity or heat to nearby load centers. HOMER can model the performance of a particular micro-grid system configuration on an annual hourly basis to determine its technical feasibility and life cycle cost, in the simulation. During optimization, HOMER simulates many different system configurations in search of one that satisfies the technical constraints at the lowest life cycle cost. In the sensitivity analysis process, HOMER performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. In this research HOMER is used to design a micro grid to meet the base demand of the region under consideration. In one sentence, HOMER is a smart tool that can help design the best mix of energy generation source to power places in the most efficient and cost-effective way.

4.3 Study design

A case study design is used to perform both a quantitative and qualitative analysis of the energy demand data that is collected through an on-field survey.

4.4: Sample design

The total number of households in Nushki are 31,255 with approximately 77percent residing in the rural areas[30]. Households are the primary units used for analysis as major decisions about consumption, future planning or investments are made at this level[31]. Since, the majority of the households reside in the rural areas, six of the most underprivileged areas were selected for this survey. A sample size of 125 households was determined using the random sampling method.

For primary data collection, a semi-structured questionnaire was designed which focused on key variables for basic household demand assessment. These parameters were outlined from literature review of the detailed household fuel usage reports by Pakistan Bureau of Statistics and National Energy Efficiency & Conservation Authority. For better understanding, the questionnaire was translated into Urdu as well. The survey was conducted by six local residents of Balochistan, including two from Nushki district. They had different language proficiencies with some fluent in Barohi, others in Balochi and Pashtu. The survey areas include Qadeerabad, Mall, Killi Rehmanzai, Killi Sahibzada, Battulandi, Killi Sahreef Khan. The percentage of households surveyed in each area is shown in figure 6. These locations were deficient in the energy use and presented underdeveloped rural settings.

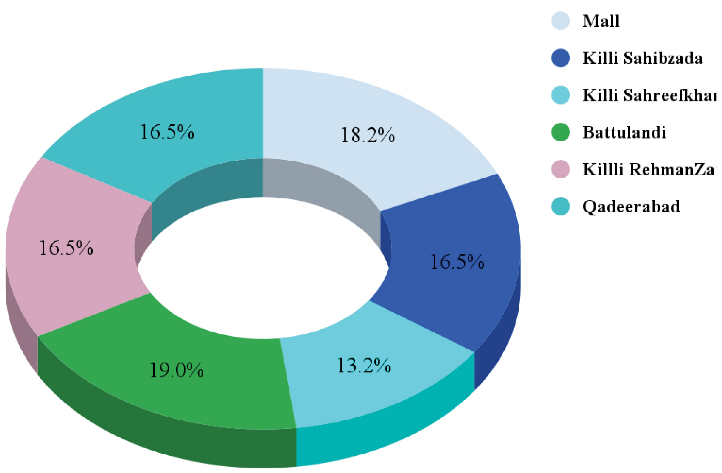


Figure 6: Percentage of Respondents in each Region Surveyed in the Nushki district

30 Table 22 : HOUSING CHARACTERISTICS, FACILITIES USED FOR FUEL, LIGHTNING AND KITCHEN BY REGION- PBS census 2023

31 Corbett, J. (1988). Famine and household coping strategies. World Development, 16(9), 1099-1112

Chapter no. 5

Scenario based energy consumption profiling and projections

This section discusses the energy consumption patterns of the Nushki District. The socio-economic characteristics, alongside the basic energy demand of households, are discussed and analyzed. Further, the other sub-sections provide the demand projections made under different scenarios formed in the LEAP software. The data sources are based on the dataset collected through field survey and later cross validated through existing official databases of the country. The growth projections are based on the historical trends from the existing databases and literature sources of the country. The results were evaluated against the stakeholders' feedback, socio-economic characteristics, and the policy limitations. The base demand was used for future energy demand projections of this area that included primary direct point emissions (Scope 1) as well.

5.1: Socio-economic characteristics of households

The analysis of results show the following socio economic characteristics of the households.

- The average household size of the sample population was approximately 10
- Most of the households i.e. 72.3percent had low income levels, with only 4.8percent of the households having a more stable income level (Refer Figure 7).
- The main source of income is farming and agriculture for approximately 33percent of the households. Around 12percent of the households rely on daily wages through labor.
- The women of these areas were mostly unemployed.
- Almost 70percent of the children from these households were enrolled in schools while the remaining were not attending.

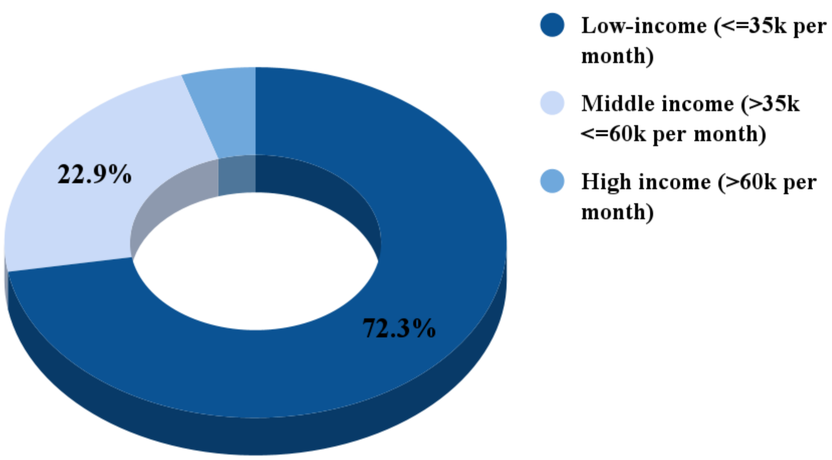


Figure 7: Income Level of Households based on high, medium and low income households

The survey results indicate that all the households experience low voltage levels, i.e. below 220V, with an average daily electricity supply of approximately 3 hours from the grid. The findings also showed that 90percent of households are electrified, while the remaining 10percent are completely unelectrified. Around 6.5percent of households are located near the grid, where grid infrastructure is available. However, due to a combination of technical and social factors, these households remain unelectrified. According to the 2023 census, 80.7percent of households were electrified through the grid and approximately 13percent relied on solar PV systems, resulting in a combined electrification rate of approximately 93percent[32]. The survey conducted in this region for this study further indicated that nearly 60percent households had solar PV systems installed (Refer to Figure 8) to supplement their daily electricity requirements. The following chart illustrates the electricity connection details of these households.

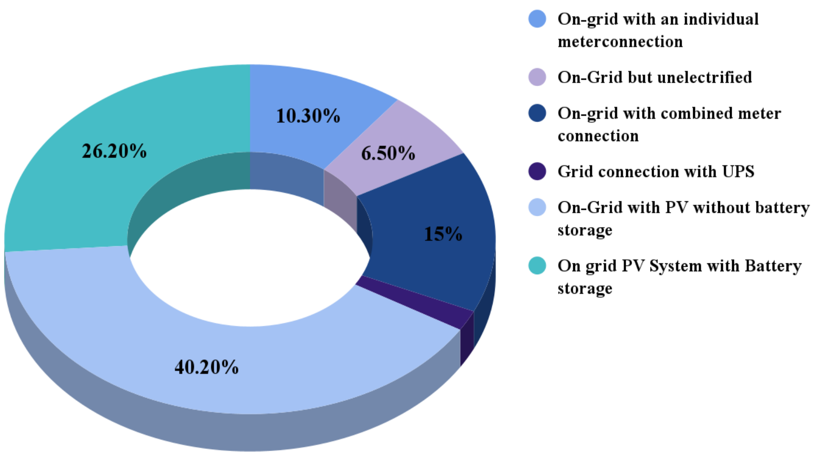


Figure 8: Percentage of household based on their electricity connections

The survey results showed that 86.2percent of the households relied on wood for their cooking and heating needs. These findings align with the PBS census 2023, which reported that 84percent[33] rural households in this district use wood as a primary fuel source. This presents an alarming situation, as it highlights a significant number of the population directly impacted by scope I carbon emissions (further discussed through the LEAP model). The residents of these areas endure harsh conditions with limited access to basic necessities. During the survey planning phase, several areas were shortlisted; however, they were later excluded due to inaccessibility, as most of the district lack proper road infrastructure.

5.2. The household energy demand forecast— the LEAP model

In the year 2024, 6 rural areas of Nushki district were home to 1260 individuals residing in 125 households. Among these households, 37.6percent received electricity through urban feeder extensions while the remaining relied on rural feeders. The survey results mentioned earlier show average electricity supply from the grid is for 2-3hrs daily. This is the time span where most of the heavy loads like refrigerators, geysers and water pumps are functional. But since the cooling and lighting load exceeds for more than 2-3 hours, the residents use solar PV as a backup. Therefore, to understand the overall base demand holistically the following simulations were carried out, based on the total electricity which includes both grids supplied electricity and electricity generated from solar PV installed by the households. Table 1 shows the results obtained from the survey of households' basic average energy consumption. The responses were categorized under two categories. Households connected to urban feeders are labeled as urban feeder extension households and the households connected to agricultural, semi-urban and rural feeders are categorized as rural feeder households. This categorization is important to highlight future technical assessments for this area. However, the final results are given cumulatively for the whole region.

32 https://www.pbs.gov.pk/sites/default/files/population/2023/tables/balochistan/dcr/table_22.pdf

33 https://www.pbs.gov.pk/sites/default/files/population/2023/tables/balochistan/dcr/table_22.pdf

Table 1: The survey results for urban feeder households' basic energy demand

Category	Appliances	%age of urban extension feeder households using the resource	Annual Energy Usage per Household (urban feeders)	%age of rural extension feeder households using the resource	Annual Energy Usage per Household (rural feeders)
Cooking	Electric stove	4.26 %	2190 kWh	3.846 %	2190 kWh
	Wood stove	87.23%	3113.6 kg	77.92%	6319.7 kg
	LPG stove	46.81%	297.78 kg	48.1%	239.6 kg
	Charcoal stove	2.12%	3200 kg	1.3%	800 kg
Lighting	Electricity	100%	277.59 kWh	100%	333.34 kWh
	Kerosene	2.12%	18 liters	0%	0 kWh
Refrigeration	Refrigerators	42.53%	603 kWh	61.53%	784.4 kWh
Cooling	Fans	74.5%	629 kWh	91.03%	492.5 kWh
	Air coolers	53.2%	110.17 kWh	84.4%	189.83 kWh
Electronics	Phones	95.74%	17.5 kWh	83.116%	25.5 kWh
	Televisions	12.76%	120.45 kWh	10.26%	160.4 kWh
	Irons	46.81%	234.21 kWh	60.25%	234.21 kWh
Others	Washing machines	38.30%	342.6 kWh	55.128%	199.9 kWh
	Water pumps	46.81%	337.06 kWh	30.76%	331.5 kWh
	Electric geysers	12.76%	619.92 kWh	17.95%	623.142 kWh

The table above reflects dominant use of highly energy intensive conventional cooking methods. An average of around 80percent cumulatively use wood fuel for cooking and heating purposes. Similarly, such high voltage cooling devices indicate the use of outdated and conventional technologies. The table further indicates the lack of use of refrigerators and other basic household appliances. Due to extreme weather conditions, a huge size of population has cooling loads. 87.23percent of urban feeder households have cooling loads and 98.72percent of rural feeder households have cooling loads. The cooling load was taken for 8 months only. The rest i.e. November - February, were taken as winter months. The total energy consumption of each category is calculated using the LEAP model and is discussed in detail ahead.

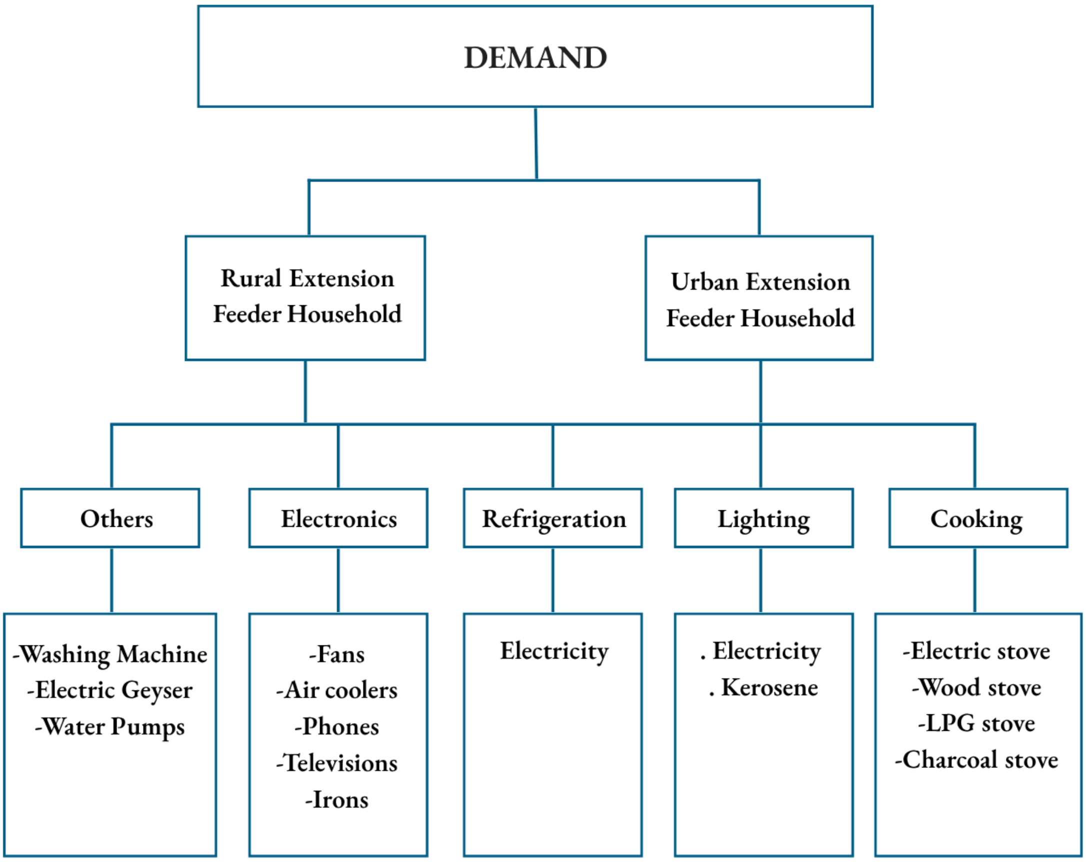


Figure 9: The Demand tree presenting the inputs made for LEAP model

Figure 8 shows the demand tree presenting the inputs under each category in the LEAP model. The base year demand is modeled using the demand tree and dataset given in Table 1. The base year demand for this area accounted for a total of 2652.8 Gigajoules for Urban Extension feeders which included a total of 270GJ (=75069KWh) electricity demand (Refer Table 2). Rural extension feeders accounted for a total of 6954.10 Gigajoules which included a total of 550 GJ (=152,837 KWh) electricity demand. The cumulative demand for the surveyed areas in the base year is 9606.9 Gigajoules. The individual consumption of each fuel type in the area can be seen in Figure 9. The base year output aligns with our earlier observation that the households use highly energy-intensive cooking methods with the cumulative consumption of these 1260 households reaching approximately 2400 Gigajoules for cooking in 2024 only. Another key result of this modeling reflects the use of inefficient appliances with their cooling load solely reaching almost 68467KWh cumulatively.

Table 2: Base Year average demand of households - LEAP model

Category	Urban extension feeders demand KWh /2024	Urban Extension feeders demand GigaJoules/2024	Rural Extension feeders demand KWh/2024	Rural extension feeders demand GigaJoules/2024
Cooking	665,791.5	2396.8	1,785,338.1	6,427.20
Lighting	13,228.20	47.6	26,000.50	93.6
Refrigeration	12,068.00	43.4	35,925.00	129.3
Cooling	21,606.20	77.8	46,860.50	168.7
Phones	787.5	2.8	1,653.20	6
Television	722.9	2.6	1,283.40	4.6
Washing Machine	6,167.10	22.2	8,597.60	31
Water Pump	7,415.60	26.7	7,953.30	28.6
Iron	5,152.80	18.6	9,270.10	33.4
Geysers	3,717.80	13.4	8,723.60	31.4
Total	738,839.60	2,652.80	1,931,690.80	6,954.10

The base year demand for this area accounted for a total of 6954 Gigajoules for Rural Extension feeders which included a total of 6953.5GJ (=152922.3 KWh) electricity demand.

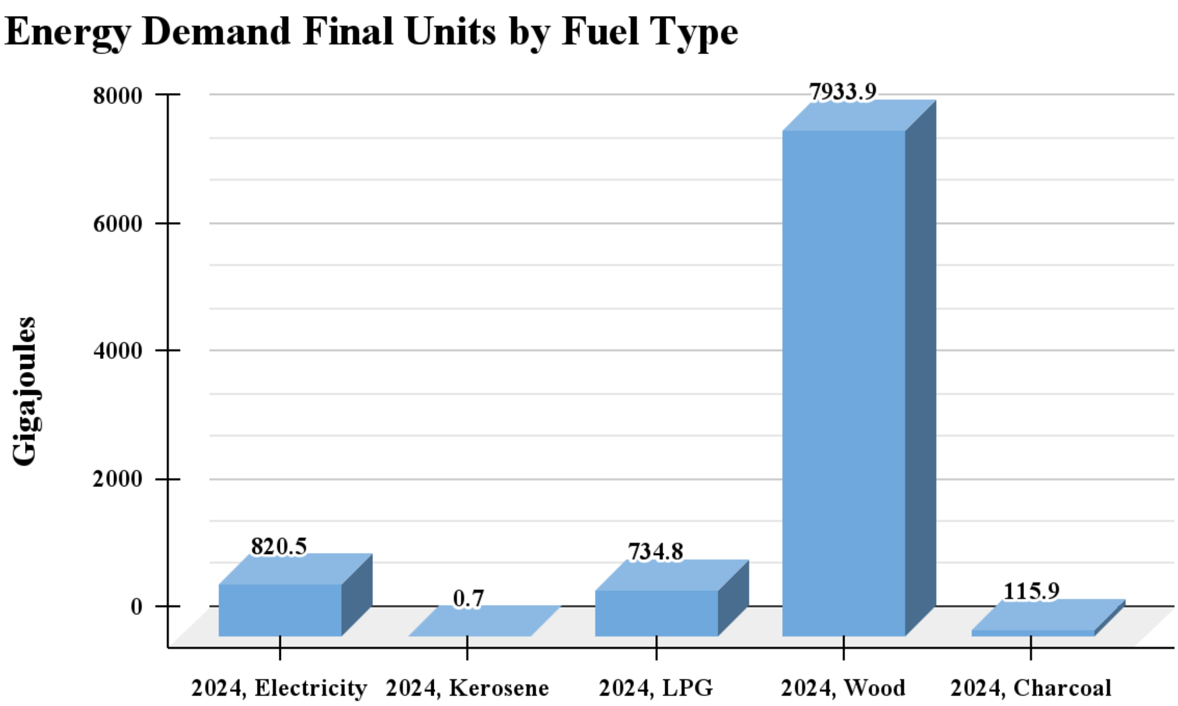


Figure 10: Energy Demand Final Units- Consumption by Fuel Type

5.3: Scenarios

Based on the historical trends of the population growth rates reported by the PBS census 2023, and the future forecast of Pakistan population growth rates by the World Bank economic indicators[34], the annual growth rate for households was taken as 5percent in all the scenarios.[35][36] The number of rural households in Nushki district in 2017 were 16,854[37] which increased to 23,995[38] in 2023. The annual growth rate of households between 2017 and 2023 is calculated from the compound annual growth rate formula[39].

The final value for annual household number growth rate using the formula is approximately 7percent. The average population growth rate in PBS census 2017 in the Nushki district was 3.51percent, but as per census 2023 it decreased to 2.51percent. Similarly, the household size of this district reduced from approximately 7.9percent to 6.6percent, while the population density in 2023 increased to 35.5 square per kilometer reflecting an increase in smaller housing units. Furthermore, the overall population of Pakistan has decreased as per the world economic indicators[40] and is expected to rise only to 6percent by 2050[41]. Keeping in mind the projected decrease in population growth rates, and the historical trends of the household growth rates, the annual household growth rate is projected to be 4percent until the year 2035.

Further, the electricity demand growth rates are also based on universal electrification targets set by the government of Pakistan in the National Electricity Plan 2023 and the rural electrification plans. Additionally, the increase in cooling load in all the scenarios is taken keeping in consideration the increased global warming, which will further raise the global temperature.

5.3.1: Business-as-usual scenario

The Business–As-Usual scenario assumes that no major policy interventions or structural changes are made, with developments continuing at a pace consistent with historical trends. The trends here essentially refer to lack of effective long-term policy planning and implementation by the authorities. The country's policies and development programs are mostly driven by foreign conditionalities[42]

Under this scenario, conventional cooking methods like the use of wood remain dominant. A small percentage of the wood stoves will be shifted to electric stoves by 2035- this trend was set keeping in consideration no significant change in the use of wood fuel in the 2023 census i.e. the percentage of rural households using wood as a fuel for cooking in the rural areas of Nushki was approximately 96percent in 2017. It only reduced to 84percent in 2023. In contrast, there was negligible LPG usage for fuel in 2017 which grew to 11percent in 2023[43]. The 2017 census showed approximately 78.8percent of households were electrified through the grid which reflects hardly any new connections are provided as the percentage barely reached to around 80percent in 2023. Hence, the growth of electric stoves was kept modest, growing at 10percent in urban extension feeders and 5percent in rural feeders. The overall cooling load is projected to increase both in urban and rural extension feeders, rising by 90percent and

34 https://databank.worldbank.org/country/PAK/556d8fa6/Popular_countries
35 https://www.pbs.gov.pk/sites/default/files/population/2017/tables/balochistan/Table01p.pdf
36 https://www.worldometers.info/world-population/pakistan-population/
37 https://www.pbs.gov.pk/sites/default/files/population/2017/results/12128.pdf
38 https://www.pbs.gov.pk/sites/default/files/population/2023/tables/balochistan/dcr/table_22.pdf
39 https://pages.uoregon.edu/rgp/PPPM613/class8a.htm
40 https://databank.worldbank.org/country/PAK/556d8fa6/Popular_countries
41 https://file.pide.org.pk/pdfpideinpress/pip-pakistans-population-boom-shaping-a-future-powerhouse.pdf
42 https://fpcci.org.pk/wp-content/uploads/2023/06/Impact-of-IMF-Programs-A-Context-of-Pakistan.pdf
43 https://www.pbs.gov.pk/sites/default/files/population/2017/results/12135.pdf

60percent by 2035 respectively. Table3,

Figure 11, and Figure 12 shows the future demand projections made under the business as usual scenario. It includes the factors that have been varied, the rest were kept the same as the base year.

Table 3: Demand Projections made for the Year 2035 under Business As Usual Scenario

Factor	Base Year household demand 2024 (Urban Extension Feeders) (A)	Projected demand by 2035	Base Year households demand 2024 (Rural Feeders) (B)	Projected demand by 2035
Wood Stoves	87.2%	80%	77.9%	70%
Electricity Stoves	4.25%	5%	3.846%	10%
Geysers	17.9%	30%	12.8%	20%
Phones	83.116%	90%	95.7%	100%
Cooling load	98.72%	100%	87.2%	95%
Fans	91.03%	95%	74.5%	80%
Air coolers	84.4%	90%	53.2%	60%

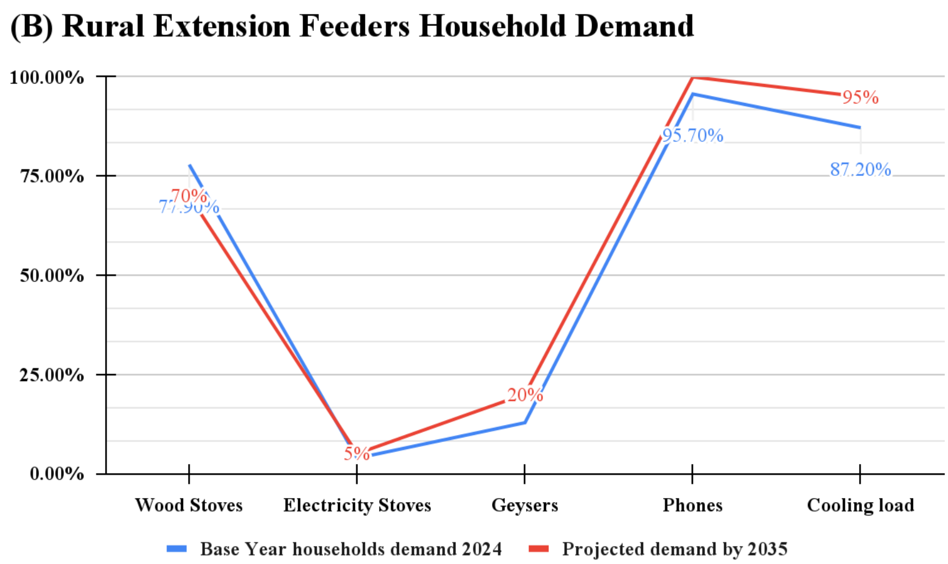


Figure 11: Base year demand vs Projected Demand by 2035- Rural extension feeders BAU Scenario

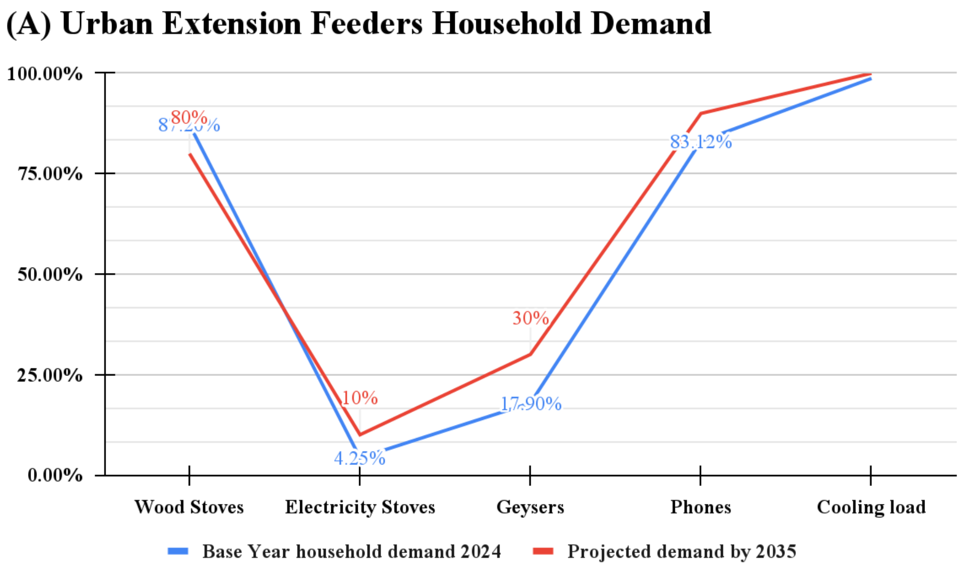


Figure 12: Base year demand vs Projected Demand by 2035- Rural extension feeders BAU Scenario

By 2035 using these demand projections the electricity demand cumulatively for rural and urban feeders reaches 382,000 KWhs, while the cumulative energy consumption from all sources reaches 14,453 GJ (Refer Figure 14). Figure 13 shows a 67.8percent increase in the electricity demand by 2035 indicating a steady rise in electricity demand from 2024 to 2035 even when no major policy developments take place.

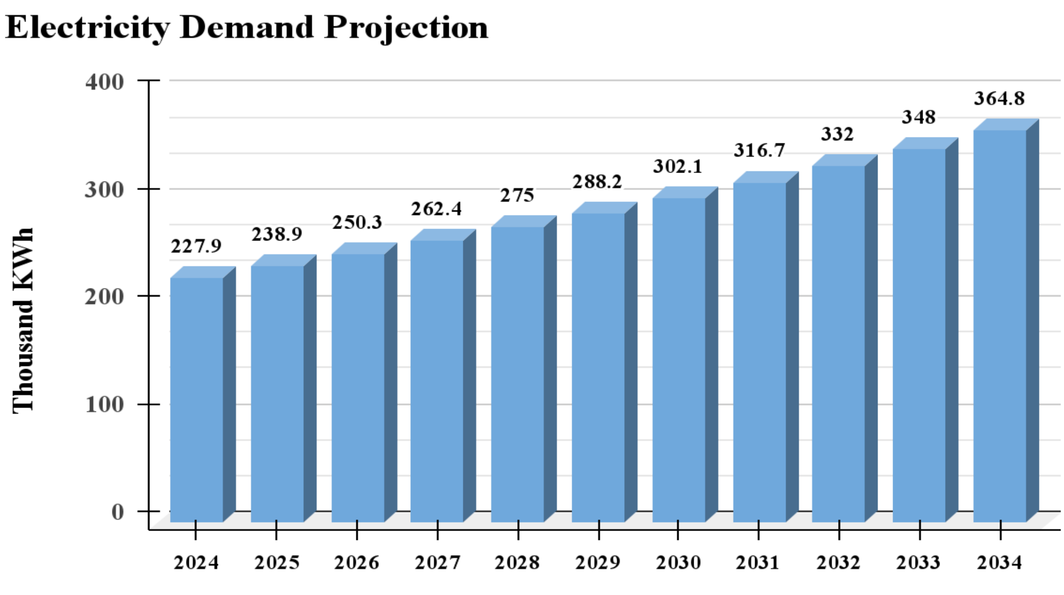


Figure 13: Electricity Demand trends by 2035 based on the projections made in Table 3

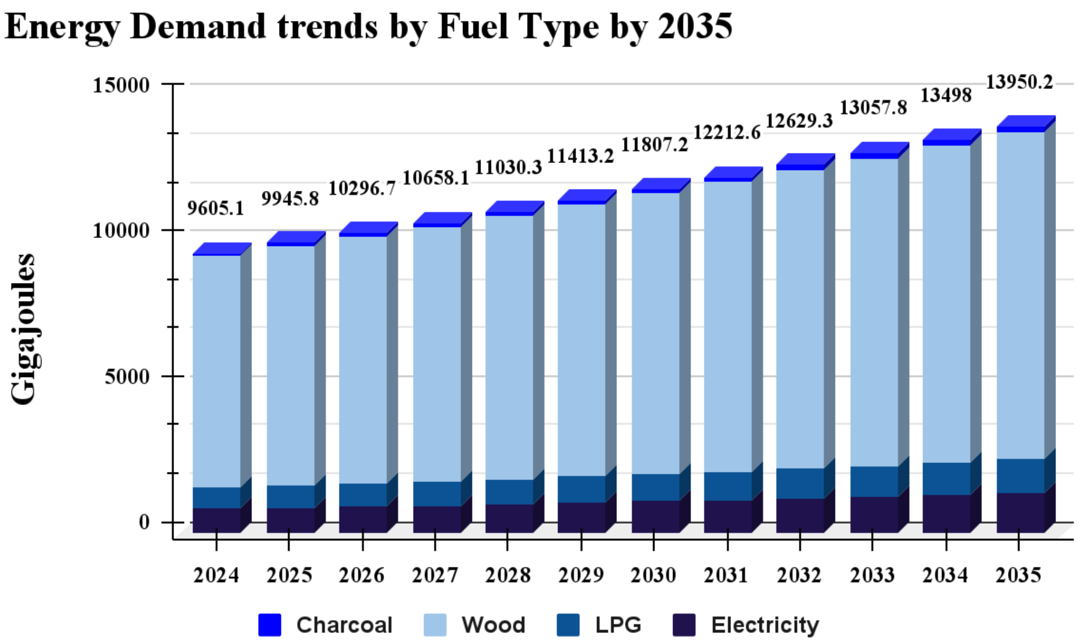


Figure 14: Energy Demand trends of all fuels by 2035 based on the projections made in Table.3

The results from this scenario reflect a steady but very slow shift towards more efficient appliances, with the traditional fuels dominating the rest. Continued reliance on biofuels such as charcoal and wood leaves significant health impacts. Hence, as the population increases, the demand goes up and the rising demand necessitates huge investments in the transmission and distribution sector as well as the overall energy sector.

5.3.2. China-Pakistan Economic Corridor (CPEC) Scenario

The growth rates for this scenario are based on the future projects planned by the CPEC[44] and the regional development that will possibly happen as a result of these investments. These include investments in transport infrastructure, establishment of special economic zones increasing the overall employment opportunities for locals[45]. Rising income levels will increase the buying power of the local, hence leading to an adoption of more efficient appliances. The development of Gwadar port will further support the urbanization of rural areas in this region. As Gwadar will provide a hub for trade and other industrial activities, attracting significant businesses. There is an expectation that the overall electricity demand will increase as a result of that. There will be rise in the use of heavy loads like geysers, which are expected to increase to 30percent both in rural and urban extension feeders, and refrigeration which is expected to grow to 60percent in urban and 70percent in rural extension feeders respectively. Furthermore, a decrease in the growth rate of wood stoves to 60percent will reduce the overall energy intensity and the direct indoor emissions. This load is diverted to LPG as fuel in this case, which is expected to reach 60percent by 2035. An increased use of electric appliances is also expected due to the urbanization that will possibly take place as a result of these developments. The detailed demand projections made under the CPEC scenario are given in Table 4, Figure 15, and Figure 16.

44 https://cpec.gov.pk/gwadar

45 https://cpec.gov.pk/news/242

Table 4: Demand Projections made for the Year 2035 under CPEC Scenario

Factor	Base Year Value (Urban Extension Feeders) (A)	Projected Demand by 2035	Base Year Value (Rural Feeders) (B)	Projected Demand by 2035
Electric Stoves	4.26%	10% by 2035	3.846%	5% by 2035
Wood Stoves	87.23%	60% by 2035	77.92%	60% by 2035
LPG Stoves	46.81%	60% by 2035	48.1%	60% by 2035
Refrigeration	42.53%	60% by 2035	61.53%	70% by 2035
Cooling	87.23%	100% by 2035	98.72%	100% by 2035
Fans	74.5%	80% by 2035	91.03%	95% by 2035
Air Coolers	53.2%	60% by 2035	84.4%	90% by 2035
Television	12.76%	20%	10.3%	20%
Phones	95.74%	100% by 2035	83.116%	90% by 2035
Geysers	12.76%	30% by 2035	17.95%	30% by 2035
Water Pump	46.81%	50% by 2035	30.76%	50% by 2035
Iron	46.81%	60% by 2035	60.25%	65% by 2035

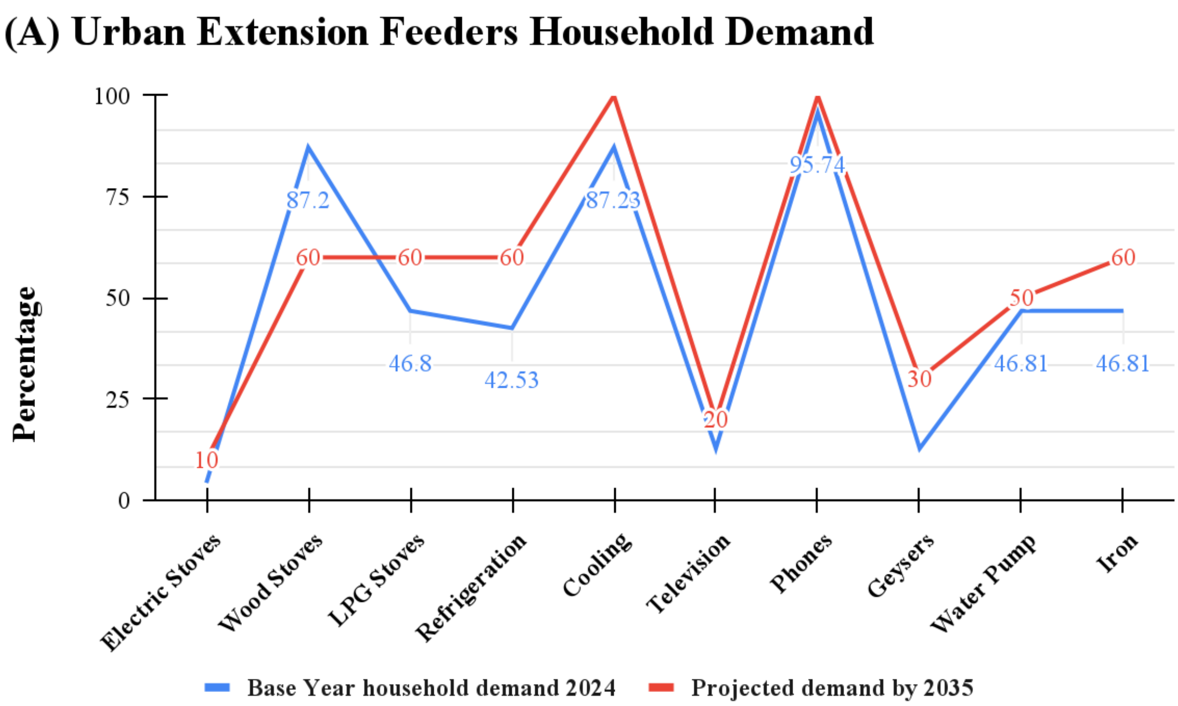


Figure 15: Base year demand vs Projected Demand by 2035- Rural extension feeders CPEC Scenario

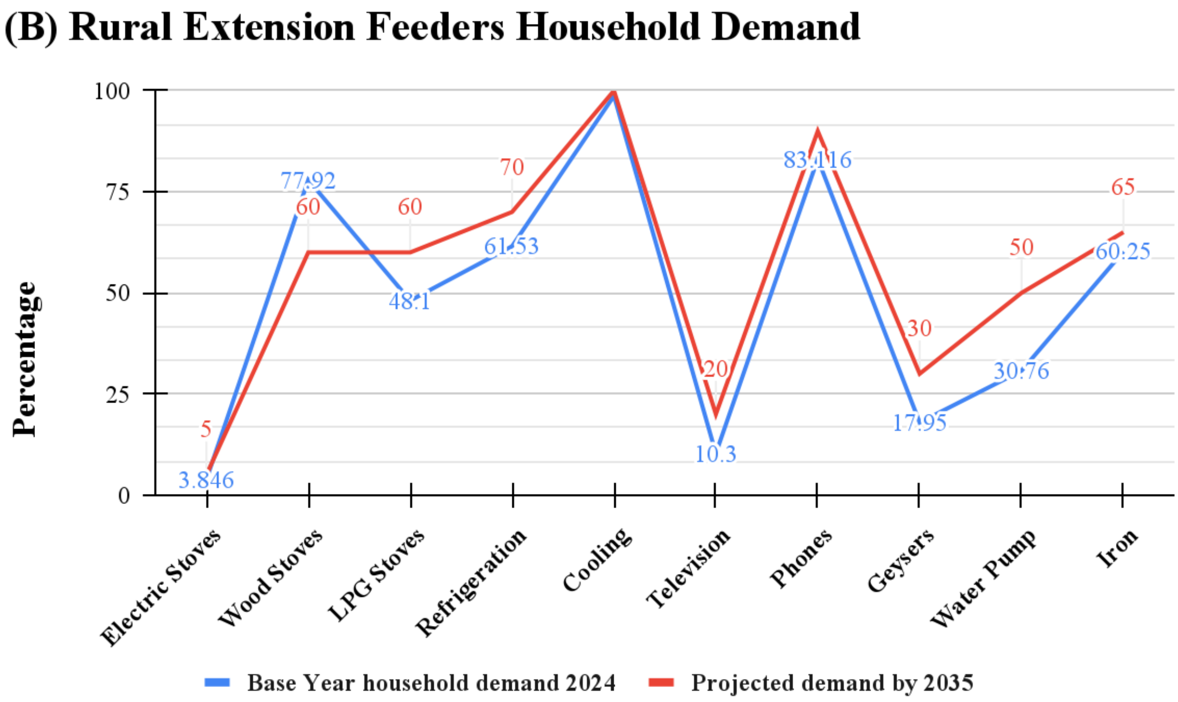


Figure 16: Base year demand vs Projected Demand by 2035- Rural extension feeders, CPEC Scenario

By 2035, using these demand projections Figure 18 shows that the overall energy demand reaches 11907 GJ, while the electricity demand grows by approximately 85percent, reaching 422700 KWh (Refer Figure 17). A huge jump in the overall electricity demand is visible due to the development of industrial and economic zones in this region. Furthermore, the gradual decrease in the consumption of wood as fuel for cooking is another very important factor that enables this transition.

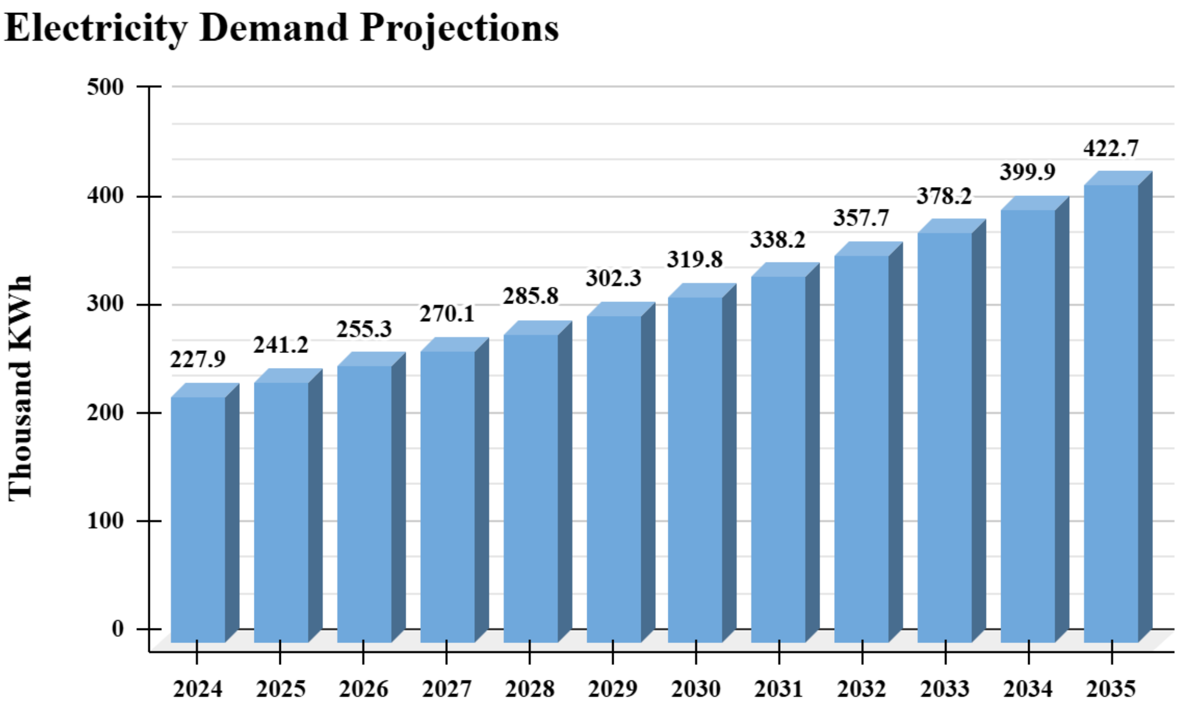


Figure 17: Electricity Demand trends by 2035 based on the projections made in Table 4

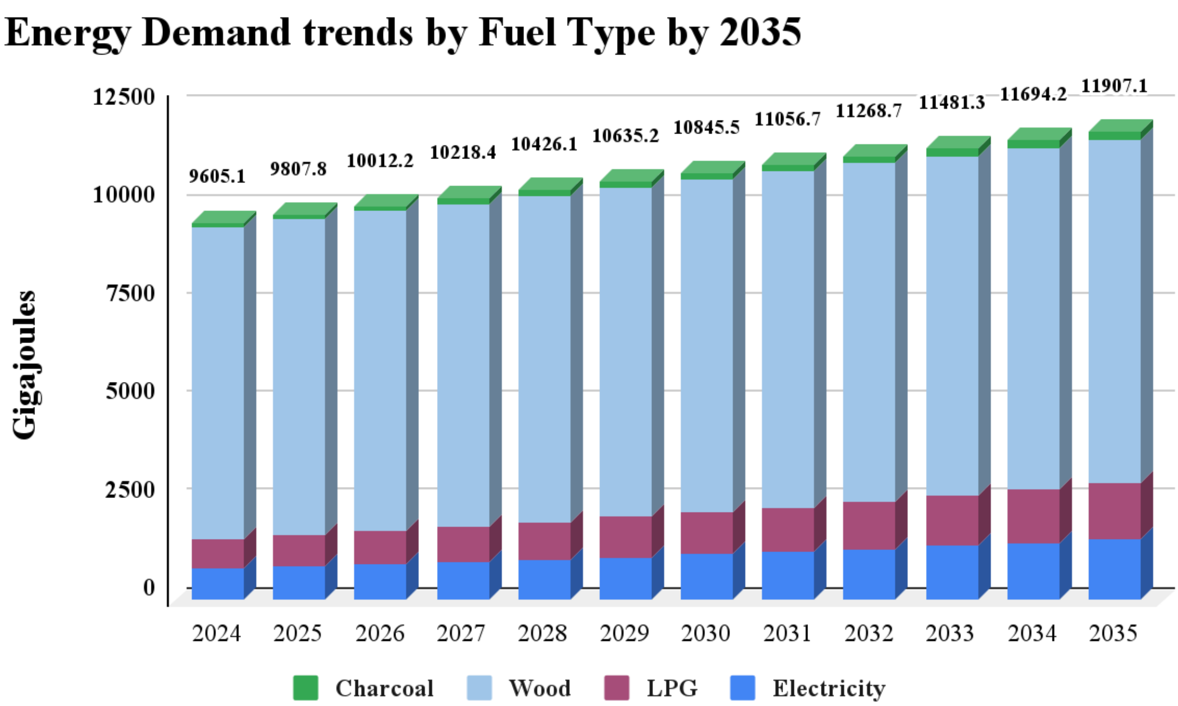


Figure 18: Energy Demand trends of all fuels by 2035 based on the projections made in Table. 4

These graphs show significant growth in the overall electricity and LPG demand, given that no delays or changes occur in any of the planned developments. The energy projects under CPEC are expected to significantly enhance energy supply and affordability enabling higher growth rates and increasing demand for cleaner fuels.

5.3.3: Optimistic Scenario - Electrification

Table 5: Policy parameters for optimistic scenario

Aspect	National Electricity Plan 2023	ARE Policy 2019	State of Industry Report 2023-24
Goal	Energy Security, sustainability, affordable access	60% renewable energy by 2030	» Solarization of off-grid households, schools, basic health units, hospitals, public offices » Grid Station Developments » Solarize 29,000 tube wells
Focus	Universal electrification and expansion	Clean Energy Transition, biomass alternatives	» Improving the province's energy infrastructure and sustainability
Impact	Expands Electricity Generation and access	Increase in renewable energy, with reduced reliance on traditional harmful fuels	» Enhance energy access, reliability and efficiency particularly in rural and underserved areas

The growth rates taken for this scenario assume that the government of Pakistan achieves the targets set in the National Electricity Plan 2023[46] and the Alternative Renewable Energy Policy 2019[47]. The former promised that the citizens of Pakistan will be able to have energy security, sustainability and access to affordable energy while the latter set its target of 60percent renewable energy by 2030. In the State of Industry Report 2024, four major rural electrification programs are planned that include, a solarization project which is assigned a fund of PKR 3120.708 million. Another village electrification program through QESCO is assigned a funding of PKR 2,707.028 million, this project aims to increase electricity accessibility in remote areas. The other planned developments include the construction of new grid stations, and strengthening of existing grid stations and transmission networks. Solarization of tube wells is also part of future planned developments[48].

The National Electricity Plan 2023 provides a roadmap for universal electrification stressing on the need of expanding electricity generation and access to rural areas. The projected growth rates reflect this commitment of the government. The plan also places significant emphasis on improving the grid infrastructure. This scenario, therefore, also assumes timely extension of transmission and distribution networks and the grid extension under different programs such as CPEC.

The Alternative Renewable Energy Policy 2019 focuses on the transition towards clean energy sources to achieve the SDG 7 goals. The shift from wood to electricity in this scenario reflects the ARE policy target to promote cleaner alternatives to biomass fuels. The growth rate for electricity stoves reaches to 50percent for both rural and urban extension feeders reducing reliance on fire wood for cooking. The cooling load reaches 100percent in the summers, with 50percent increased penetration of electric geysers for winters by 2035. With the increase in employment opportunities the living standards will improve, it is therefore expected that all the households will have

46 https://power.gov.pk/SiteImage/Policy/National%20Electricity%20Plan%202023-27.pdf

47 https://www.ppib.gov.pk/policies/ARE_Policy_2019_-_Gazette_Notified.pdf

48 https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202024.pdf

phones and irons and 80percent of the households will install water pumps. The detailed demand projections made under the CPEC scenario are given in Table 5, Figure 19, and Figure 20.

Table 6: Demand Projections made for the Year 2035 under Optimistic Scenario

Factor	Base Year 2024 Value (Urban Extension Feeders) (A)	Projected demand by 2035	Base Year Value (Rural Feeders)	Projected demand by 2035
Electricity Stoves	4.26%	30% by 2035	3.846%	30% by 2035
Wood Stoves	87.23%	30% by 2035	77.92%	30% by 2035
LPG Stoves	46.81%	40% by 2035	48.1%	40% by 2035
Charcoal Stoves	2.1%	0% by 2035	1.3%	0% by 2035
Refrigeration	42.53%	80% by 2035	61.53%	80% by 2035
Cooling	87.23%	100% by 2035	98.72%	100% by 2035
Fans	74.5%	100% by 2035	91.03%	100% by 2035
Air Coolers	53.2%	80% by 2035	84.4%	80% by 2035
Television	12.76%	50%	10.3%	50%
Phones	95.74%	100% by 2035	83.116%	100% by 2035
Geysers	12.76%	50% by 2035	17.95%	50% by 2035
Water Pump	46.81%	80% by 2035	30.76%	80% by 2035
Iron	46.81%	100% by 2035	60.25%	100% by 2035

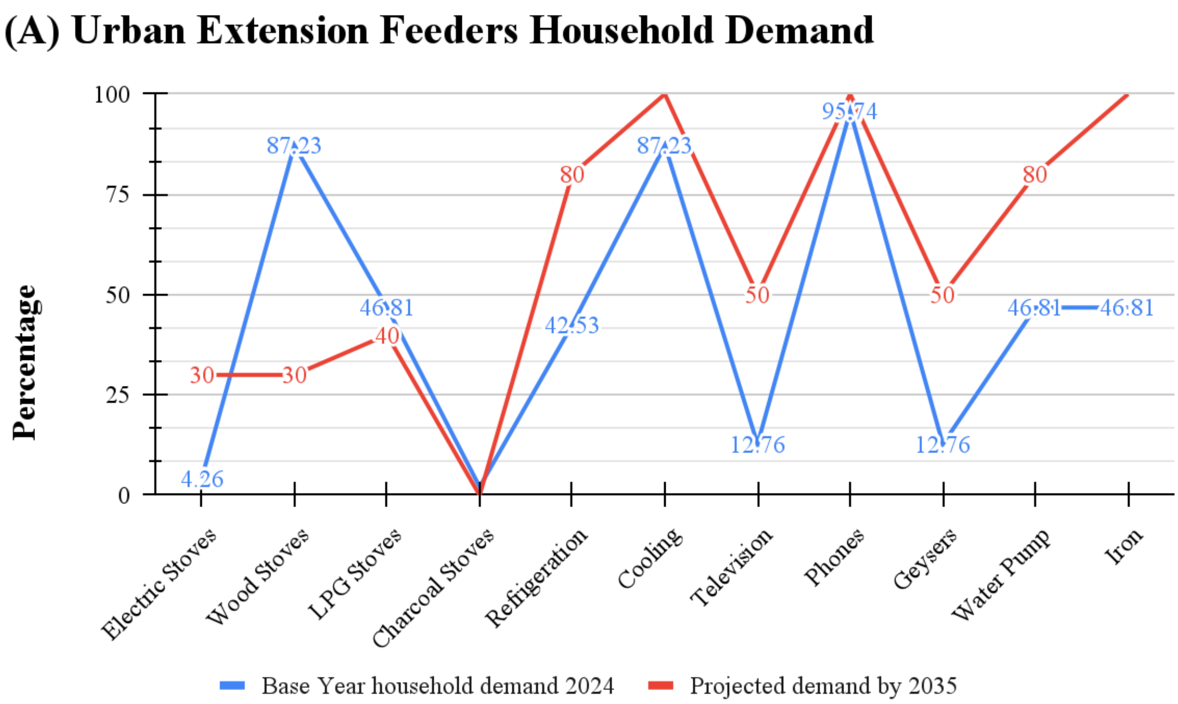


Figure 19: Base year demand vs Projected Demand by 2035- Urban extension feeders Optimistic Scenario

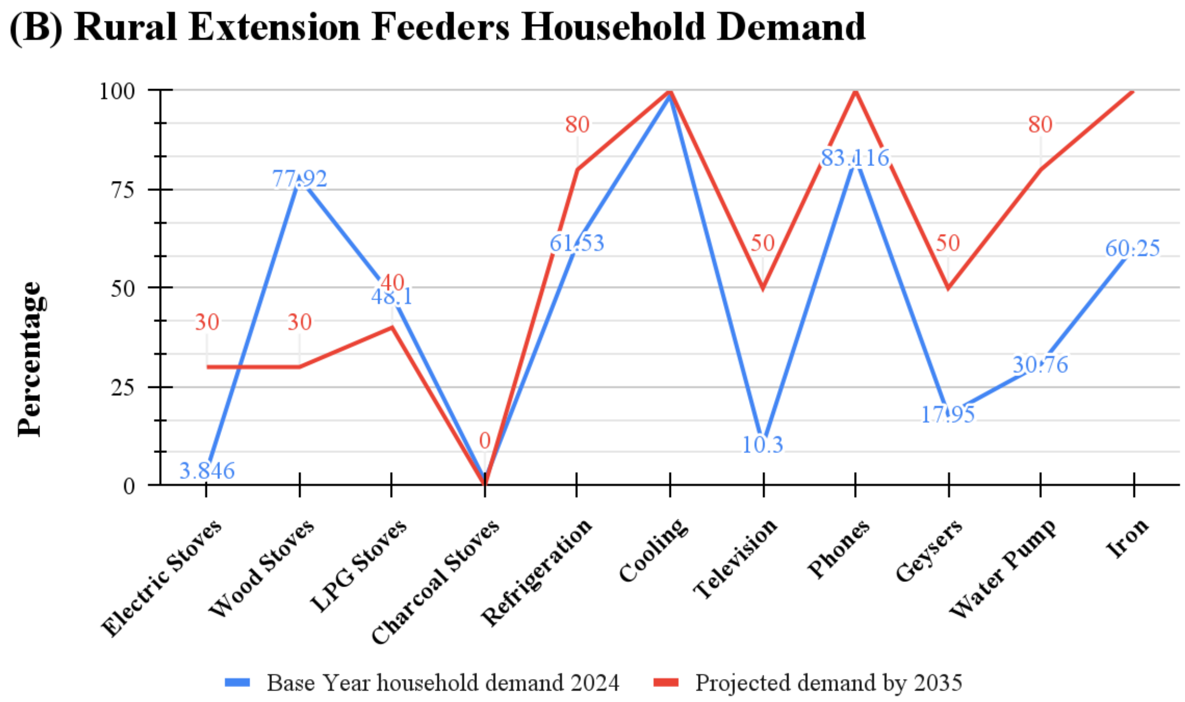


Figure 20: Base year demand vs Projected Demand by 2035- Rural extension feeders Optimistic Scenario

Based on these demand projections, by the year 2035, a decrease in the overall energy demand is observed reaching 7609.5GJ (Refer figure 22), while the electricity demand increases by almost 177percent as visible from the trend in figure 21. The decrease in demand is mostly attributed to the gradual phase out of wood fuel and increase in the electricity consumption. This trend is seen as a result of different interrelated factors. These include the higher efficiency of electric appliances, the displacement of biomass with cleaner fuels, and the systematic efficiencies brought about by centralized power generation and modern energy practices.

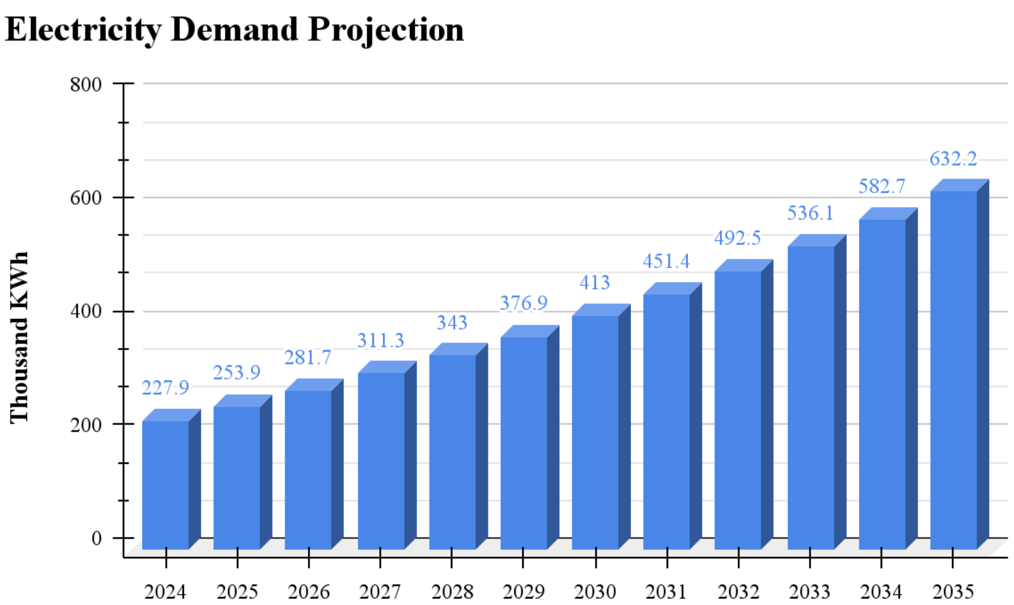


Figure 21: Electricity Demand trends by 2035 based on the projections made in Table 6

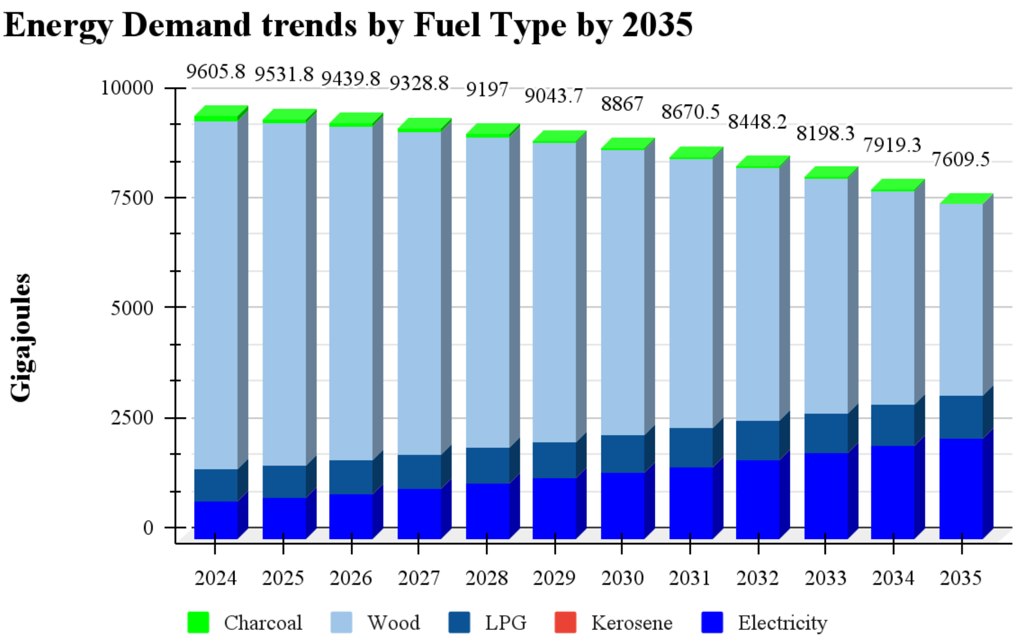


Figure 22: Energy Demand trends of all fuels by 2035 based on the projections made in Table. 6

Such a trend highlights the potential for rural electrification to not only improve energy access but also reduce overall energy consumption while fostering sustainable development.

5.3.4. Discussion of findings

The findings of this study show that lack of infrastructure development is a major reason for the residents of this region being deprived of their basic energy needs. Other reasons include: the low income levels, huge dependence on agriculture and daily wages, and a large average household size of 10. The limited energy access for basic needs of the households, for example an unstable electricity supply, makes the region more vulnerable to economic setbacks. Despite 90percent of the households being electrified, they all receive low level voltage supply and that too for a daily average of 3 hours only. This situation compels Pakistan to move towards decentralized renewable energy systems that are more cost effective than the traditional centralized grids[49].

All the scenarios developed in the LEAP model present distinct patterns of energy consumption across all households. With the conventional cooking methods dominant, the reliance on firewood for cooking increases in the baseline scenario, whereas in the cases of CPEC and optimistic scenarios, we observe an increased dependence on electricity. The projected growth in cooling load and the heating load in all scenarios also aligns well with extreme weather impacts of the climate change[50] .

The business as usual - the scenario anticipated as the most realistic scenario- shows huge annual usage of fire wood (6,319.7 kg per household), starkly contrasting with the lower usage of LPG and electricity stoves, an evidence of affordability and accessibility issues prevailing in the region. The use of inefficient appliances leading to higher electricity consumption, highlights the need of transition towards more efficient appliances.

49 https://www.sciencedirect.com/science/article/pii/S0973082624000693

50 https://blogs.worldbank.org/en/endpovertyinsouthasia/south-asia-needs-equitable-cooling-heatwaves-worsen

CPEC and the optimistic scenario requires significant transformative reforms in terms of infrastructure developments and implementation of the plans and programmes designed by the government of Pakistan. The growth in electricity demand underscores the immediate need of investments in the grid infrastructure.

Table 7: Scenario Comparison

Aspect	Business as Usual	CPEC	Optimistic- Household electrification
Major Themes	Incremental Changes, traditional energy reliance	CPEC Projects, Infrastructure development focus	Renewable energy policies, SDG 7.1 achievement
Energy Mix	Fossil fuels with slow renewable increase	Increased coal, potential power projects	Dominance of renewables diversified mix
Investment	Limited private investment, government reliance	Chinese Investment in energy infrastructure	High private investment in renewable
Infrastructure	Aging infrastructure, high technical losses	Improved infrastructure due to CPEC projects	Modernized Grid for Renewable Integration
Policy & Regulation	Inconsistent policies, regulatory hurdle	Policy Alignment with CPEC objectives	Stable Renewable Energy Investment Policy environment
Technology Adoption	Slow Adoption of advanced technologies	Potential technology transfer from China	Rapid Adoption of advanced technologies
Environmental Impact	High Indoor emissions	Increased emissions from fossil fuel power plants	Reduced Emissions, sustainable practices
Energy Access	Uneven access, high tariffs	Improved access	Universal access to reliable and affordable electricity
Economic Impact	Moderate growth	Increased economic activity	Significant growth due to private investment
SDG 7.1	Limited progress towards SDG 7.1	Potential Improvements	Full achievement of SDG 7.1 targets
Geopolitics	Dependent on imported fossil fuels	Increased reliance on China	Reduced fossil fuel dependence
Climate Resilience	Vulnerable to climate change impacts	Renewable energy projects under CPEC	Increased resilience to climate change

5.3.5: The emissions from each scenario

The huge reliance on biomass for cooking exposes the residents to indoor pollution leaving adverse health impacts on women and children, especially[51]. Air contamination inside the house caused by solid fuel combustion has been a cause of major casualties. Globally, 2.6 million people died prematurely due to diseases caused by indoor contamination in 2016, as reported by the Institute for Health Metrics and Evaluation[52]. Figures 23, 24, & 25 represent the amount of direct point emissions under each scenario.

51 James BS, Shetty RS, Kamath A, Shetty A. Household cooking fuel use and its health effects among rural women in southern India-A cross-sectional study. PLoS One. 2020 Apr 27;15(4):e0231757. doi: 10.1371/journal.pone.0231757. PMID: 32339177; PMCID: PMC7185712.

52 https://pmc.ncbi.nlm.nih.gov/articles/PMC7185712/#pone.0231757.ref001

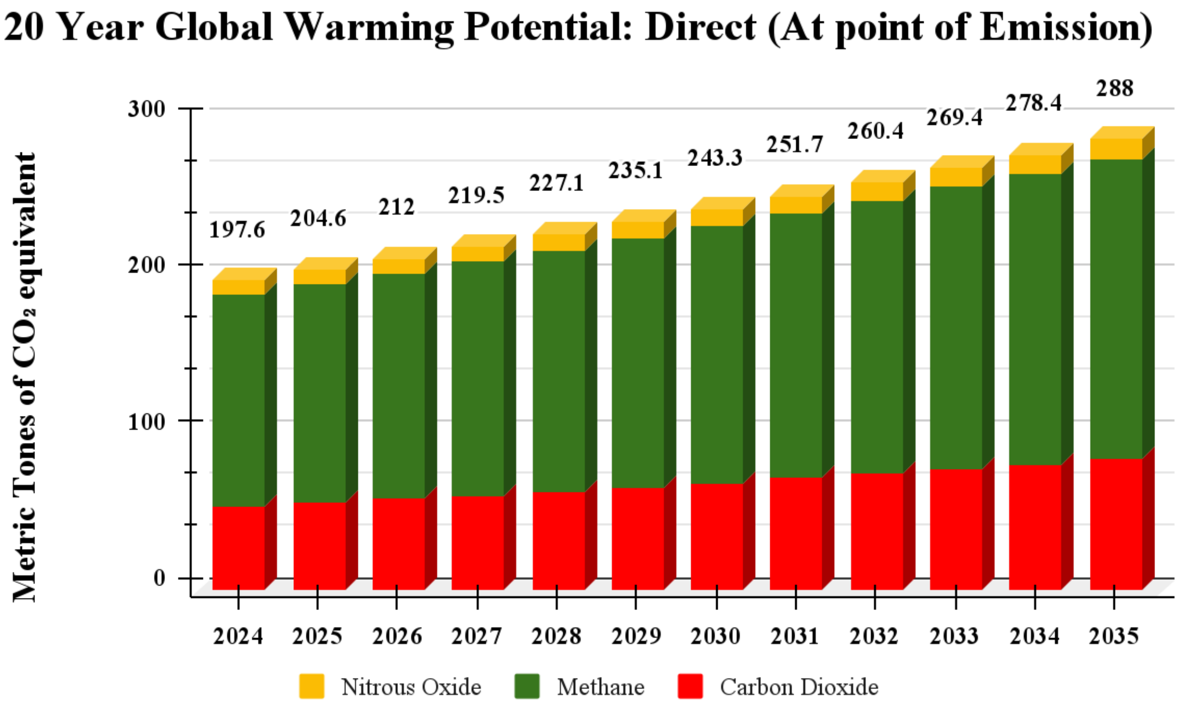


Figure 23: 20-year global warming potential: Direct (At point of Emissions) Business-As-Usual Scenario[53]

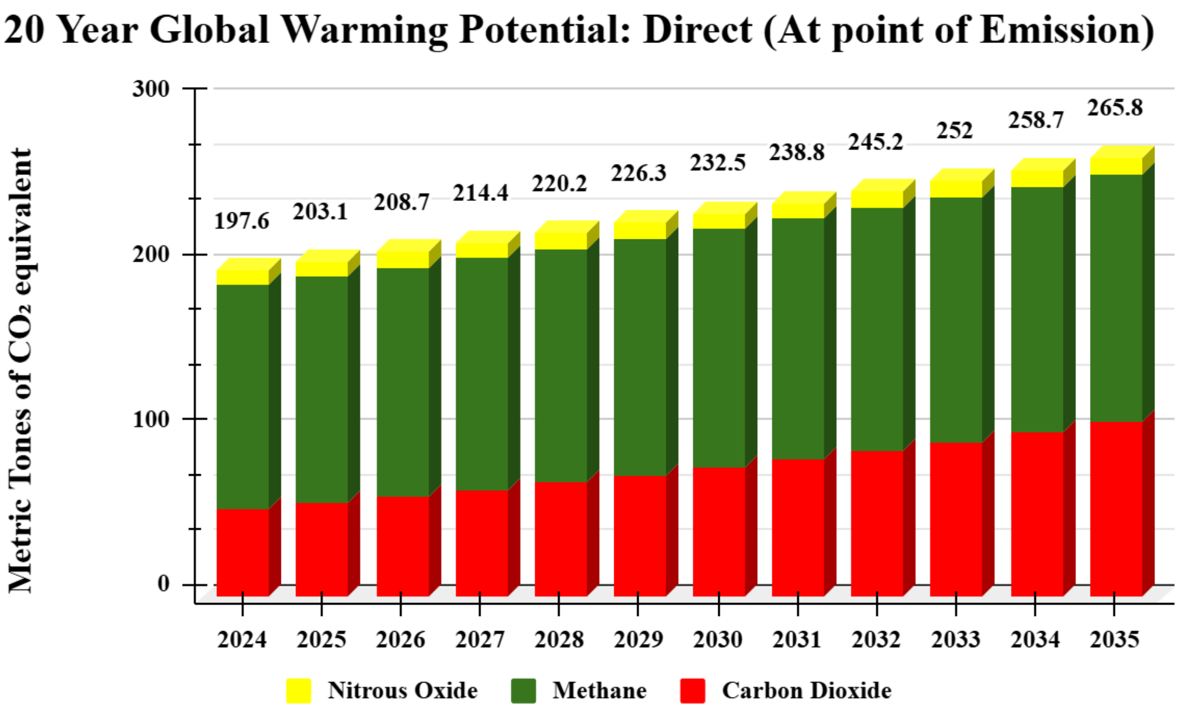


Figure 24: 20-year global warming potential: Direct (At point of Emissions) CPEC Scenario

53 *20-Year Global Warming Potential (GWP): Focuses on short-lived gases, reflecting their impact over a 20-year period, distinct from long-term trends like 50 and 100 years.*

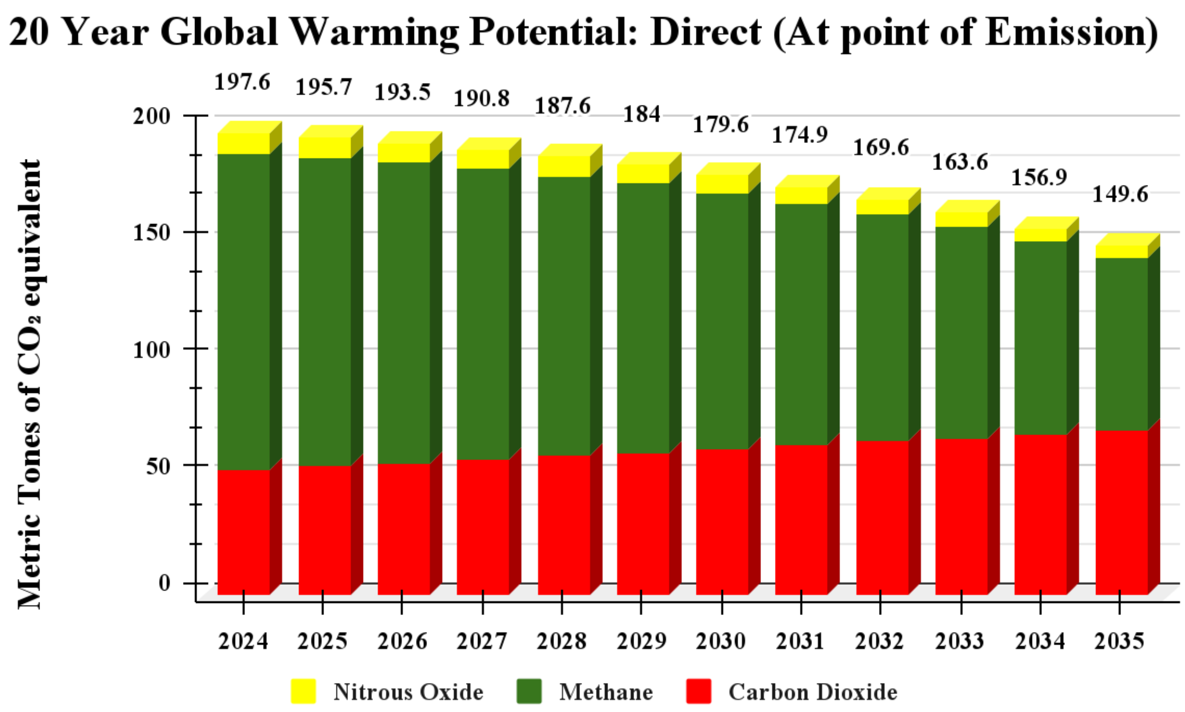


Figure 25: 20 -year global warming potential: Direct (At point of Emissions) Optimistic Scenario

A comparison of the above graphs shows that the majority of emission reduction is happening in the optimistic scenario while the Business as Usual (BAU) scenario shows an increase in the overall emissions. These are the emissions coming directly from the cooking activities only. Women and children are the most affected by these indoor emissions. Figure 19 shows a projected increase of approximately 18.98percent by 2030 in the medium term and an overall increase of 45.7percent in the long-term scenario by 2035, reaching 288 metric tons of CO_2 equivalent in 2035 in the BAU scenario. For CPEC, the emissions will increase at a slower rate due to reduced reliance on firewood. Figure 20 shows a projected increase of approximately 17.6percent by 2030 in the medium term and an overall increase of 34.5percent in the long-term scenario by 2035, reaching 265.8 metric tonnes of CO_2 equivalent in 2035. With increased penetration of electricity as a fuel in the households in the optimistic scenario, a projected decrease of approximately 9percent by 2030 in the medium term is observed, and a decrease by 24.3percent in the long-term scenario by 2035, showing a significant reduction reaching 149.6 metric tonnes of CO_2 equivalent by 2035.

Table 8: Scenario-wise Emission in the medium and long term

Scenarios	Base Year emissions 2024/ metric tonnes CO2 Equivalent	Medium Term emissions 2030 / metric tonnes CO2 Equivalent	Long Term emissions 2035/ metric tonnes CO2 Equivalent
BAU	197.7	243.3	288
CPEC	197.7	232.5	265.8
OPT	197.7	179.6	149.6

Table 9: Climate Change Impacts

Pollutant	Effect	Lifetime	GHG Reduction under Optimistic Scenario	Cost Savings
Nitrous Oxide	Powerful GHG with ~273x global warming potential than CO_2	121 years	-43.3%	$15,375/year globally from improved indoor air quality
Methane	Potent GHG, ~84x stronger than CO_2 over 20 years; key target for near-term climate action	12 years	-45.3%	$27,000 /year from reduced respiratory illness and premature deaths
Carbon Dioxide	Primary driver of long-term climate change; baseline for GWP comparison	>300 to 1,000 years	31.7%	$14,250/year in health and energy productivity savings

Conclusion

The findings of the research indicate the energy crisis faced by the domestic sector in the rural regions of Nushki district. Limited hours of electricity supply from the grid and the low voltage levels worsen the overall living conditions in these areas. Additionally, conventional carbon-intensive cooking methods expose many children and women to indoor air pollution. These circumstances combined with the poverty levels in this area limit any opportunities available for the socioeconomic development of this area.

However, this study highlights opportunities available for the development of this area through rural electrification and infrastructure development. The optimistic scenario presents significant potential for reforms and developments if timely strategic investments are made. The proximity of the Nushki district to one of the biggest wind corridors, Chaghai, provides significant opportunities to exploit the potential of variable renewable energy in the area. Additionally, this aids in gaining maximum benefits by introducing decentralized solutions in the regions. Therefore, integrating renewables into the system and promoting decentralized generation will help people meet their basic electricity needs and will improve their living conditions. Additionally, the replacement of wood cooking stoves with electricity stoves and the introduction of efficient appliances to meet cooling and heating demands will further reduce the overall energy intensity of this area.

Recommendations

1. **Grid Infrastructure Development:** Our study highlights the need for urgent grid expansion to meet the increasing electricity demand in Nushki. To address this the government should invest in upgrading the grid infrastructure to ensure stable voltage levels and expand the electricity grid to many other underserved areas, prioritizing rural feeder reliability. Additionally, deploying smart grid and storage technologies, such as smart meters and automated distribution systems, can improve efficiency. Encouraging public-private partnerships for investment in the energy sector, particularly in grid expansion and maintenance, can also help address the energy challenges in Nushki and other remote areas of Pakistan. Additionally, it is recommended to ensure that any foreign investment programs like CPEC also work on regional development.

2. **Promoting Decentralized Renewable Energy Systems:** Nushki's proximity to the Chaghai wind corridor presents a significant opportunity for renewable energy development. Decentralized systems, such as solar-wind hybrid mini-grids, microgrids, and even swarm grids can provide a cost-effective and stable energy solution for rural areas without the need of extensive investment in transmission or grid accessibility to such regions. The government should develop off-grid renewable energy mini-grids for rural areas and promote community-managed energy cooperatives for long-term sustainability. Leveraging Chaghai's wind energy potential and attracting investment especially under CPEC in wind power projects can also help serve local demand. There are many lessons that could be learnt from the peer regional countries, like Bangladesh, India, Myanmar, and Nepal where hybrid solar PV minigrids have been deployed to meet rural electricity demand.

3. **Reducing Dependence on Biomass and Promoting Clean Cooking Technologies:** The study's findings also emphasize the need to reduce dependence on biomass and promote clean cooking technologies. To achieve this, the government should subsidize and promote cleaner cooking alternatives, such as electric stoves, LPG, and biogas systems. Expanding micro-financing schemes for rural households transitioning to clean cooking and strengthening LPG and biogas

distribution networks can also help. Public awareness campaigns on the health and environmental impacts of biomass use can educate communities on the dangers of indoor air pollution.

4. **Promoting Energy-Efficient Appliances to manage overall Energy Demand:** This study also explains the significance of promoting energy-efficient appliances to reduce overall energy intensity. To achieve this, the government should encourage the adoption of energy-efficient appliances, such as high-efficiency cooling, heating, and cooking appliances. Implementing minimum energy performance standards (MEPS) to regulate appliance efficiency and developing government-led awareness programs on energy efficiency can also help.

5. **Support for Rural Development**: Any investors working on different projects in the region should be compelled to work on the development of this region on multiple fronts that include road infrastructure, education, basic facilities like water pumps etc.

6. **Aligning Energy Policy with Economic Development under CPEC:** As under our CPEC scenario results, Naushki's electricity demand grows by 85percent by 2035, it emphasizes the imperative need to align energy policy with economic development under CPEC. To achieve this, the government should ensure that grid expansion meets industrial growth needs, provide special tariff rates for industries using renewable energy, and introduce energy efficiency regulations for industrial zones. Electrifying agricultural operations to improve productivity and investing in energy-efficient cold storage and processing facilities for agricultural goods can also help.

7. **Subsidize Cottage industries:** Welfare programs by the government to support women and encourage them to participate in economic activities. This could be done by providing them with basic support like installing rooftop solar panels to support their industry.

8. **Strengthening Climate Resilience and Emission Reduction Strategies:** The study's findings highlight the need to strengthen climate resilience and emission reduction strategies. To achieve this, the government should expand renewable energy to reduce carbon emissions, implement carbon credit mechanisms to finance renewable projects, and encourage electrification to replace biomass fuels. Developing climate adaptation strategies for rural energy infrastructure and promoting community-based climate resilience programs focused on sustainable energy can also help.

Conclusively, for regions like Nushki, a multifaceted approach should be employed that includes efficient planning and implementation of policy reforms to solve the ground issues in this area and therefore, contribute to a more sustainable development.

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