Cardiff University

Domestic energy consumption data, drivers and prediction models for Punjab, Pakistan plus the potential energy supply contribution from domestic solar technologies

by

Usman Mehmood Awan

M.Sc., Cardiff University, UK

B-Arch, UET Lahore, Pakistan

Lead Supervisor: Prof. Dr Ian Knight

Co-Supervisor: Huw Jenkins

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Abstract

Pakistan is an emerging economy with 210 million people and growing domestic energy demand, facing economic, geographic, geopolitical, energy supply and climate change challenges. The findings from this research are intended to support future government and energy industry policy in this area, especially the transition to a low carbon economy. Currently, 67% of Pakistan's energy demand is met with non-renewable resources. The domestic sector consumes ~48% of Pakistan's total energy demand, including biofuels. This thesis presents novel insights into Punjab (52% of Pakistan's population) domestic sector energy demand drivers. A statistically significant 4597 responses obtained from a physical questionnaire survey conducted in 2017-18 allowed the derivation of domestic sector energy prediction models, along with the rooftop areas available for renewable energy generation amongst other unique data insights. The survey covered all ten Punjab divisions, enabling the models produced to be generally applicable to Punjab.

The research found the key drivers of electrical energy demand ***per household*** *are the number of appliances, number of lights, and the number and area of conditioned rooms. In the* ***per capita*** *models, the key drivers are the overall power rating of the appliances, particularly the power rating of the air conditioners for cooling. For annual gas use, the gross internal floor area and occupancy are found as weak demand drivers.*

The data obtained from the survey also allowed exploration of the potential for domestic solar renewable energy generation. The available rooftop area was shown to have potential to exceed the total current electrical energy demand of the domestic sector many times using current PV technology. A similar finding was achieved for the use of solar thermal technology for domestic hot water and space heating throughout the year. The thesis findings suggest that addressing the energy demand drivers of the domestic sector, and the encouragement of installation of domestic renewable energy systems could form a significant component in Pakistan's transition towards a more resilient energy supply system and a low carbon future.

Acknowledgement

*First of all, I would like to thank the supreme power the Almighty Allah, who is obviously the one who has always guided me to work on the right path in life. The author acknowledges the financial support given by the University of Engineering and Technology Lahore (**UET**), under the faculty development program to go abroad and pursue this PhD research, and the government of Pakistan.*

*After this, I would like to express my sincere gratitude to my thesis supervisor **Prof. Ian Knight**, for his continuous support for my PhD and research, for his patience, motivation, and immense knowledge. He has completely changed the way I used to take the research before; also, he has put a great influence in changing my personality as a humble and graceful human being. The very long discussion meetings we used to have has also trained me a lot for how to conduct research, and how to prepare someone to do a research. I am very grateful to him for every kind advice he gave during my stay in Cardiff. I could not have imagined having a better advisor and mentor for my PhD study.*

I am also thankful to the Welsh School of Architecture (Cardiff University, UK) for the support it has provided during my stay in Cardiff in the form of facilities, pleasant working environment, necessary training, and workshops. My sincere thanks go to the respondents, who took part in the survey for their time and patience; and to the 'creative groups of companies' for providing smart meters data.

Last but not least, I would like to thank my parents, who are also praying for my success, and my wife for her continuous care & support for providing me most delicious homemade food, in spite of the fact she was herself working on her PhD during this time. In the end, I would like to thank and convey my love to my daughter Anaya (who was a baby when I started this thesis, and she grew with it), for her immense love, baby talks and mischiefs, which provided at times huge relaxation, mental balance and emotional support during this study.

Dedications

My humble effort is dedicated to my loving and caring

Father & Mother,

Whose affection, love, encouragement and prayers for day and time make me able to get such success and honour.

Along with my wife, and daughter, Anaya. I hope she understands one day why baba spent so much time on the laptop. Over time I hope she will see me spend less time on a laptop and more time with her.

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Acronyms

APERC	Asia Pacific Energy Research Centre
AGR	Annual Growth Rate
AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
ANOVA	Analysis of Variance
ASR	Area Solar Model
ATM	Atmospheric and Topographic Model
BFA	Building Footprint Area
BOS	Bureau of Statistics
C°	Centigrade
CAS	Complex Adaptive Systems
CCUS	Carbon Capture, Utilization, and Storage Technique
CEC	Conference of European Churches
CERs	Certified Emission Reductions
CI	Confidence Interval
CL	Confidence Level
CNG	Compressed natural gas
CO_2	Carbon dioxide
DHA	Defence Housing Authority
DHW	Domestic Hot Water
DHW	Domestic hot water
DNI	Direct Normal Irradiation
DSHWS	Domestic Solar Hot Water Systems
DSM	Digital Surface Model
DSWH	Domestic Solar Water Heating
ESMA	Energy Sector Management Assistance Program
ESMAP	Energy Sector Management Assistance Program
ETC	Evacuated Tube Collector
EU	European Union
EYR	Energy Yield Ratio
FPC	Flat-Plate Collector
GDP	Gross Domestic Product
GENCO	Generation Company
GHG	Green House Gas
GHI	Global Horizontal Irradiation
GIFA	Gross Internal Floor Area
GIS	Global Information System
GOES	Geostationary Operational Environmental Satellite
GOP	Government of Pakistan
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GW	Gigawatts
GWh	Giga Watt-hour
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IPPs	Independent Power Producers
J	Joules
K	Kilo or 1000
KDA	Karachi Development Authority
$kgCO_2$	Kilo gram of Carbon Dioxide
KPK	Khyber Pakhtoon Khan
kWh	Kilo-Watt hour
kWh/a	Kilo-Watt hour/annum
L	Litres
LDA	Lahore Development Authority

LEAP	long-range Energy Alternatives Planning
LESCO	Lahore Electric Supply Company
LIDAR	Light Detection and Ranging
LNG	liquified Natural Gas
LPG	liquified Petroleum Gas
M	Million
m^2	Meter Square (always refers to floor area of house unless otherwise specified)
MDMS	Meter Data Management System
MKEP	Milton Keynes Energy Park Project
MMBtu	Million British Thermal Units
Mtoe	Millions of tonnes of oil equivalent
MW	MegaWatt
MWh	Mega Watt-hour
NASA	National Aeronautics and Space Administration
NEPRA	National Electric Power Regulatory Authority
NMA	National Meteorological Agency
NREL	National Renewable Energy Laboratory, USA
NUST	National University of Sciences & Technology -Islamabad
p/km^2	person per kilometre-square
PCRET	Pakistan Council of Renewable Energy Technology
PCRET	Pakistan Council of Renewable Energy Technologies
PHATA	Punjab Housing and Town Planning Department
PMD	Pakistan Meteorological Department
PPDB	Punjab Power Development Board
PSLM	Pakistan Social and Living Standards Measurement
PV	Photovoltaic
PVT	Photovoltaic-Thermal
Pvt. Ltd	Private Limited
R.Y. Khan	Raheem Yar Khan
RECS	Residential Energy Consumption Survey
RHI	Renewable Heat Incentive
RMSD	`Root-Mean-Square' Deviation
RMSE	Root-Mean-Square Error
SHS	Solar Home System
SMS	Short Message Service
Sq. Ft	Square Feet
SUPARCO	Space & Upper Atmosphere Research Commission
TCO_2	Total Carbon Dioxide
TV	Television
TWh	Tera Watt Hour
UAE	United Arab Emirate
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
UN-HABITAT	United Nations Human Settlements Programme
USA	United States of America
W	Watt
WAPDA	Water and Power Development Authority
Wp	Watt peak
WRDC	World Radiation Data Centre

Chapter 1

Introduction

1 Introduction

1.1 Motivation

At the time of undertaking this thesis, the author is a qualified architect in Pakistan, having already undertaken an MSc in Environmental Design of buildings. The thesis arose from a desire to understand how he might contribute towards the twin problems of improving both living conditions and energy supply security, affecting the domestic sector in Pakistan.

The author's motivation, as an architect, was to understand how domestic design in Punjab should evolve in order to ensure that all properties have access to energy and comfort conditions they would aspire to have. In looking at this problem, it became apparent what was not available, the detailed understanding of the exact occupancy of these residences in Punjab. Further, what drove the energy demand in them was not available, so that work is needed to be done first. The main body of the thesis is about undertaking the underpinning research to provide a firm grounding for future work looking at to how domestic design may now evolve to produce better domestic buildings.

The initial aim for this thesis was to quantify and contextualise the role buildings could play in Pakistan's move towards a zero-impact and resilient energy supply system, as part of its responsibilities in helping to meet global resource and climate challenges. This thesis also intends that the assembled evidence and information will be of use to policymakers, authorities and other actors within Punjab, Pakistan's most populated region, in planning how to meet these aims.

Resilience in energy terms is:

"The ability of assets, networks, and systems to anticipate, absorb, adapt to and/or rapidly recover from a disruptive event" [1].

The holistic definition of Zero impact is:

"A zero-impact building seeks the highest efficiency of resources management and maximum generation of renewable resources. The resources management emphasizes the viability of harnessing renewable resources, including energy and water and achieves a closed loop of material and land use" [2] .

1.2 Background

The context and requirement for this study come from several issues facing Pakistan. Pakistan is a developing country with a rapidly growing population, but its energy use per capita is far below that of more developed counties in the world [3]. However, it already faces energy crises which restrict its potential to grow from a living standard viewpoint. This crisis hampers both economic and social progress [4] [5] [6].

The literature review addresses the following specific topics to enable context to put to these problems:

- Where does Pakistan currently get its energy from?
- What are the risks to energy supply in Pakistan?
- What alternative energy sources might Pakistan have access to?
- What are the drivers of energy demand in Pakistan?
- How much energy is needed, and at what times?
- What might a zero-impact system look like for Pakistan?
- What is Pakistan already doing to move towards a zero-impact energy system?
- What role does the domestic sector play in the overall energy demand?

1.3 Research Aims

The thesis aims to provide deep insight into domestic energy consumption data, drivers ad prediction models, along with an evidence-based quantification of the role domestic buildings could play in moving Punjab towards a zero-impact and resilient energy supply system with sufficient capacity to meet predicted future energy demands.

1.4 Research objectives

1. To understand current energy demands by the domestic sector of Punjab, and provide the drivers for this demand, through surveys and modelling
2. To predict the potential ranges of future need for Punjab's domestic energy sector by developing energy prediction models
3. To clarify the timing of energy demand across the year from measured data
4. To model renewable energy generation potential by the Punjab domestic sector

The data obtained will be used to conclude what impact the Domestic industry might have in meeting future demands and in increasing energy resilience

1.5 Thesis Structure

To meet the research objectives thesis is structured as follows;

Chapter 2 - Literature review; To establish what is already published in this area relating to the project aims. This will enable understanding of the current state of knowledge and allows conclusions to be drawn as to where the thesis research should start, and what methodologies should be used.

Chapter 3 - Research Methodology; Building on Chapter 2, this chapter examines the possible methodological approaches to answering the thesis aims, before proposing and justifying the methodologies chosen.

Chapter 4 – Research; This chapter presents the research undertaken, showing methods used, caveats to the data and displays the datasets obtained.

Chapter 5 - Analysis and Results; This chapter analyses data obtained in terms of the project aims and notes any other notable findings and observations arising from the study.

Chapter 6 –Conclusions; This chapter concludes the overall findings from the thesis and proposes what they mean in terms of broader motivations for the dissertation. It also provides observations, notes the limitations to work and proposals for future research.

References: A full list of the references cited in the thesis

Appendices: This section contains extensive detail of the datasets obtained and additional analyses that did not fit comfortably in the main body of the thesis.

1.6 Summary

This chapter has summarised the motivations, approach, and structure of this thesis.

Chapter 2

Literature Review

2 Literature Review

2.1 Introduction

To set the scene for the thesis research into how Pakistan might evolve to a low carbon future (1.2), the current state of knowledge related to the thesis aims is explored using a literature review structured around the following topics:

i. Introduction/background and global perspective
ii. Pakistan energy demand
iii. Pakistan energy supply
iv. Pakistan energy consumption/demand drivers
v. Resilience in energy supply & transition paths to a Low/Zero Carbon economy
vi. Pakistan’s domestic sector energy scenario and demand drivers
vii. Low carbon energy generation potential from the domestic sector

Figure 2.1 presents the structure of the literature review using ‘**what & why’** concerning the overall thesis aims.

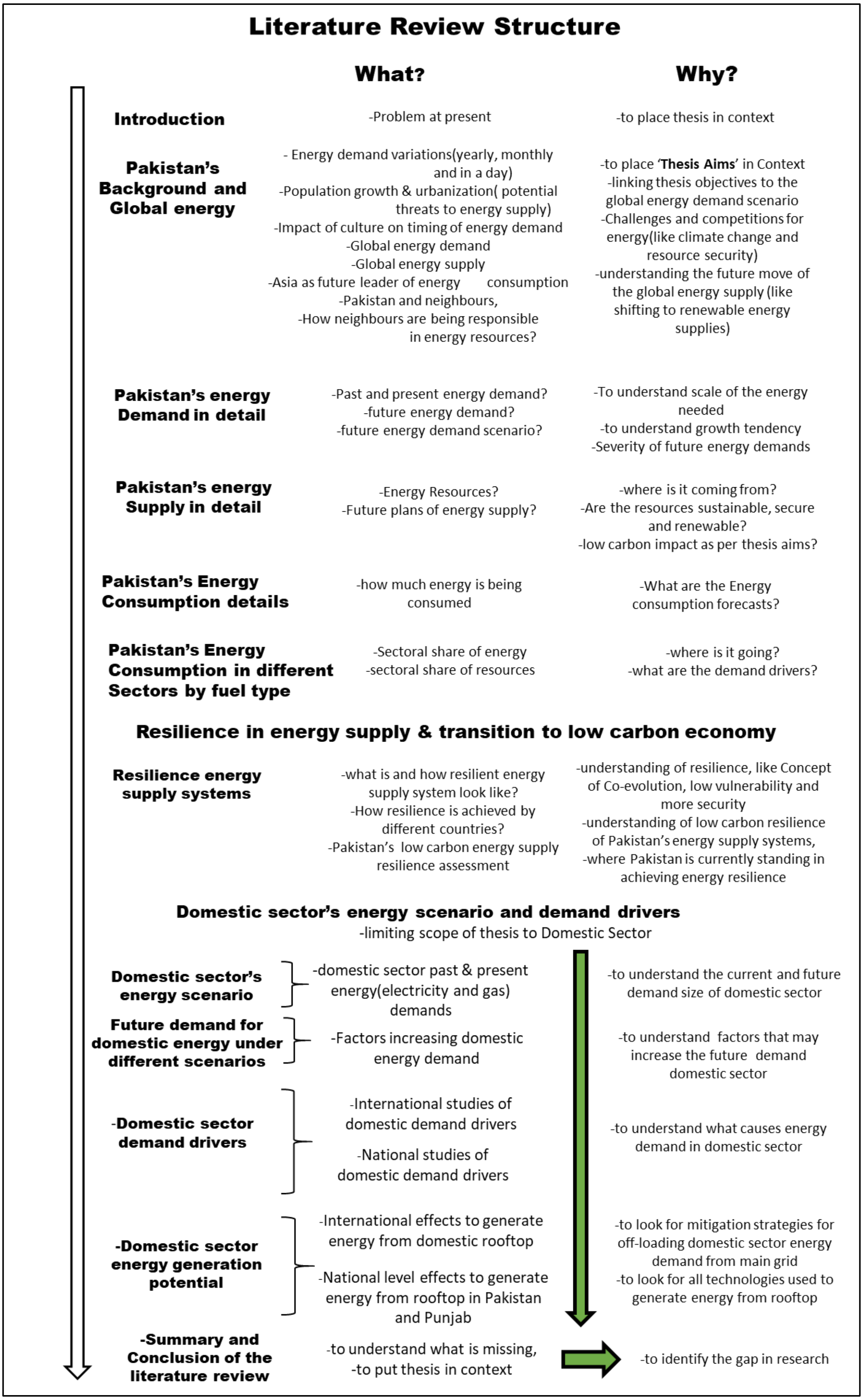


Figure 2.1 Literature review structure

2.2 Pakistan background and global energy

Pakistan is situated in South Asia. It came into existence in 1947, as a result of the separation of the sub-continent. It shares boundaries with China, India, Afghanistan, and Iran [7]. Pakistan consists of four provinces as shown in Figure 2.2, and Punjab (which is the focus of this thesis) is the largest in terms of gross domestic product[1] (GDP) share of 60%, having a population of 53%.

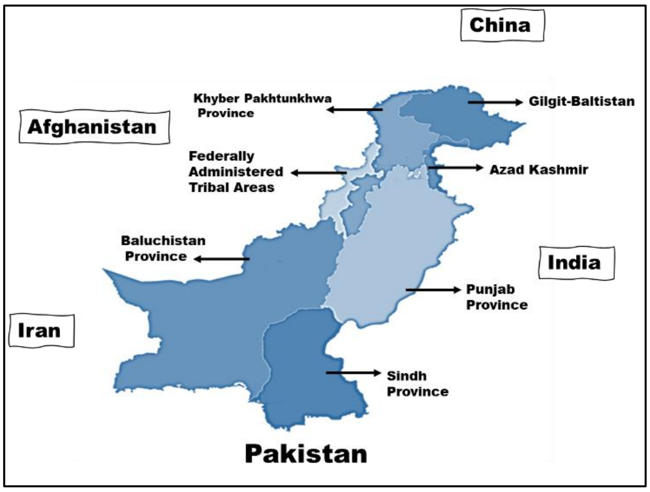


Figure 2.2 Map of Pakistan with neighbours, [7]

Since Pakistan came into existence, it has to face problems in almost all areas like transport, industry, agriculture and housing [8], and struggling hard to meet its energy requirements [9] [10] (especially power) in different sectors [11]. Lack of proper administration [12] [13] [14], education facilities [15] , skilled personnel [16], inadequate energy [17] [18], improper planning [19] and inefficient policies [20] [21] are some of the issues Pakistan is facing. Currently, Pakistan is facing a severe energy crisis, especially in the power sector, where the authorities must do power-cuts for several hours in the country.

2.2.1 Climatic and Seasonal Variations

The geographical location of Pakistan offers the enormous potential of solar energy [22] [23] [24] [25] [26] [27], limited wind energy [28] [29] [30] and it experiences four different seasons within the year [31], causing different energy demand profiles within a year of heating and cooling with the temperature variations of -10C° to 51C° [31].

2.2.2 Population and urban context

The demographic data of Pakistan shows it has a population of 210M (Punjab 110M) [32] [7] [33]. According to one estimate it is going to increase at the rate of 5-7% per 5 years [34] [35], by the year 2030 & 2050 it would be 245M & 310M respectively [36] [37] [38] [39] Figure 2.3.

[1] GDP, The Gross Domestic Product measures the value of economic activity within a country. The equation used to calculate the GDP: GDP = C + I + G + (X – M) or GDP = private consumption + gross investment + government investment + government spending + (exports – imports).

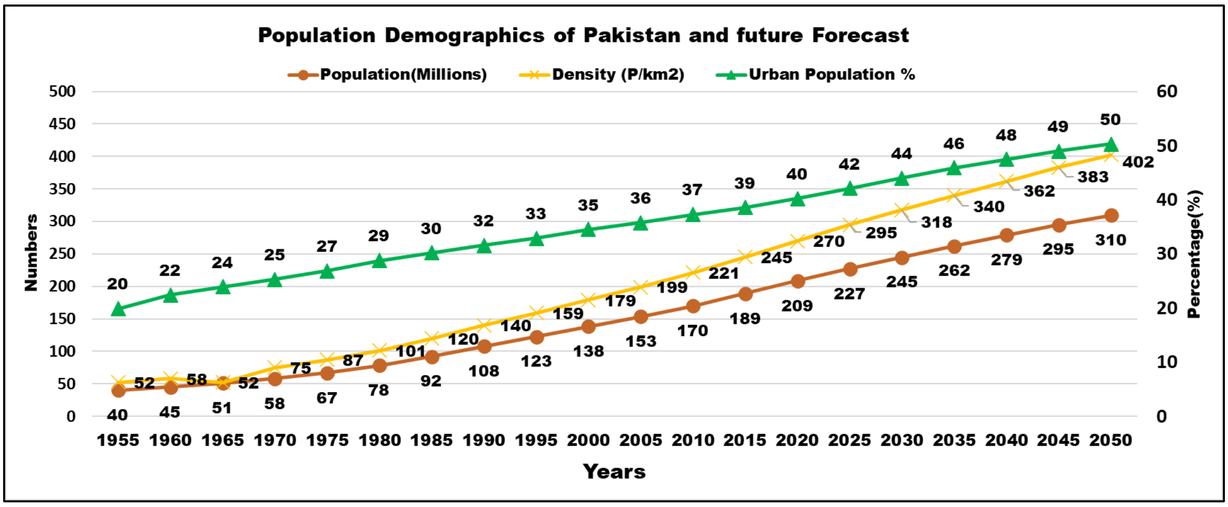


Figure 2.3 Pakistan's population growth and density trends, source: [38] [39]

Current population density of 255p/km^2 (person per kilometre-square)is increasing at the rate of approximately 7% per 5 years, by 2030 it would be 318p/km^2 which is 25% more than the current value, which will reach to 402p/km^2 in the year 2050 [38] [39], as a result, energy usage per km^2 would increase at rapid speed. Out of the total population, 39.2% in Urban and 60.8% rural(Punjab-urban 64%) [38] [38] and there is an increasing trend of urbanization in the country, around 60% [40] [41] of the population tend to adopt a modern lifestyle of cities [42] [43] with 5% emigrant every five years Figure 2.3. All these statistics show that Pakistan is a rapidly growing country, and likewise, its energy demand would increase two-fold shortly. The situation of energy crisis may increase if adequate measures not taken in time.

2.2.3 Impact of culture on the timing of energy demands

Religion is an integral part of Pakistan and Punjab's culture. The population of Punjab is 97% Muslims [7]. People go to mosques five times a day in huge gatherings (approximately 200k mosques in Punjab). So, we need to have instantaneous additional energy for its proper functioning. There are some urban and rural cultural traits like devotional fairs, Urs and Melahs [7] need huge energy demand at different times of the year. Some of the social attributes attached to the urban and rural culture which affect the energy demand are. (i) Shops to remain open late night from 10 am to 1:00 am during the night and adds to commercial energy demand, (ii) Wedding Activities occur late at night till 2-3 am in houses and banquet halls causing huge uncertain energy demand. (iii) Late sleeping habits; the people in the cities go to bed as late as 1-2 am [31]. Further, the dependency ratio in Punjab is very high, mostly on average, one member of the family is working in a group of 5-6 [31]. So, every member of the family has a different daily routine. Especially during the summer breaks in the schools and colleges, which remain closed for almost three months of the year (June-August), resulting most of the spaces in the house occupied, causing highest energy demand during this time of the year [31] throughout the day.

2.2.4 Pakistan historical and current energy demand in a global context

Energy demand is increasing in the world as time passes. It is due to rapid demand growth in all sectors of energy consumption like transport, industry and buildings [44]. The 25 years record of energy demand increase, to take the glimpse of the situation, shows that there is a 52.4 % increase in the world energy demand. Asia has seen the vast demand increase of 169.2% in the same time frame and South Asia (of which Pakistan is a part), has seen the demand increase of 134.3%, and Pakistan has grown its demand to 125.5% during the same timescale from 1990-2016 Figure 2.4. The gradual demand increase at an interval of 5 years is shown in Figure 2.4 [44]. This increasing trend of global & local energy demand draws our attention towards a dire need to decrease demand on the available global resources. We need to look for the resilient energy supply systems for the future, which should be addressing the issue of climate change by reducing their impact on the environment.

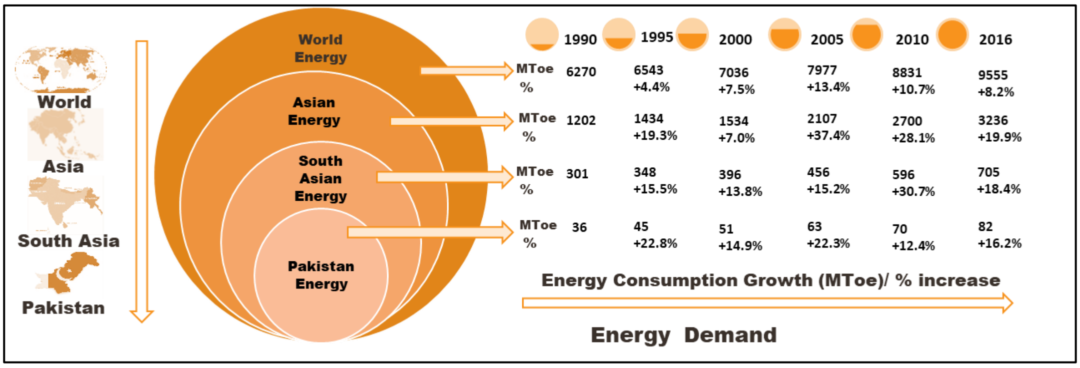


Figure 2.4 Global energy demand/consumption growth from 1990-2016 [45] [44]

We see that World, Asian, South Asian, and Pakistan's oil demand have increased to 50%, 301.7%, 245.6% and 136.8% in the last 25 years respectively, and for gas, it had increased to 52.4%,587.4%, 339.2% & 187.5% and for electricity, it has grown up to 115.1%, 691.6%, 406.1% & 227.1% respectively from 1990-2016 (Table 2.1). There is enormous demand growth of all these three resources of energy in Asia and South Asia, being followed by Pakistan where only the electricity demand is grown to 227.1% during the last 25 years [44]. During the same time frame (1990-2016), world renewable consumption is increased to 1450%, Asian and South Asian to 2200% & 600% respectively. Pakistan has not benefitted from these sources of energy, and its growth is not more than 0.1% in Table 2.1 (presented in millions of tonnes of oil equivalent -MToe). There is a need that Pakistan could also start to develop renewable energy resources.

Table 2.1 Growth in the demand for energy resources 1990-2016 (Global- Pakistan) [44]

Year	1990	1995	2000	2005	2010	2016	%age growth[1] over 25 years
Oil Consumption Growth-MToe							
World	2605	2804	3122	3444	3593	3908	50
Asian	239	343	452	590	736	960	301
South Asian	60.94	83.31	112.09	123.89	152.93	210.58	245
Pakistan	7.75	10	11.8	11.55	11.56	18.35	136
Gas Consumption Growth –MToe							
World	945	1006	1118	1192	1344	1440	52
Asian	31	41	55	88	146	213	587
South Asian	13.43	21.28	23.45	33.51	54.15	58.99	339
Pakistan	6.01	8.2	10.18	15.54	19.53	17.28	187
Electricity Consumption Growth –MToe							
World	834	934	1089	1301	1539	1794	115
Asian	83	131	172	284	447	657	691
South Asian	21.64	31.82	38.1	50.54	73.1	109.54	406
Pakistan	2.47	3.6	4.18	5.83	6.64	8.08	227
Solar/Tide/Wind Energy Consumption Growth –MToe							
World	2	2	5	7	15	31	1450
Asian	0	0	1	3	8	23	2200
South Asian	0	0	0	0.1	0.3	0.7	600
Pakistan	0	0	0	0	0	0.1	0.1

2.2.5 Future global energy demand

In the sprouting growth scenario, by 2040 the world GDP will be doubled, mainly caused by the rapidly developing economies of the world, which will result in an uplift of 2.5 billion people from low incomes [46]. We see that in 2035 global energy consumption demand would be increased up to 17517MToe, Asia would be 7684MToe, and the Middle East would need 1144Mtoe [47]. World energy demand would increase by 30% in the year 2040, with an average economic growth rate of 3.4%. Asia and South Asia are the main contributors to the increase in global future primary energy demand. Pakistan is part of it, (India and China would be a leader in energy consumption) While few countries in the world are focusing on decreasing their demand like US, UK, Europe and Japan [48]. Because of population growth and prosperity, buildings energy demand growth is high in Asia (66%), Middle East (13%), and Africa (14%), accounting for almost 90% growth in building energy use. [46] Two/thirds of the energy demand increase in 2040 is in Asia, and an overall increase in primary energy consumption would be up to 17983MToe in 2040 than its value in 2016 (9555MToe) [46], almost double.

2.2.6 Energy demand growth of neighbouring countries

China and India are two neighbouring countries which have grown their energy consumption 199% and 244% respectively in the last 25 years, Pakistan's growth rate during this time is 126% [45].

[1] % increase = Increase ÷ Original Number × 100, where increase or growth= New Number - Original Number

Five yearly growth rates of energy consumption shown in Figure 2.5, China and Iran have the highest growth rates and Sri-Lanka being the lowest in the regional context.

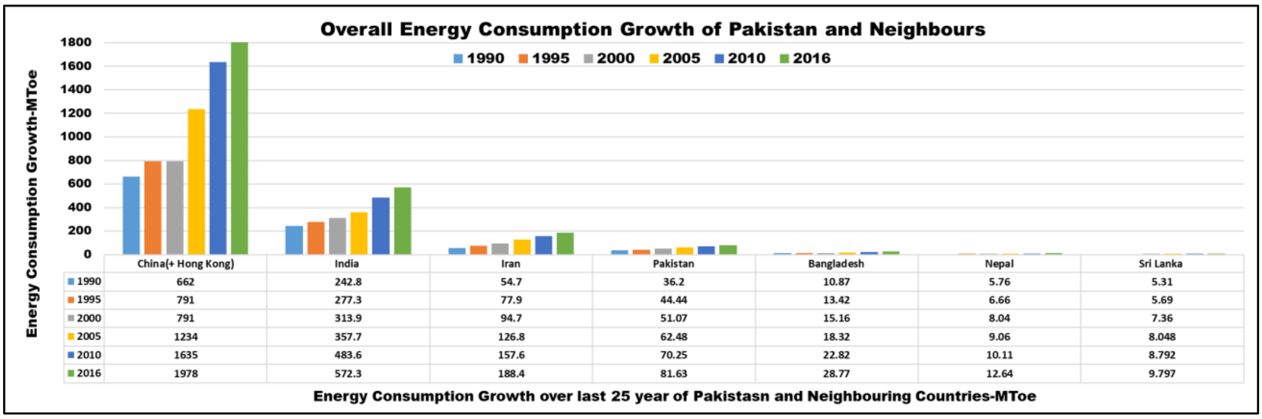


Figure 2.5 Energy consumption growth of Pakistan and neighbours, Source [44]

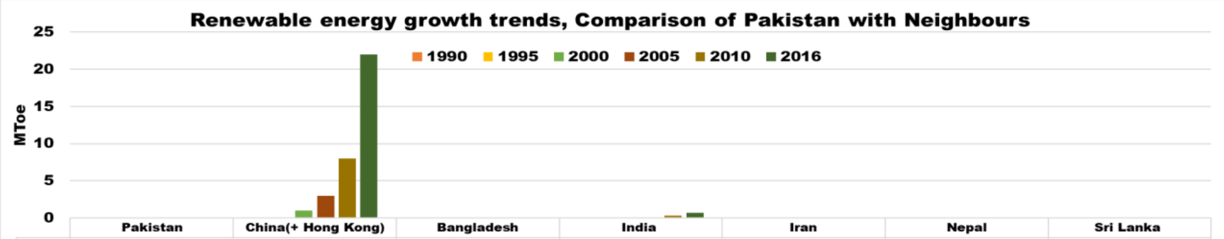
Neighbouring countries have high growth rates of energy (oil, gas & electricity) consumption during the last decades. The electricity in Pakistan has the highest growth rate during the previous two decades, being 227.1%. Gas and oil have the second and third growth rates, 187.5 and 136.8% respectively Table 2.2. Pakistan has the lowest growth rates of oil, gas, and electricity consumption (except Iran, which has the lowest oil consumption growth rate) in the region in Table 2.2.

Table 2.2 Growth in the demand for energy resources 1990-2016 (Pakistan & neighbours) [44]

Year	1990	1995	2000	2005	2010	2016	%age growth (25 years)
Oil Consumption Growth-MToe							
Pakistan	7.75	10	11.8	11.55	11.56	18.4	137
China (+ Hong Kong)	88	130	186	277	372	498.0	466
Bangladesh	1.57	2.41	2.71	3.17	3.22	3.93	150
India	50.2	68.7	94.4	105.6	134.2	182.3	263
Iran	40.7	48.21	57.0	67.4	65.1	64.8	59
Nepal	0.24	0.48	0.69	0.72	0.99	1.95	713
Sri Lanka	1.18	1.71	2.499	2.85	2.96	4.05	244
Gas Consumption Growth -MToe							
Pakistan	6.01	8.2	10.18	15.54	19.53	17.28	188
China (+ Hong Kong)	9	10	13	29	61	114	1167
Bangladesh	1.85	2.87	3.57	4.67	7.42	9.61	420
India	5.6	8.4	9.7	13.3	27.2	32.1	473
Iran	9.4	23	29.2	46.6	75.6	101.8	983
Nepal	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0
Electricity Consumption Growth -MToe							
Pakistan	2.47	3.6	4.18	5.83	6.64	8.08	227
China (+ Hong Kong)	41	68	92	175	300	449	995
Bangladesh	0.4	0.72	1.07	1.91	2.97	4.55	1038
India	18.5	27.1	32.3	42.1	62.4	95.4	416
Iran	4.2	5.8	8.1	11.6	16.07	20.7	393
Nepal	0.05	0.07	0.11	0.17	0.24	0.42	740
Sri Lanka	0.224	0.324	0.417	0.532	0.792	1.093	388

China and India are only two countries in the regional context, who are currently exploiting renewable energy resources (like solar/tide/wind). In the last two decades, their green energy production/consumption has grown to 633.3% & 600. % respectively, consuming 22MToe and

0.7MToe as of 2016. Pakistan currently utilizing its renewable potential to only 0.1MToe Figure 2.6



	Pakistan	China(+ Hong Kong)	Bangladesh	India	Iran	Nepal	Sri Lanka
1990	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0
2000	0	1	0	0	0	0	0
2005	0	3	0	0.1	0	0	0
2010	0	8	0	0.3	0	0	0
2016	0.1	22	0	0.7	0	0	0

Neighbourhold Perspective of renewable Energy growth, (25 years Growth)

Figure 2.6 Renewable energy growth comparison of Pakistan with neighbours, source [44]

2.2.7 Summary and conclusion

In overcoming the energy crisis of Pakistan, China and Iran can be potentially helpful neighbours (2.2). Pakistan has reasonable renewable potential to meet the seasonal (2.2.1) & occasional (2.2.3) demands of energy for the rapid population growth (310M in 2050) with increased density (402 P/km^2) and 50% urbanites(, 2.2.2).

As indicated (2.2.1), we see considerable variations in the climate conditions and occasional energy demands (2.2.3) of the country. Comfortable indoor conditions need colossal input of energy for different times of the year, months and even within a day, as it is away from the comfort band of 18-26C° and requires efficient energy mitigation strategies as per the demand occurs. Further, the rapid population growth and urbanization trends would be demanding more energy resources to avoid the energy crisis . The global energy demand is increasing at rapid speed (Figure 2.4) and mostly relies on non-renewable resources (Table 2.1). The energy security would be an issue in the future and in place of that, renewable resources have started to take part in the global energy supply system. We are looking at this in the context of global challenges in trying to move towards zero impact and global challenges of availability of resources as there is a competition for resources.

During the last 25 years, Asian energy demand, mainly from non-renewable sources Table 1, has increased 3-4 times the growth rate of the world's need and Pakistan's requirement has risen to 125.5 % (2.2.4, Figure 2.4). Further, Asia has the highest future energy demand, mainly concentrated in the building sector (66%, 2.2.5). Renewable energy sources have become part of energy supply system in the world and Asia, while Pakistan is way behind in this course while having China and India among neighbours, exploiting these resources (Figure 2.6, 2.2.6)

We conclude that there is a rapid growth trend in energy demand among neighbours and Pakistan. This global energy demand growth is an area where Pakistan should focus in the future and play its responsible role by exploiting the renewable resources to meet the ambition of developing low impact and resilient future energy supply system of Pakistan. In pursuit of this goal, we will see if Pakistan is on track to achieve it and place this thesis in context, where currently there is a massive energy crisis. In the next section, we will see what the past, present and future demands of the energy of Pakistan are, to understand the overall growth tendency and severity of future needs.

2.3 Pakistan energy demand in detail

2.3.1 Historical and current energy demand in Pakistan

Pakistan is one of the progressing and developing countries of South-Asia, this progress is evident in every walk of life, though its pace being inconsistent in the history of Pakistan. Energy is the primary source or commodity, which ensures the smooth journey of this development.

In the year 1973, Pakistan's total energy consumption was 16.83 MToe which had grown to 22.5 Mtoe, with an increase of 34% in the year 1980 [44]. The most significant percentage increase 61%, in the energy consumption in ten years, is between 1980-1990 and considerably higher percentage increases (41%), were seen between 1990-2000 with an overall demand raised to 51.07Mtoe [44]. Approximately 60% of demand increase is from 2000-2016, and demand grew to 81.63 MToe. (Figure 2.7) (This is the highest demand figure we find in literature)

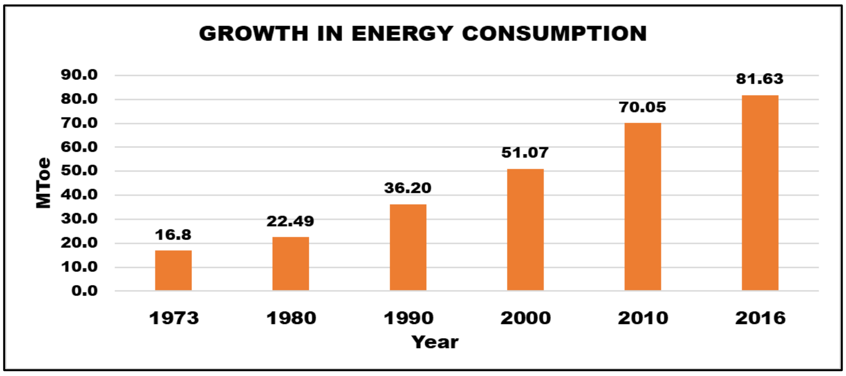


Figure 2.7 Historical growth in the consumption of energy 1973-2016, source: [45], Author's production

2.3.2 Predicted Pakistan energy demand

Pakistan's energy demand is increasing at an exponential rate [49]. It was 81.63 Mtoe in 2016 and would be 361.3 Mtoe in the year 2030. Figure 2.8 is explaining energy supply and demand as predicted by PCRET (Pakistan council of renewable energy technology). This increase in demand is enormous and ideally could be addressed with resilient supply systems.

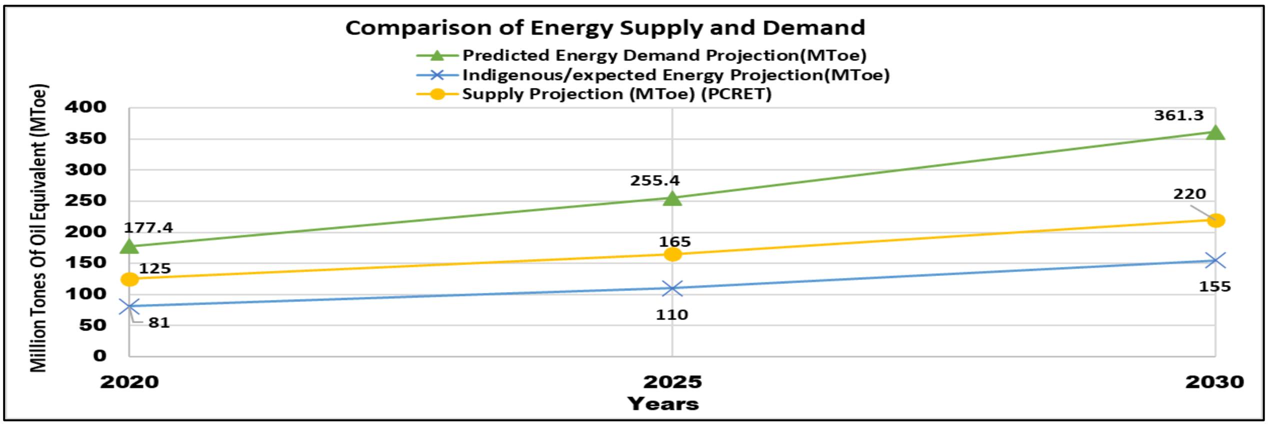


Figure 2.8 Predicted future supply and demand projection, source: [50] [51] Author's production

2.3.3 Pakistan electrical energy demand

The electrical demand for Pakistan is considered a relevant section to study on its own, as this is likely to be critical to a low or zero-carbon future based on currently available technologies. Pakistan's electrical power (17GW) demand is increasing exponentially. It would be 101.4 gigawatts (GW) in the year 2030 *Figure 2.9* (water and power development authority, WAPDA). Approximately, 62-67% [52] [53] of the population with electricity supply, the projected peak electricity demand as of 2020, *Figure 2.9* would be 54.4 GW. This future demand is around three times higher than the current 22GW electricity generation capacity of Pakistan. It indicates that we cannot meet future demand.

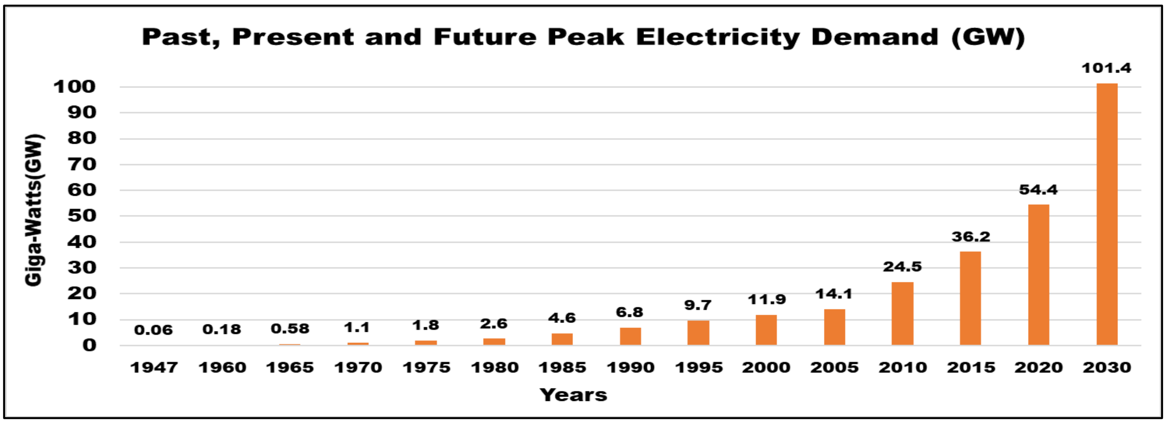


Figure 2.9 Predicted past, present, and future electricity demand(GW), source *[53]* WAPDA & K-electric, Author's production

Even though in 2017 [54] 32% of the population in Pakistan had no access to electricity, there is a current shortfall of approximately 5.0-7.0 GW (Mahmood, Javaid et al. 2014). This shortfall is 31% of the country's peak load demand of 17.0 GW and causing approximately 15 hours of daily electricity blackouts [10] in rural areas and 6-8 hours in urban areas. Figure 2.10 summarises the current situation as of 2017.

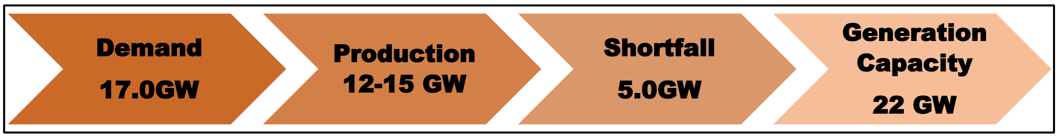


Figure 2.10 Electrical energy situation in Pakistan (as of 2017-2019), source: [55] Author's production

2.3.4 Future energy demand scenarios

comparing the annual electrical energy consumption per capita of Pakistan with other advanced and neighbouring countries, we found that Pakistan is currently consuming only 490 kWh of energy per capita/annum which is far less per capita than the energy consumed by most other countries. The range of annual per capita energy consumption varies from 330 kWh/a (Bangladesh) to 12920 kWh/a (UAE). This higher energy consumed per capita(kWh/a) by other countries could be the potential future demand of Pakistan's per capita energy and needs to be mediated in Figure 2.11.

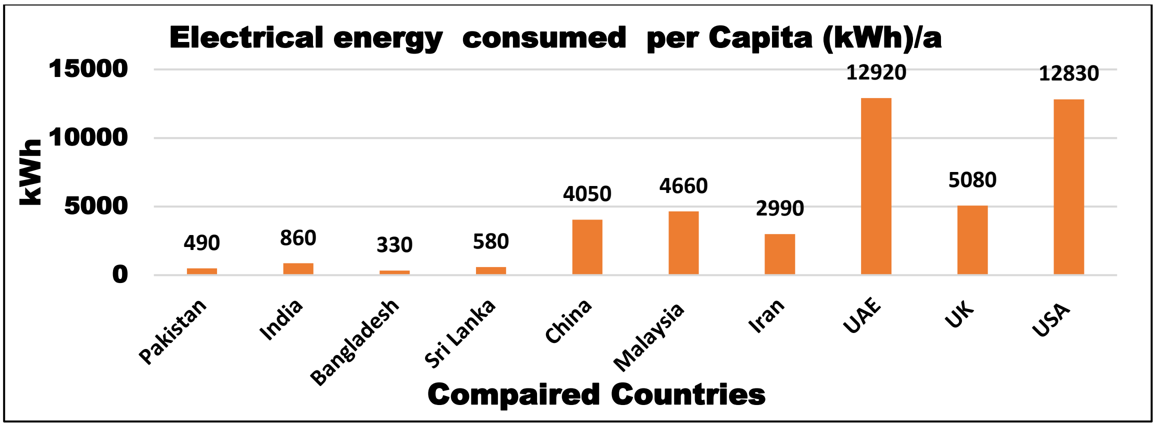


Figure 2.11 Pakistan's electrical energy consumed per capita, comparison with other countries source: [44] [56] [57] [58] [59]

2.3.5 Conclusion

Historically Pakistan's overall energy demand growth rate shows that the country is making a continued progress. As a result, energy consumption is increasing per year (2.3.1, Figure 2.7), further, as predicted statistics of energy demand and supply suggests that Pakistan would lack much behind (demand 361.3MToe or supply 155 Mtoe) in the fulfilment of its energy demand and this gap will continue to increase in future (2.3.2,Figure 2.8). We see a similar situation in electrical energy consumption (2.3.3). Past, present and future energy trends show that its demand would increase exponentially during 2020-2030(*Figure 2.9*). There would be a massive challenge for Pakistan to meet this demand, even currently, there is a shortfall of electricity in the country (Figure 2.10). We have noted that Pakistan's per capita electrical energy consumption is far less than advanced and neighbouring countries, which could be the future potential of demand increase for Pakistan Figure 2.11.

It is crucial to understand in such circumstances that how Pakistan is getting its energy? Are the sources sustainable? Are the sources secure? Answering these question would help us to understand the possible difficulties that Pakistan has to face in the future to achieve the low/zero impact and resilient energy supply system, which we will see in the next section (2.4). In such a situation, there is a need to invest in the energy supply system, and alternate options like renewable sources should also be exploited. This research will try to highlight the graveness of the situation and will suggest where Pakistan should be investing in the future for its energy supply.

2.4 Pakistan energy supply in detail

2.4.1 Historical and current energy sources

Electricity, biofuels & waste, gas, coal, and oil are significant sources of energy in the history of Pakistan. In the year 1973, electricity contributed 3.14% to the energy demand, with a growth in percentage share as an energy source it is currently (2016) contributing 9.9% towards the energy demand, which is 215% increase as a source of energy in the last 50 years. Bio-fuels & waste has been the prime source of energy, especially for cooking in the domestic sector, in the year 1973 was sharing 66% towards the total demand of energy, which is reduced to 40% in the year 2016 (Figure 2.12)(Table 2.3). This reduction in the use of biofuel would increase the use of other sources of energy in the future, which is mostly non-renewables.

Gas has been a prime source in the year 1973; the gas share was 10.68% which is grown to 21.17% in the year 2016. Oil was the second-largest source of energy in 1973 contributing 16.9% after bio-fuels & wastes; currently 2016, oil is contributing 22.48% towards the total energy demand of Pakistan (Figure 2.12) (Table 2.3).

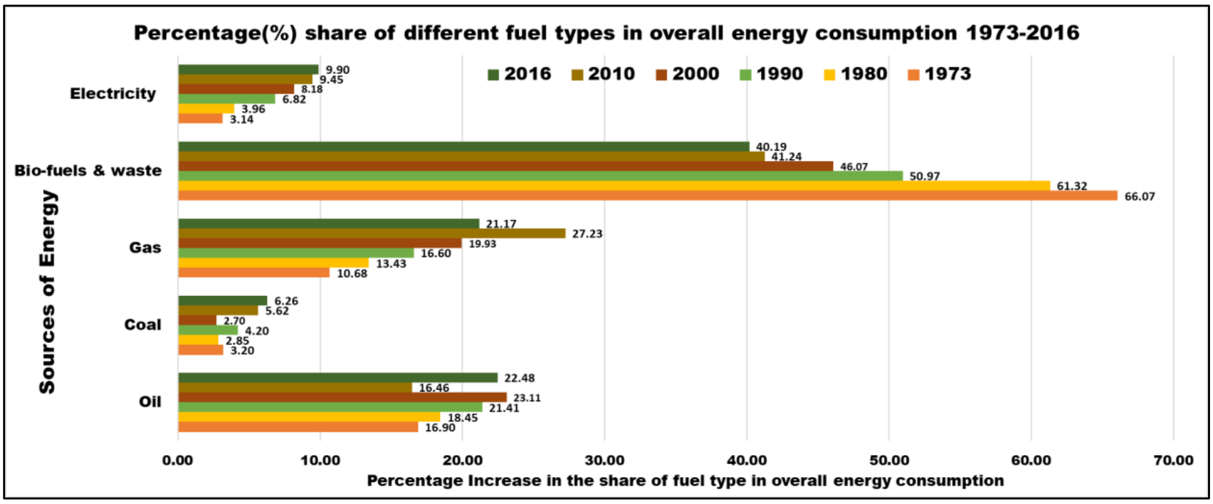


Figure 2.12 Historical comparison of percentage (%) share of each fuel type, (1793-2016), source: [53] IEA, Author's production

Table 2.3 Historic Consumption of fuels (Mtoe)

years	1973	1980	1990	2000	2010	2016
Oil	2.9	4.2	7.8	11.8	11.6	18.4
Coal	0.5	0.6	1.5	1.4	3.9	5.1
Gas	1.8	3.1	6.0	10.2	19.1	17.3
Biofuels & waste	11.2	13.8	18.5	23.5	28.9	32.8
Electricity	0.5	0.9	2.5	4.2	6.7	8.1
Total	16.9	22.5	36.2	51.1	70.3	81.6

In the year 2015, Pakistan started to exploit renewable resources of energy, mostly solar and wind; however, the combined production of electricity from these renewable resources was not more than 0.3 Mtoe in 2015. Pakistan is also utilizing the liquified natural gas (LNG) and liquified petroleum gas (LPG) as a source of energy on a small scale. Each of these sources contributed 0.7 Mtoe in the year 2015.

2.4.1.1 Electricity supply sources

Pakistan uses multiple resources for electrical energy generation. Every resource has a different percentage of its usage as per the availability of resource and generation systems involved; Figure 2.13 explains various sources of power generation.

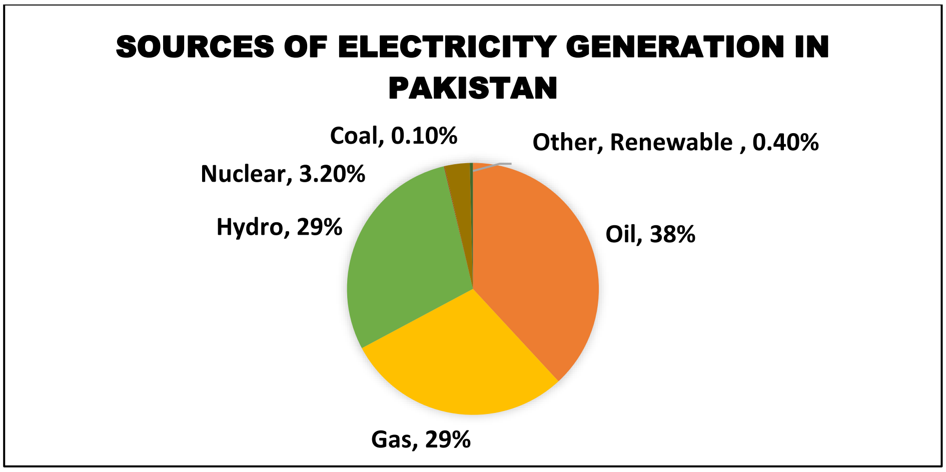


Figure 2.13 Sources of electricity generation in Pakistan (Author's production)

The primary source of power generation in Pakistan is thermal (oil & gas, 67%) and hydro 29%, though its percentage share has been very different throughout history (Sheikh 2010). In the year 2014-2015, the government started to look for alternate sources of electric energy and LNG (Liquefied natural gas) imported, and renewable resources were exploited on a small scale (0.40% only) in electricity generation Figure 2.13.

2.4.2 Pakistan future energy supply plans

Current and future energy mix trends show that the non-renewable thermal would remain as the primary source of energy production in Pakistan,(Yousuf, Ghumman et al. 2014) till the year 2025, and would be sharing 55% instead of 80% as of the year 2015. Likewise, coal consumption would increase from 5% to 10%, which is again a non-renewable source. There would be more focus on the renewable and nuclear power supply, and it would be sharing 18% in total instead of the 3% in 2015, Figure 2.14 below explains the case.

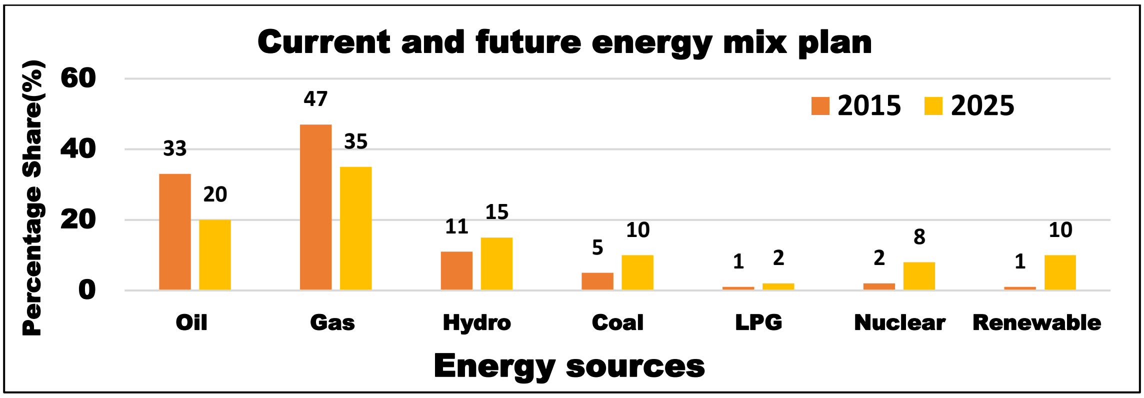


Figure 2.14 Pakistan current and proposed energy mix, source: [60] (Planning Commission of Pakistan) Author's production

The future power generation potential by renewable resources by the year 2030, 2040 and 2050 are 17.9, 18.6 & 19.3 GW respectively, by using solar, wind and small hydro resources (Sahir and Qureshi 2008) (Farooq and Kumar 2013). In another estimate, the National Electric Power Regulatory Authority (NEPRA) has plans to invest in renewable resources and total generation by the year 2030 would be 9.7 GW Figure 2.15. These future energy generation plans are promising but insufficient if low or zero-emission energy supply is to be achieved.

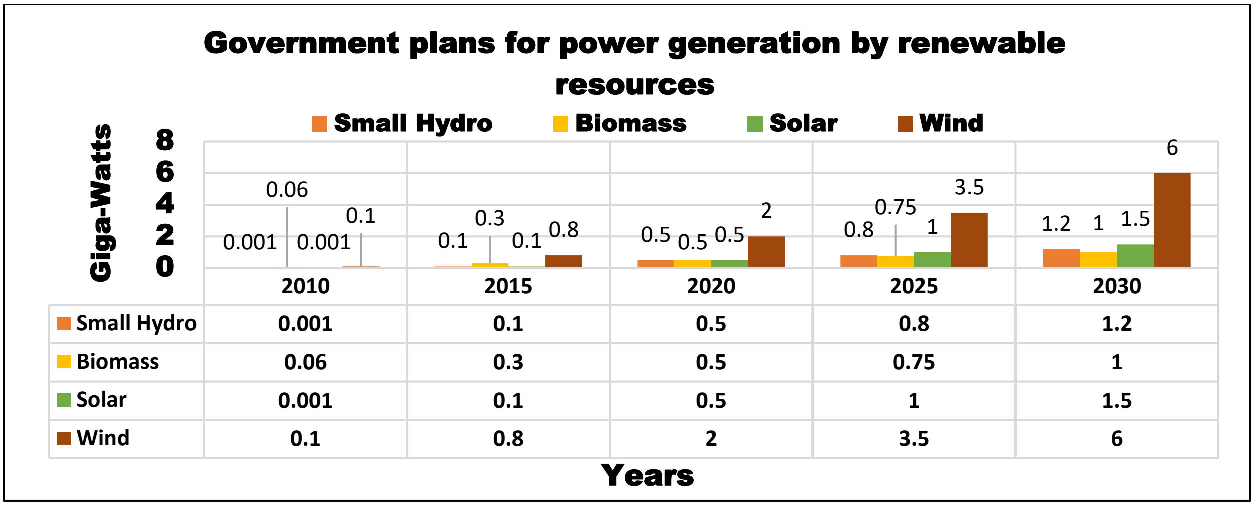


Figure 2.15 Government plan for power generation from renewable resources, source [61] [NEPRA]

2.4.2.1 Additional Electricity Generation Projects

The government of Pakistan has taken some initiatives to install new projects to overcome the power crisis. Mixed fuel is going to be used for power generation, mainly thermal and hydro would be the source to produce electricity. As per one ambition of the GOP (Government of Pakistan), there are a few solar projects as well with a total capacity of 1.0 GW out of 16.6 GW of new power generation by the end of 2018. A list of projects and their capacity is given in Table 2.4 below [19] [62] [63]. The majority are run on non-renewable resources which will not help to achieve a low carbon supply system.

Table 2.4 New power projects in Pakistan source: (Khalid and Kumar 2013) [63]

Sr. No.	Year	Name of the Projects	Capacity GW	Agency	Fuel
1	2014	Guddu-1	0.24	GENCOs	GAS
2		Nandipur Power Project	0.43	GENCOs	OIL
3		Guddu-2	0.24	GENCOs	GAS
4		Quaid-e-Azam Solar Park (Phase-I)	0.10	PPDB	SOLAR
5		Quaid-e-Azam Solar Park (Phase-II)	0.30	PPDB	SOLAR
6		Guddu Steam (3)	0.26	GENCOs	GAS
7	2015	Quaid-e-Azam Park slr. (Phase-III)	0.60	PPDB	SOLAR
8	2016	Neelum Jhelum Hydel	0.97	WAPDA	HYDRO
9		Golen Gol	0.11	WAPDA	HYDRO
10		Patrind HPP	0.15	PPDB	HYDRO
11	2017	Tarbela 4th Extension	1.41	WAPDA	HYDRO
12		Coal Plant at Sahiwal	1.20	PPDB	COAL
13	2018	Coal Plant at Jamshoro	1.32	GENCOs	COAL
14		Thar Coal Plant	1.32	GENCOs	COAL
15		Coal Plant Larkana	1.32	GENCOs	COAL
16		Gadani Power Park	6.60	Pvt.Ltd	OIL
		Up to 2018 addition in Generation	**16.6**		

2.4.3 Resilience and low carbon issues

2.4.3.1 Resource emissions

We have seen, in Figure 2.14, that collectively (by oil, gas, coal, and LPG) Pakistan's energy sources (excluding biofuel) currently are 86 % non-renewable, and only a slightly improved situation would be seen in the year 2025 as the supply system would still be 67% based on non-renewable sources. The detailed analysis of power generation in Pakistan shows that it is highly unsustainable. It is currently generating 64% (13.64 GW) of its electricity from non-renewable resources, i.e. oil & gas, and produces only 36 %(7.68GW) by renewable resources like hydro and solar. Future generation would use 78% thermal and only 22% by renewable adding of a total of 9.6 GW by the year 2030 Figure 2.15. These statistics show that mainly resources of the energy supply of Pakistan are non-renewable, and hence, unsustainable.

2.4.3.2 Pakistan's resilience and low carbon challenges

We have shown that around 36% of the annual electrical energy supplied is produced by hydro, for this Pakistan relies on its monsoon rains and river waters, it brings several risks. Firstly, Pakistan has observed uncertain climatic conditions, where there is less rainfall or early/late rain spells. Which is causing unpredicted power supply and shortage possibilities, secondly, unfortunately, Pakistan does not have good relationships with India. Pakistan's leading source of renewable power is hydro, and it depends on its five rivers for power production and agriculture. According to the 'Indus Waters Treaty 1960',[1] Pakistan is supposed to have rights on three rivers, which are originating from India. This treaty is often violated by India stopping water coming from their side following the construction of several dams on these rivers. The impact is such that only traces of the Bias river flow is now left in Pakistan.

Pakistan's reliance on hydro as a leading source of energy is therefore risky both politically and geographically. One consequence of this can be seen in the increasing use of pumped groundwater wells as a source of irrigation because of the changing trends of rainfall and the unavailability of water from rivers. In 2013 there were about 1.1M such wells in Punjab alone, of which 0.9M were operated by diesel and 0.2M by electricity [31].

Oil & coal provide approximately 28.74% of energy in Pakistan (as of 2016, Figure 2.12) and 66% of these energy resources are imported from abroad, which is a considerable percentage. Pakistan's economy is greatly affected by this dilemma. Uncertainty is often observed in the power sector of Pakistan, where approximately 47% of its output is produced by oil. Due to lack of funds and administrative abilities of the government, there developed a situation of circular debt [64]. The crisis started due to the wrong mix of fuel roughly two decades ago when the power sector largely shifted to thermal production from hydro. Most of the oil in the country is imported from foreign countries,

[1] Indus Waters Treaty, signed on September 19, 1960, between India and Pakistan and arranged by the World Bank. The treaty fixed and delimited the rights and obligations of both countries concerning the use of the waters of the Indus River system.

and its price is not in the hands of local government. As a result, power generation costs increased, coupled with high transmission and distribution losses, so overall supply tariffs became very high. It became tough for consumers to timely pay the electricity bills [64] [65]. So high circular debt was accumulated [66] [67], which in turn caused delayed payments to the oil companies and other gas suppliers [19].

Circular debt affected the operation of power plants and their optimal generation capacity [68]. when this scenario was developed and as most of the power generation was based on thermal (around 80%), it ended up in the electrical energy crisis in Pakistan. (Rauf, Wang et al. 2015), Figure 2.16 illustrates this situation [61] (Asif 2009) [69] [70]. This situation resulted in fear of future investors investing in Pakistan's power sector [71].

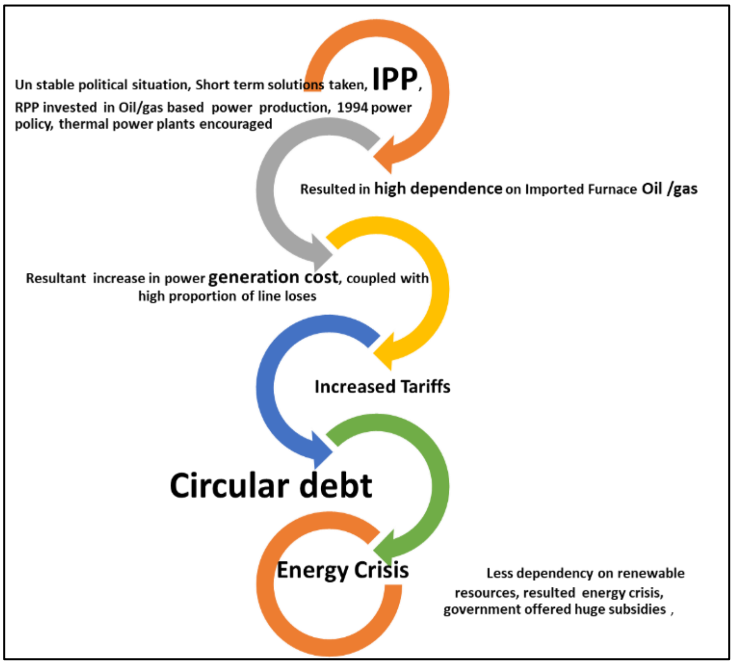


Figure 2.16 Conceptual understanding of power Crisis in Pakistan, source: Author's production

2.4.4 Conclusion

The current energy supply resources of Pakistan are mostly non-renewable (Figure 2.12 & Figure 2.13), and their demand has clear growth trends (2.4.1). When we look at the percentage growth in the sources of energy in the overall energy consumption of Pakistan, we found that bio-fuels & waste is the only source of energy whose percentage share is decreased in the last 50 years. This reduction in percentage share of biofuel has been taken up by other sources of energy in Pakistan which are largely non-renewable and have a high environmental impact. All other sources of energy have an increasing trend of their percentage share in the overall energy consumption. Not only the past and present sources of energy are non-renewable but also plans of energy supply show (2.4.2, Figure 2.15) that still there would be a significant dependency on non- renewable resources, and the problem will sustain.

Moreover, some of the potential risks and threats discussed (2.4.3.2) indicate that it would be much difficult for Pakistan to meet its future energy needs by utilizing oil, gas, coal, and LPG as significant sources. Based on the statistics of 2016 and future supply sources, approximately 87% & 67% (Figure 2.14)of energy sources of Pakistan are and would be non-renewable and high producers of carbon. It would be implausible to fulfil the aim and objectives of this thesis. Therefore, these high environmental impact sources, of energy should be replaced by renewables to meet the future increasing energy demand of Pakistan, achieving low impact and resilience.

In the next section, we will look at where the energy is being consumed in Pakistan? What are the demand drivers? To understand the key consumers of energy and individual resources of energy and to look for possible mitigation strategies that can be adopted.

2.5 Pakistan energy consumption details

We have seen in the previous section (2.4) that electricity, oil, gas, biofuels & wastes, and coal are the major sources of energy in Pakistan and most of these sources of energy supply are non-renewable and would be depleted soon. In this section we will see where is this energy being consumed and where it would be required in a more substantial amount in future to meet the growing demands of different sectors, to understand which energy consumption sector would have its more extensive influence on the non-renewable energy demand.

The energy in Pakistan is mostly consumed by commercial, industry, agriculture, transport, other government and domestic sectors (Sheikh 2010) [72]. Each sector has a different allocation of energy consumption in the overall energy available in Pakistan(Sahir and Qureshi 2008) [9] Figure 2.17 illustrates different percentages of energy being consumed by various sectors. When electricity, oil, gas, bio-fuels & wastes, and coal are taken as significant sources of energy in Pakistan, we see that in 1973, the domestic sector was the only major sector which had consumed **62%** of the available energy of Pakistan. The industry was the second-largest consumer of energy, consumed 24% of the total energy at that time. Other sectors like commercial, agriculture and transport consumed 5%, 3% and 6% of the available energy of Pakistan in 1973.

Domestic and industry sectors not only remained the primary consumers of energy in the ’80s & ’90s and consumed 55% and 24% of total energy by the end of 2000 respectively, but also remained the main consumers in the new century. since last 16 years (as of 2016) these two sectors are the dominant sectors in the consumption of energy although their percentage share is changed, domestic sector’s share is reduced a bit to **48%,** and industry sector share has increased to 28% (in the year 2016), but still, the domestic sector is the largest consumer of available energy in Pakistan Figure 2.17

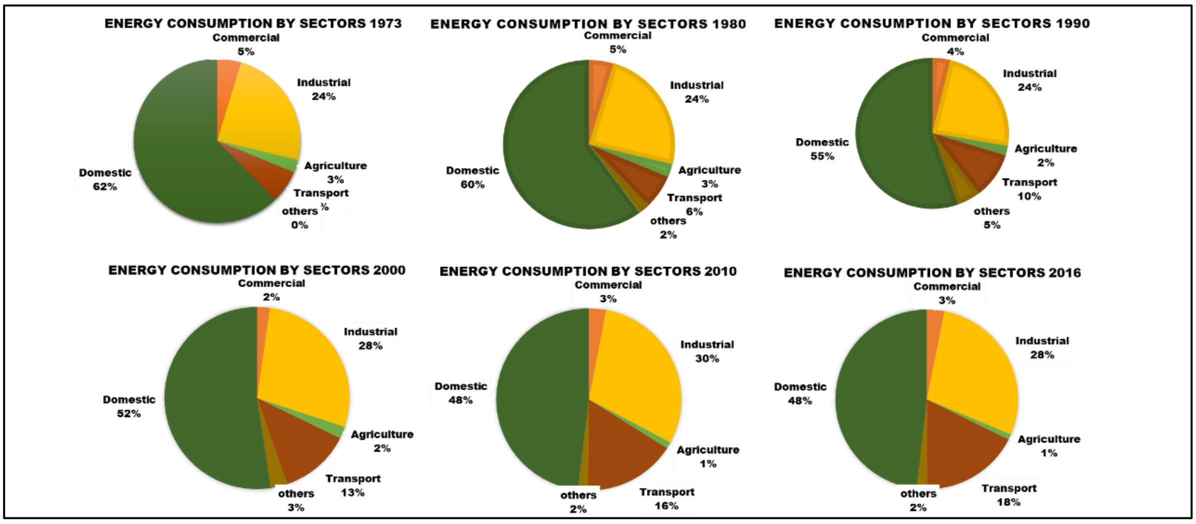


Figure 2.17 Energy consumption (including biofuels & wastes) by sectors source: [73] (Author's production)

The other sector which has shown growth in energy consumption is the transport, where its energy share has grown from 6 %(1973) to 18% in the year 2016 [74]. Commercial and agricultural sectors have remained on the lower side of energy share in the history of Pakistan Figure 2.17.

We see that the oil, gas, electricity and coal are primary sources of energy (excluding bio-fuels & wastes) of Pakistan. We found that in 2008, three sectors like industry, transport and domestic consumed most of the energy, 42.6%, 29.30% & 20.4% respectively [72](Figure 2.18). This trend of energy use shares changed with time (in 2008, the domestic sector was using 20.4%) [75] [9] and there is a gradual increase in domestic energy consumption, and it reached 24.50% by the year 2015 Figure 2.18. There is a decrease in energy consumption by the industrial sector and reaches to 34.6% in 2015 from 42.6% in the year 2008. Transport sectoral consumption remained the same with a slight increase from 29.30% to 32.40% in the year 2015 [74]. Energy consumption by other sectors can be seen from Figure 2.18 below, commercial, other government, and agriculture sectors consumed 4%, 2.2% & 1.7% respectively, as of 2015.

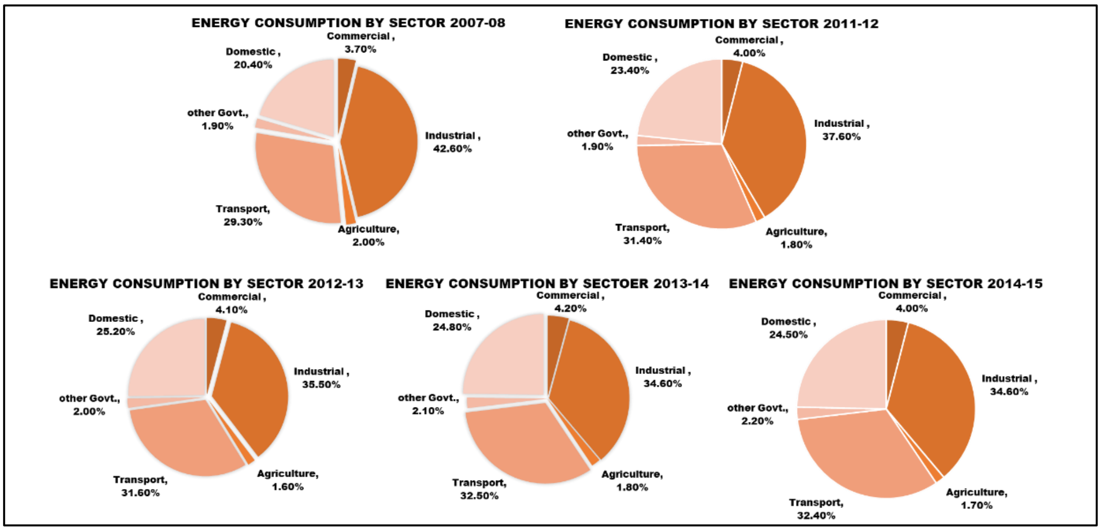


Figure 2.18 Energy consumption (excluding biofuels & wastes) by sectors, source: [76] (Author's production)

2.5.1 Conclusion of energy consumption

It is evident (Figure 2.17) that biofuels and wastes are those sources (renewable sources) of energy in Pakistan which are fulfilling most of the domestic energy demand. With their consumption included, the domestic sector is using 48% of the total energy consumed in Pakistan. Further, the dependency on non-renewable energy fuels statistics and changing trends of energy usage, stated during the last epoch (2007-2015) indicates that the Domestic sector is becoming one of the primary consumers of energy in Pakistan (after the industrial sector) (Figure 2.18). Consequently, its carbon emission would increase too, and this gives an insight into the opportunity to reduce CO_2 if this sector is analysed with respects to its energy usage patterns. Where the domestic sector energy is going, how much it will need in future. We need to look for some mitigation strategies to meet the demand effectively in line with the aim of this thesis, i.e. to look for the role the domestic sector can play in the move towards a low impact and resilient energy future of Pakistan.

In the next section, we will see how much percentage (%) each of these sectors is individually consuming the primary sources of energy of Pakistan, i.e. of electricity, gas, oil, biofuel & waste, and coal. To understand the influence of each sector which are dependent on these sources and to find out how they are causing the impact on the environment and how much resilience initiative can be actualised by taking reductive measures of non-renewable source consumption. At this stage, we have identified that the **domestic sector** is the largest sector consuming most of the energy of Pakistan. Each non-renewable source of energy consumption by different sectors of Pakistan are discussed in the next section.

2.6 Pakistan energy consumption in different sectors by fuel type

2.6.1 Sectoral consumption of electricity

Now we will see how much of manageable electricity is consumed by different sectors in Pakistan to have an idea of sectoral share in the overall current power crisis in the country. Widely electricity in Pakistan is being consumed by agriculture, industry and domestic sectors. These three sectors are consistent as significant consumers of electricity since 1973 [77] Figure 2.19 below illustrates the electricity consumption since 1973 to date, and clearly shows that industrial sector was the largest consumer of electricity in the history of Pakistan consuming 59% in the year 1973. Its consumption share continued to reduce in the last 50 years, and as of 2016, it consumed 28% of the electrical energy. In contrary, the domestic sector had consumed only 9% of electricity in 1973. Its consumption share has been increasing, in 2016 it consumed 48% of the electricity in the country. It became the largest consumer of electricity; during the last 35 years, its percentage share is increased from 23% to 48% between 1980-2016.

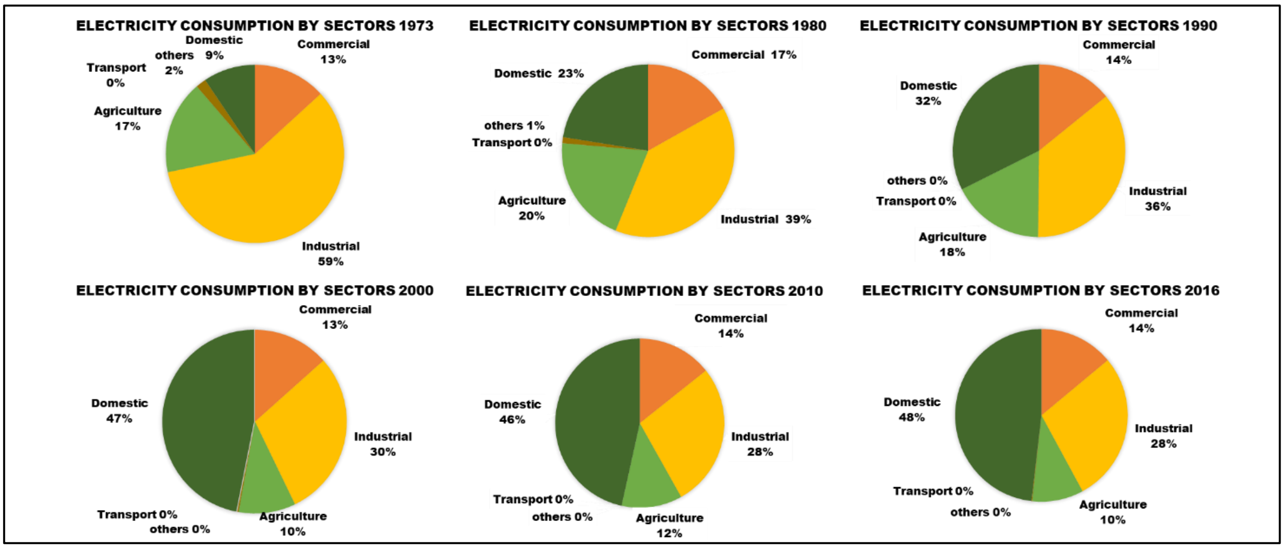


Figure 2.19 Electricity consumption by different sector in Pakistan, source: [78], [76], [45], (Author's production)

Agricultural and commercial sectors remained at the lower side of electrical consumption in the history of Pakistan, they were consuming 17% & 13% in 1973 and recently, in 2016, they consumed 10% & 14%, which is not much of difference than in the past. Notably, the transport sector was never being and nor is the consumer of electricity in Pakistan .

2.6.2 Sectoral consumption of gas

Historically, we found a similar trend of sectoral gas consumption; in the past (1973) 76% of gas was being consumed by the industry. Its consumption share reduced to 36% in 2016 (almost halved) whereas, the domestic sectoral share was only 4% (1973), and its share has increased to 33% in the year 2016, so currently, industry and domestic sectors are the primary consumers of gas energy in Pakistan collectively consuming 69% Figure 2.20. Gas was never used for the transport sector until nearly 2000. when by late '90s Compressed natural gas (CNG) stations were installed, and gas started to be used as car fuel, and by 2010 its percentage share raised to 13% which government has to reduce to 8% in 2016 because of its requirement in other sectors Figure 2.20. Gas is never adopted as fuel for the agriculture sector, and its usage in the commercial area remained low between 3-4% in the last 50 years (1973-2016) Figure 2.20

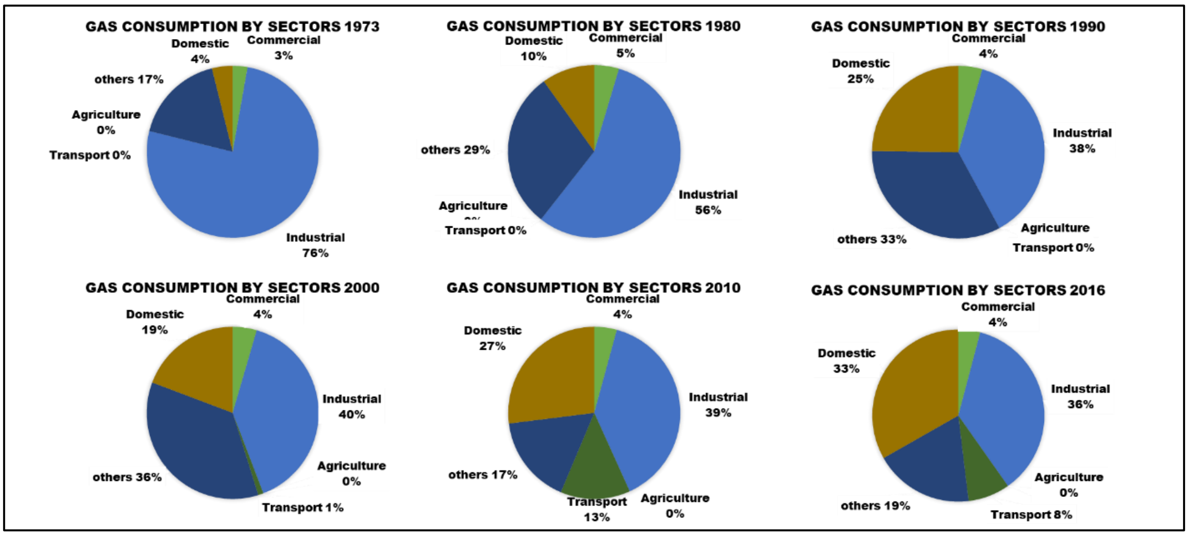


Figure 2.20 Gas consumption by different sectors in Pakistan, source: [78], [76], [45], (Author's production)

2.6.3 Sectoral consumption of oil

The transport sector is the largest consumer of oil in Pakistan, in past (1973) it had consumed 38% of oil along with commercial (23%) and domestic sector (14%) as other major sectors of oil consumption. As time passed till 1990, the percentage shares of oil in transport and domestic sectors had been increased to 58% and 17% respectively. After this epoch, the consumption share of oil to the transport sector has been growing till 2016 it was consuming 78% of fuel available to Pakistan, while domestic and commercial sectors shares have been reduced since then. In the year 2016, they only consumed 3% & 4% respectively Figure 2.21.

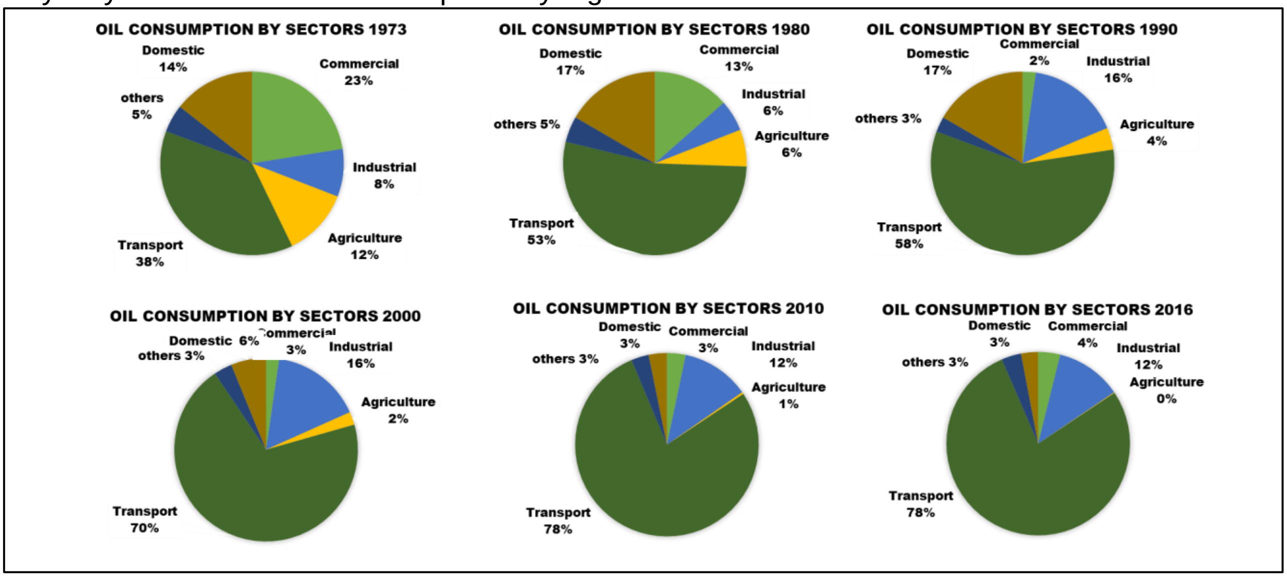


Figure 2.21 Oil consumption by different sectors in Pakistan, source: [79], [76] [45] (Author's production)

Agricultural sector consumed 12% of oil in the year 1973, but in the latter years its share was reduced, and by the year 2016 its share is completely taken off. The industrial sector has been consuming a fair percentage of oil 12% in the year 1973 and touched the peak of consumption share of 16% in the year 2000; however, it consumed 12% in 2016 Figure 2.21

2.6.4 Sectoral consumption of biofuel & wastes

The domestic sector has used a substantial amount of biofuel & wastes sources available in Pakistan. It had consumed 89% of this energy in 1973, and the same percentage was consumption in 2016. In the past (1973) and present (2016) Industry is the only other sector which is using biofuels as a source of energy-consuming 11% of it in Figure 2.22.

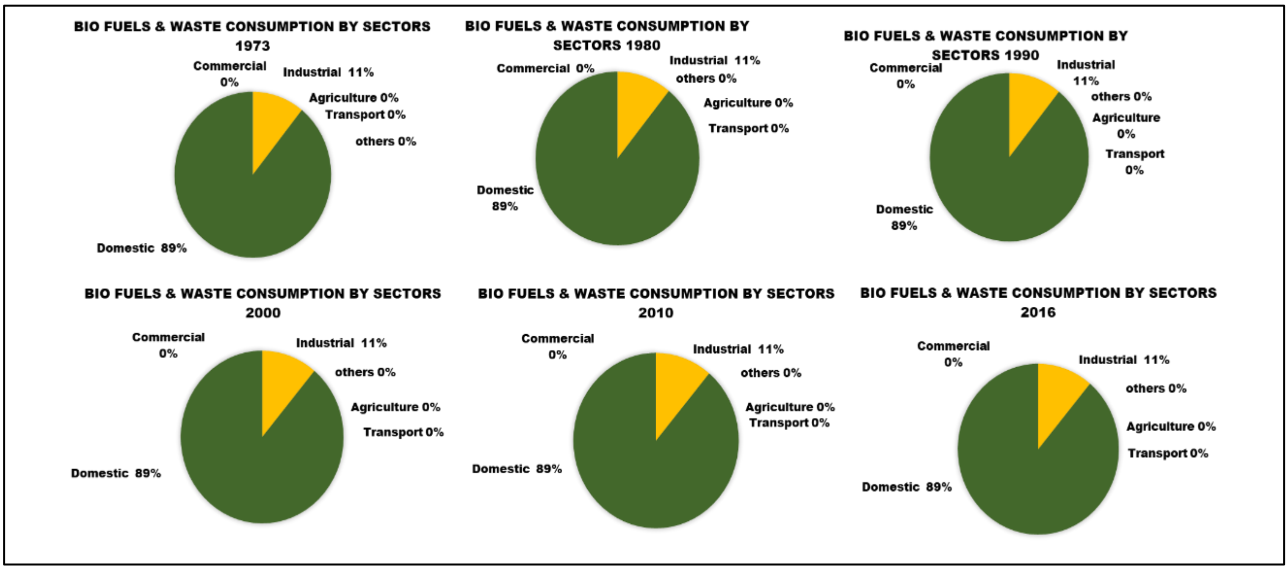


Figure 2.22 Bio-fuels and wastes consumption by different sectors in Pakistan, source: [45], (Author's production)

2.6.5 Sectoral consumption of coal

Coal is completely being consumed in the industrial sector of Pakistan. Initially, it was also being used by the domestic and commercial sectors; however, the combined percentage was not more than 4% in the years 1973 & 1980. From the '90s coal is only being used by the industry Figure 2.23.

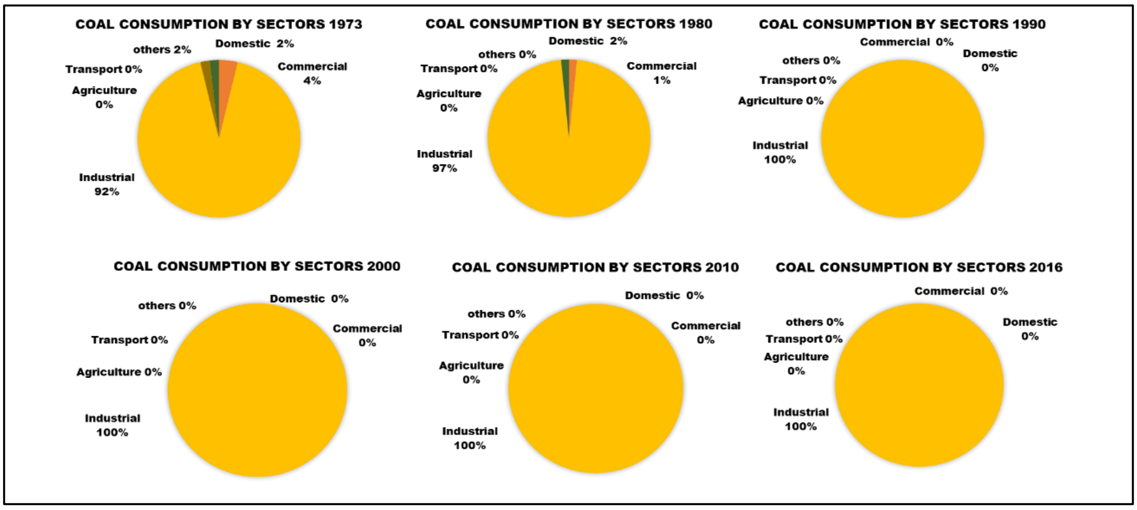


Figure 2.23 Coal consumption by different sectors in Pakistan, source: [53], [45], (Author's production)

2.6.6 Conclusions

we found that the domestic sector is one of the more significant consumers of renewable (Figure 2.17) and non-renewable sources of energy in Pakistan (Figure 2.18). It consumed 48% of the total energy of Pakistan in the year 2016 when bio-fuel was included as a source of energy and 24.5% of total energy (without biofuel).

The historical statistics (2.6.1) indicate that electricity is mainly consumed by the domestic sector (48%), and its consumption share is increased in the last 50 years. Any significant reduction by this sector will significantly help to reduce the power crisis currently prevailing in Pakistan directly and in the reduction of CO_2 emission. Further, as discussed previously, 66% of electricity in Pakistan is produced by non-renewable sources (as of 2015 statistics) from oil, gas, and coal (2.4.1.1), so the domestic sector can be conducive to achieve the thesis aims.

The domestic sector is consuming a substantial amount of gas (33%) as well, and gas is being used as a domestic fuel for cooking throughout the year and for water and general heating, during winter mainly in the urban areas. Gas is a non-renewable source of energy and will be depleted soon if its use left unchecked (2.6.2). Animal wastes (dung cake), wood and crop wastes are the sources of bio-fuels in Pakistan and the domestic sector; it is mostly being used for cooking. As discussed later, this fuel is mainly used in rural areas. There is the considerable tendency of urbanization in Pakistan, where most of the houses use gas for cooking, this shift from bio-fuel to gas or electricity for cooking would cause a huge demand of these non-renewable resources. (Detail discussion is presented in the domestic energy demand increase section).

We have seen (Figure 2.21) that the transport sector is the major consumer of oil in Pakistan. Petroleum is non-renewable and has higher carbon emission content, any mitigation strategy to take a load of the transport sector from oil and shifting it to some renewable source would help to achieve the aim of this thesis.

In summary, the domestic sector consumes significant quantities of Pakistan’s energy use - electricity (48%,Figure 2.19), gas (33%, Figure 2.20) and biofuels (89%, Figure 2.17) - which places the domestic sector as the most significant consumer of energy. At this stage, as identified, this thesis now limits its scope to the domestic sector only. In the next section, we will discuss the energy demand of the domestic sector and its growth under different scenarios, especially, of electricity and gas as these are the significant sources of non-renewable energy being used by the household industry. The purpose is to understand the drivers of energy demand, especially nonrenewable, its future demand increases and potential of the domestic sector to produce its energy to minimize its impact on the environment and attaining resilience.

Before looking into details of energy demand in the domestic sector, firstly, we will investigate the literature to define what is meant by low carbon and resilient energy supply system, and how such a system might look like for Punjab.

2.7 Resilient energy supply systems

2.7.1 Introduction

As we set in the ambitions of this study where we are looking for a cleaner energy supply system for Pakistan to meet its demand in different sectors, this would only be acceptable when the supplies are resilient. The critical thing for the government to cater to keep the business working would be the availability of energy in the first place, and then to make as much as possible to achieve resilience through greener energy supply to meet low carbon supply ambitions. The next part of the literature review would try to understand what the resilient energy supply system is and how far Pakistan is currently standing to achieve it. In pursuit of our aims and ambitions set at the start of this thesis, we need to understand the following

- What is and how does a resilient energy supply system look like?
- How is resilience achieved in different countries?
- Where does Pakistan stand in the transition towards low carbon and resilient energy supply?
- What does the literature suggest about Pakistan having a resilient energy supply system?

2.7.2 Defining a resilient energy supply system

"*Resilience is the capacity of an energy system to tolerate disturbance and to continue to deliver affordable energy services to consumers. A resilient energy system can speedily recover from shocks and can provide alternative means of satisfying energy service needs in the event of changed external circumstances"* [80] [1].

In a nut-shell, Resilience expands how systems can respond to disruptive challenges. It is a measure of adaptive capacity and ability to learn how to cope and adjust. In an energy system context, resilience should be envisioned as a process of **co-evolution** where actors and technologies interact within a system to minimise vulnerabilities and maximise opportunities [81]. In a resilient energy system, new technologies must be adopted, and the users of the energy system must learn and adjust to cope (when and how) with the new challenges. To better understand the resilience, we need to know what vulnerability is?

The vulnerability of the energy system is the degree to which that system is unable to cope with when there are disruptions [82]. The vulnerability has been taken as a cause of system complexity, technical failure, accidents, and resource availability and constraints, diversity of resources and political disruptions. Vulnerability and resilience are opposites [83]. The system's vulnerability reflects the existence of a physical or operational weakness which allows a threat to cause damage or loss of functionality.

2.7.2.1 Conceptualizing resilient energy systems

A resilient system is a dynamic interacting process [84] in nature. It relies on the adaptive capacity, innovation capacity(to unknown stressors), improvisation capacity(to unknown, sudden stressors [83]) and transformability (Walker defines transformability as 'the capability to produce a new system when ecological, economic or socio-technical structures makes existing system absurd') to reduce its vulnerabilities [85]. In disruption, it will use its adaptive capacity to adjust to the new conditions and be able to perform and up-grade. At the conservation point, the energy system manages to use and sustain the resource base. New technology and management at disruption, recognize the new resource and start to shift to utilize at release stage, latter by re-organization of energy system required for the new resource, the resilient system will begin the exploitation of this new resource. Resilient system by its adaptive capacity will overcome the barriers to change and will avoid the situation of being pathologically resistant to change [86]. This enables the system to evade overexploitation of resources by adopting new trajectories. For example, in the UK the successful response to disruption was the transition from biomass to coal with new technologies that emerged for transport (from horsepower to steam power), and the shift to petroleum, the internal combustion engine and advancement of personal transport [81]. Figure 2.24 below explains this metaphor.

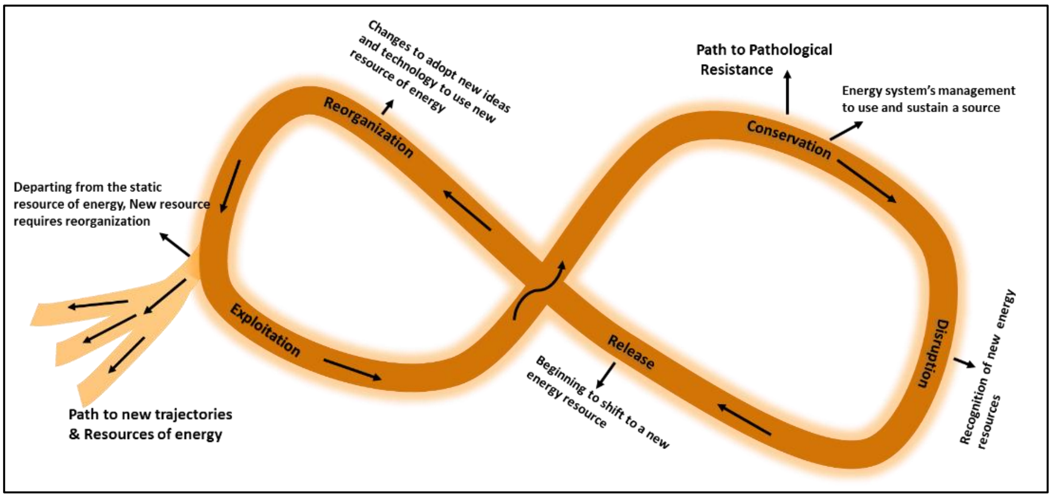


Figure 2.24 Conceptualizing resilience, source: Adapted from Holling, 2004 & [81]

The fossil fuel resilience is hindered by two significant disruptions of the scarcity of resources and climate change concerns. There is no deficiency of energy availability if the renewable resources are exploited and made a part of energy systems. Ideally, resilience is not concentrated on what is missing but on what is present (resources and adaptive capacity). Resilience building is not a static process instead it is dynamic, and there is no end to it, as rightly explained by O'Brien

'A resilient energy system exhibits the adaptive capacity to cope with and respond to disruptions by minimising vulnerabilities and exploiting beneficial opportunities through socio-technical co-evolution.'

To be able to attain resilience in energy systems, we need to understand and address the issues of the phenomenon of energy security.

2.7.2.2 Defining energy security

Defined as 'low vulnerability to vital energy systems', vital energy systems are energy resources, technologies, infrastructures and uses, linked together by energy flows [87]. The energy supply system must secure two dimensions, namely physical digestion, referred to availability, reliability, and accessibility, and economic aspect as price stability and affordability [88]. It is suggested that to evaluate the energy security methods chosen should be (i) dynamic and change over time, (ii) comparing energy carriers and supply chains in average framework times (iii) and incorporating approaches of adaptive capacity and transformability [85].

2.7.3 How the UK and EU seek energy resilience

2.7.3.1 UK energy resilience

The UKERC energy 2050 report has concerns about developing a resilient, low carbon energy system for the UK. The UK back up energy system for 2050 is based on the 2 x 2 matrix, one dimension is to reduce the CO_2 emission, and the other is 'Resilience', of the energy system to external shocks. A **low carbon resilient approach** is considered appropriate to counter the issue of CO_2 emission. It will help to meet the reduction targets of 80% by 2050 as of its value in 1990 and achieving resilience. Resilience for UK energy system is defined as ***"The set of technologies, physical infrastructure, institutions, policies and practices located in and associated with the UK which enable energy services to be delivered to UK consumers".***

The UK has identified energy security as; Physical (avoiding energy cuts), price (avoiding price spikes) and geopolitical (avoiding reliance on specific nations, ensuring freedom in foreign policy) security. The UK is aimed to achieve this, in a resilient system, by **reducing the level of imports** and demand, **diversity of supply** (no single energy source share more than 40%, even for electricity generation) and **robust infrastructures** enabling system to be reliable not only for minor disturbances but also for more significant shocks. In the UK's energy system, especially for electricity, a low carbon scenario is considered. In contrast, low carbon resilient scenario would take a longer time to achieve the electric de-carbonization. The policies for resilience in the energy system of the UK include the increasing **energy efficiencies** of buildings and transport, and adequate capacity margin of power companies to meet demand and incorporating the market supply (through price signals). Further, there is a report (on electricity reforms 2011) suggests that the government should make 'strategic' investment in the gas infrastructures, which can be used in the adverse circumstances, ensuring to meet low carbon scenario, in a supply-led energy strategy [89]. In the domestic sector, UK is achieving its low carbon targets by energy efficiencies, electrification of heating system and using renewable heat (RHI incentives, by adopting solar thermal, biomass and heat pumps, for space heating) and in the transport sector by shifting to electric vehicles [90]. It has also launched an electricity market reforms program focusing on the decarbonisation of electricity by adopting renewable technologies like the wind as well as carbon capture, utilization, and storage (CCUS)technique.

2.7.3.2 The European Union (EU) approach

The EU (Conference of European Churches, CEC, 2008) [91] takes a broader approach to energy resilience. The Commission has proposed a five-point action Plan which tacitly responds to concerns about price and geopolitical security, which are: (a) Infrastructure needs and the diversification of energy supplies, (b) external energy relations, (c) Oil and gas stocks and crisis response mechanisms, (d) energy efficiency, (e) making the best use of the EU's indigenous energy resources.

2.7.3.3 EU energy resilience strategies

The external supply chain of energy resources, if mostly dependent on, can be interrupted due to the instability of supplier governments, sea piracy, terrorism, wars, strikes sabotage, vandalism, theft, and riots [92]. Disruption management approaches of EU include risk management and resilience, (supply chain must be able to react to disruption and manage it), management strategies (i.e., diversification of supply) and information sharing (timely identification of disruption). Further, EU has developed rules among member states, to develop new infrastructures, construction of pipelines, maintaining oil and gas stocks (90 days of average daily supply or 61 days of average daily consumption), and show solidarity. It also ensures protection of infrastructures, foreign politics (act as one unit in international affairs, resolving conflicts, developing understandings), reduction of dependency (new resources of energy, making more relation with new countries), and crisis management [93].

Pakistan can also take similar steps to help achieve the resilience in the supply system, which is currently highly vulnerable, as most of the energy is imported in the form of oil, CNG and LNG.

2.7.4 Pakistan situation about low carbon and resilient energy supply

We have seen that Pakistan's current and future energy supply system is mostly dependent on non-renewable resources. Almost 86% (Figure 2.14) of its energy is coming from oil, gas, and coal, and future energy would be using 62% non-renewable resources. We have also noted that there are high risks and challenges involved to meet the energy need of Pakistan, due to political instability and economic incapability to provide for the increasing demand for energy (2.4.3.2). Therefore, it is inevitable that Pakistan should take productive measures as adopted by the UK, EU, and other developed nations of the world. It may include energy efficiency, reduction on external dependency, energy storage, and diversity of supply and mainly, more exploitation of renewable resources to achieve a low carbon resilient energy supply system aims set for future. Whilst the ambition is to move towards a zero-carbon grid, the reality is that none of these will happen without the grid being resilient and providing what is needed. From the approaches adopted by other countries to achieve low carbon resilience, we need to look at which of the sustainable strategies applicable elsewhere would be appropriate in Pakistan? And Pakistan's current situation regarding the energy resilience. The relevant literature suggests that capturing intermittent and diffuse energy resources is a way forward ensuring resilience for Pakistan. Figure 2.25, explains that the resilient energy system of Pakistan should capture intermittent renewable energy (like solar, wind, tide, hydro) at the local level. If required, the energy can also be supplied from the conventional central large-scale generation and distribution system by a monitored process. In a resilient energy supply system, there is a need to move from a gigantic central generation and distribution system to a **mixed** central and localised generation system. It would have a more adaptive capacity, ensuring maximum new resource capture (Figure 2.25) and less reliance on the central supply system.

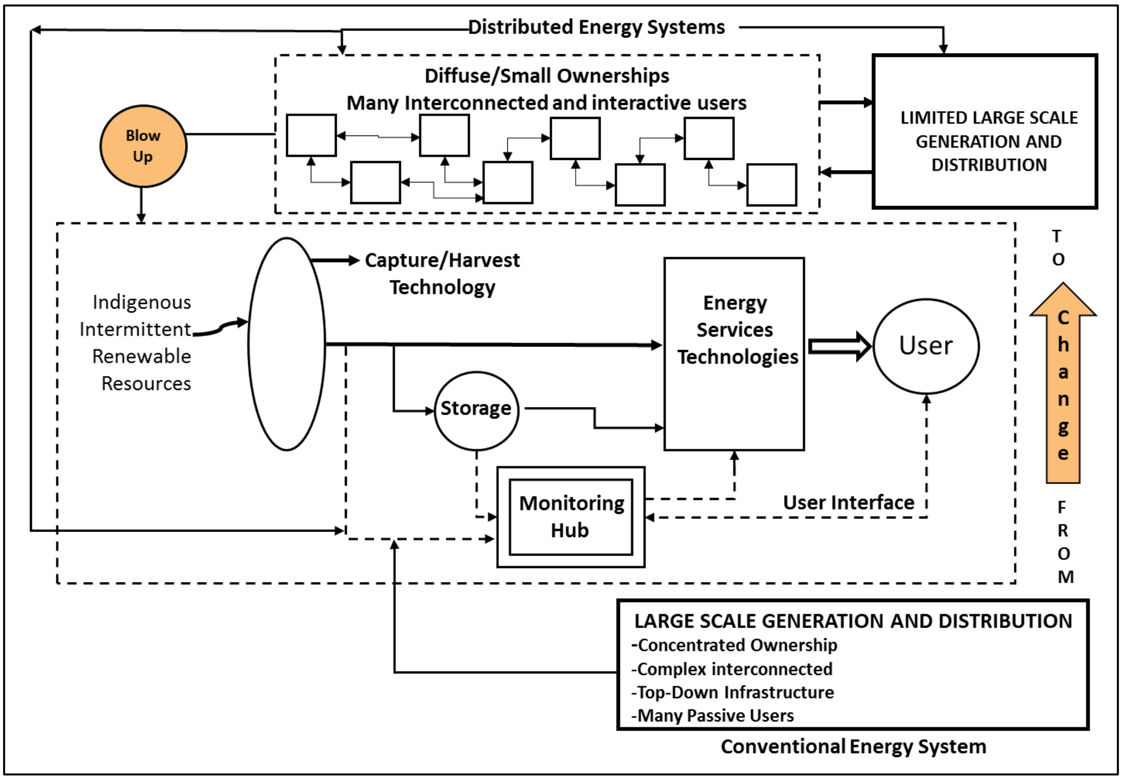


Figure 2.25 Conceptual transition of conventional to low carbon, Pakistan's resilient energy supply systems based on literature, source: [81], by author

Pakistan needs to adopt three energy security perspectives discussed in the research; these are 'sovereignty (political domain), robustness (science and engineering domain) and Resilience (Economics, complex system analysis domain)'. Sovereignty perspective focused on external threats like hostile states, terrorism, unreliable exporters, or sabotages malign agents, and political bans. Preventive measures for this include shifting to trusted suppliers, adding multiple agents (diversification, substituting imported resources with domestic). Robustness perspective sees threats as demand increase, scarcity of resources, ageing of infrastructures, technical failure, and it can be addressed by upgrading infrastructures, adopting new resources and technologies. Resilience perspective looks for unpredictable and uncontrollable factors due to the complexity of energy systems and technologies. The threats to this approach are economic crises, political instability, and climatic constraints (which are very dominant threats in Pakistan). It responds to these threats by considering flexibility, adaptability, and diversity of energy system which are ready to protect against any risks and surprises [94]. It is agreed in research that an integrated approach considering all these three perspectives is required for the future concerns of energy security and resilience. One such integrated approach is reported mainly as 4A's (World Energy Council (2007) 3-A's, Asia Pacific energy research centre (APERC-2007) 4-A's) in literature as: 'availability (physically), accessibility (a geopolitical aspect of resources), affordability (economic cost of energy) and acceptability (social and environmental), this approach has widely attracted the policymakers and users [95] and would require for the case of Pakistan.

One of the interpretations of available literature, an attempt has made to develop a comprehensive resilient energy supply system 'Orbital-model' for Pakistan as reflected in literature. Geopolitical events, natural disasters, severe weather, public acceptance of energy activities, increasingly automated and integrated energy systems, and the impact of climate change are just some of the factors impacting on energy systems [96]. The complex adaptive systems (CAS) approach or policy-oriented approach in research has explained a much broader perspective of energy resilience. It is based on the 'system of systems'(SOS). It takes in to account many subsystems of socio-technical, governance, infrastructure and energy resources. The financial market, communication systems, international market, international agencies, environmental system are also included, and all the risks and threats were coming along them in an interconnected manner. This process of **co-evolution** of all agents and these systems is emphasized in the overall resilient energy security system [96] [83]. '**Resilient energy system (orbital Model')** is developed to ensure the failsafe resilience in the energy system, which takes in to account the goals, aspirations, stresses/ shocks and all sub-systems occurring and interacting in an energy supply chain Figure 2.26.

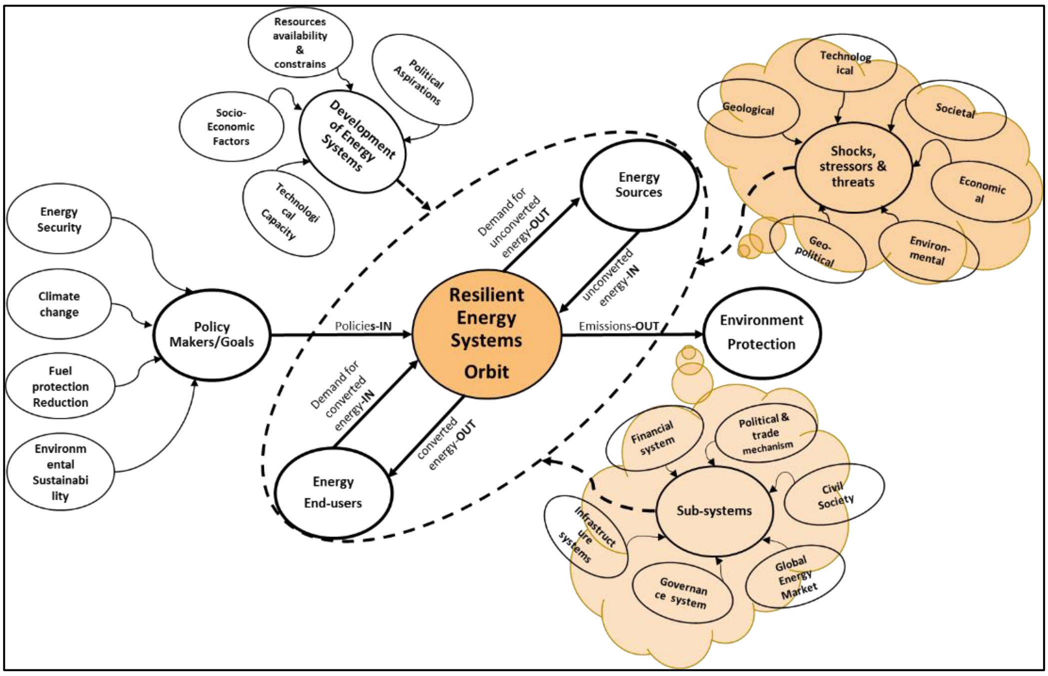


Figure 2.26 Resilient energy systems 'Orbit' developed for Pakistan based on literature, source: developed by author and adapted from [96], [81], [97]

2.7.5 Summary & conclusion

Pakistan should look for a dynamic interacting system which has low vulnerability (to vital energy resources) and high adaptive and innovative capacities. Addressing disruptions (especially resource scarcity and climate change concerns), ensuring capacity building of user's (or user's focussed processes) and all stakeholders, capturing intermittent energies, will bring it close to low carbon resilient energy pathway. Its energy supply must be secured by considering dynamic methods. It should look for energy barriers and supply chains at medium frameworks times. The system could have larger adaptive capacity, transformability, and decentralization of energy intensity; and ensure sovereignty, robustness and resilience.

A similar low carbon resilient approach, as adopted by the UK &EU encapsulating low CO^2 emission and attaining resilience by reducing energy imports, diversity of energy supply, systems robustness, increasing energy efficiencies, sufficient storage and capacity margins is needed. Further, renewable heat initiative (RHI) approaches, better-administered market supply, reducing dependency, decarbonization of energy supply, shift to electric vehicles, local energy resources utilization and most importantly, exploitation of renewable energy resources approach, must be adopted.

The inherent vulnerability in the conventional energy system gives emphasis to adopting the resilient approach in the move towards a low carbon pathway. A localised approach is considered a possible solution to the problem of vulnerability of the energy supply system of Pakistan, rather than a centralised, top-down interconnected system. It is found that the transition towards a low carbon pathway should be laid on resilience, counter to vulnerability. A shift to a low carbon pathway for Pakistan's future energy supply system looks to adopt renewable resources. It incorporates intermittent energy resources on the principles of 'capture/harvest-when-available' and 'store-till-required, ensuring high end-use efficiency and attitude of energy-saving as predicted in Figure 2.25. By comparing with the advanced and developed economies of the world (2.2.3, Figure 2.11), we can conclude that Pakistan's current energy consumption per capita is far less and there is a vast potential of its increase in the future if energy becomes available. Achieving this target would require the co-evolution of all actors (like the capacity building of users, policy-making goals, aspirations for energy system developments, subsystems in the interaction orbit-model, preparedness to threats,) and related technologies summarised in the resilient energy orbital model. Attaining zero impact and resilience energy system in the context of Pakistan, a comprehensive broader approach is needed incorporating not only the 'supply and demand' nexus of specific energy but giving due importance to interconnected agents affecting the energy security Figure 2.26.

In the next section, as identified that the domestic sector (Figure 2.17 & Figure 2.18, 2.6.6) is one of the major consumers of energy in Pakistan, we will see how much energy is consumed in the domestic sector? What are the future scenarios of domestic energy? What are the drivers of domestic energy?

2.8 Domestic sector's energy scenario

2.8.1 Introduction

Now the scope of this thesis is reduced to the domestic sector. It is identified in the literature as one of the major consumers of energy. It consumes 48% (Figure 2.17) of total energy when bio-fuel is included and 24.5 % (Figure 2.18) when it is not included in the energy sources of Pakistan. In both cases, it is consuming a substantial amount of available energy in the country. The domestic sector consumes 89 % (Figure 2.22) of bio-fuel to fulfil its current domestic energy demand which is 36.4 % (29.7MToe) of total 81.63MToe of current Pakistan's energy consumption [45]. When this domestic energy demand would be shifted (as discussed later in a future scenario of domestic energy demand) to other sources of energy like electricity, oil, gas and coal, (which are other sources of energy of Pakistan) the environmental impact of the domestic sector would be increased.

Further, 48 % () of electricity and 33 % (Figure 2.20) of gas is consumed by the domestic sector and makes it a more important sector to be investigated in detail to know what is past, present and future demands of domestic energy? (To understand the severity of demand) What are the demand drivers of this energy? (To know where in dwellings the energy is being consumed) Furthermore, what are the potentials to generate energy from domestic sectors? (To understand the percentage of this energy demand, that can be off-loaded possibly from the primary grid)

2.8.2 Past and present domestic sector energy demand scenarios

In Pakistan, electricity and gas are the two primary forms of energy sources being consumed by the domestic sector, apart from biofuel, which we discussed in the earlier part of the literature review. Now we will see the non-renewable sources of energy, i.e., electricity and gas in the consumption perspective of the domestic sector in detail.

2.8.2.1 Electricity consumption by the domestic sector

The domestic sector had been a prime consumer of electricity in the last fifteen years, and there is a linear growth of electricity consumption, and percentage usage Figure 2.27. We see that the domestic sector is consuming (41450 GWh 48.3% in the year 2015) almost half of the total electricity consumed in the country (85818 GWh) (Figure 2.27 & Figure 2.28), in the epoch of 2000-2015 domestic sector remained the major consumer of electricity. Electricity consumption growth in Pakistan is related to foreign investment, population, and income. If there is 1% burgeon in the above variables, there is 0.056%, 1.605% & 0.97% growth respectively [98].The growing population in Pakistan is discussed earlier in the background section (), and it indicates there would be a huge increase in electricity demand by the domestic sector and need to be addressed [12]. According to one estimate demand for electricity is growing at the rate of 10% annually. Whereas, supply grows at a rate of 7% and resulting in many hours of an electricity outage.

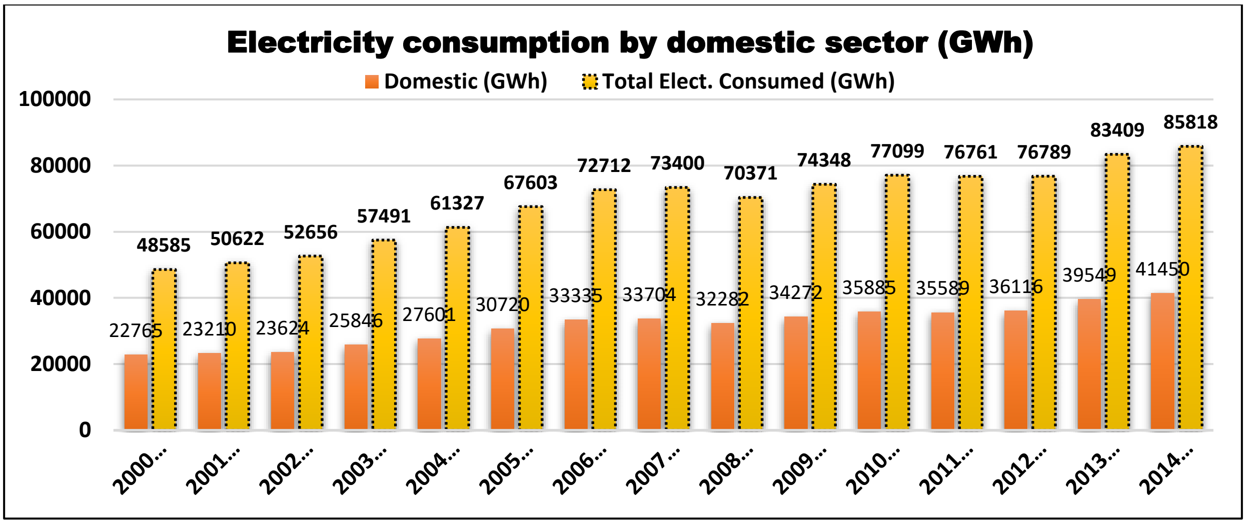


Figure 2.27 Electricity consumption by domestic sector, source: [99] (Author's production)

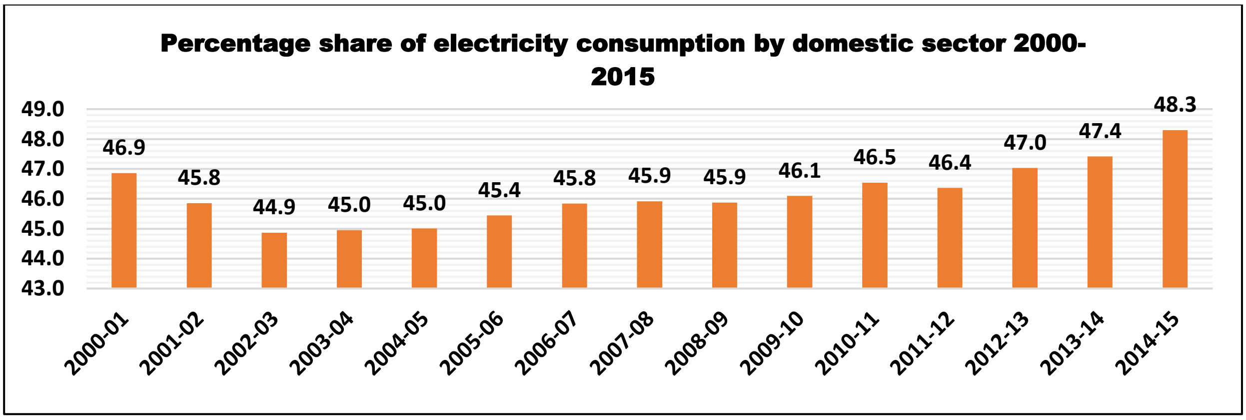


Figure 2.28 Percentage share of electricity consumption by the domestic sector, source: [99] (Author's production)

In Pakistan, the domestic sector has the most significant number of consumer's connections (14.8M), Figure 2.29 showing the percentages of other consumers as of 2006. Punjab had **9.9M** domestic consumers at present out of total 14.8M in Pakistan.

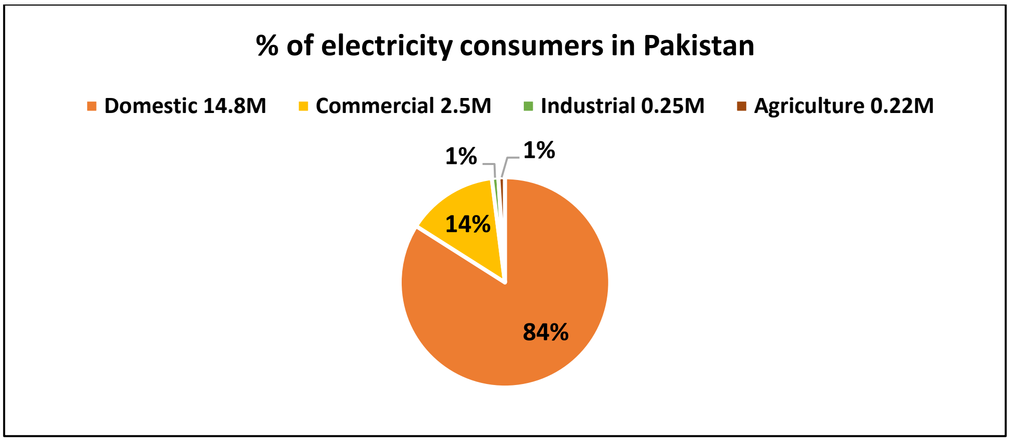


Figure 2.29 Percentage of electricity consumers in Pakistan as of 2006, source: [100]

Punjab has been consuming a significant share of electricity produced in the country, year-wise consumption from 1990-2012 is shown below in Figure 2.30, indicating it was consuming 57.5% in 1990. In the year 2012, it was consuming 62 % out of the total electricity available to the country.

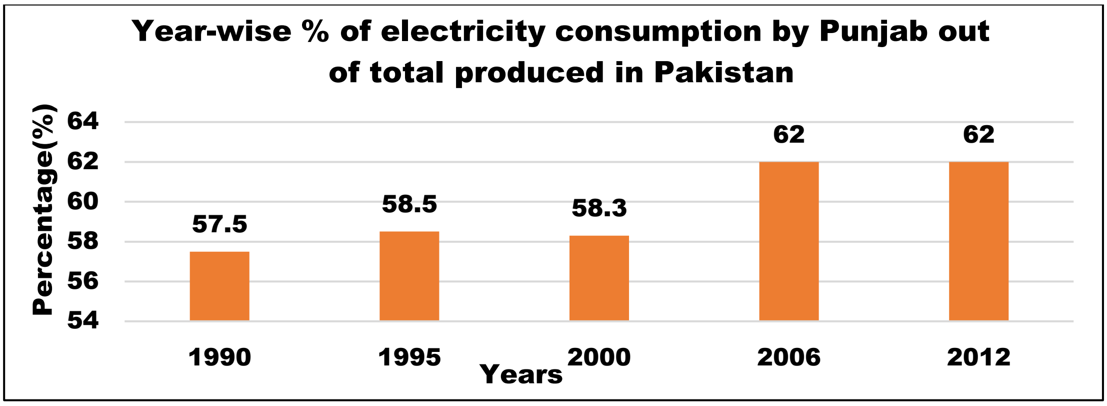


Figure 2.30 Year-wise electricity consumption of Punjab out of total produced in Pakistan, source: [100] [101]

Punjab consumed 62% of electricity produced in the country in 2012 and out of which the domestic sector uses 85.6 % [101]. (Figure 2.31) which is 25.47% of total power produced in the country and makes Punjab's domestic sector-major consumer of electricity Figure 2.31.

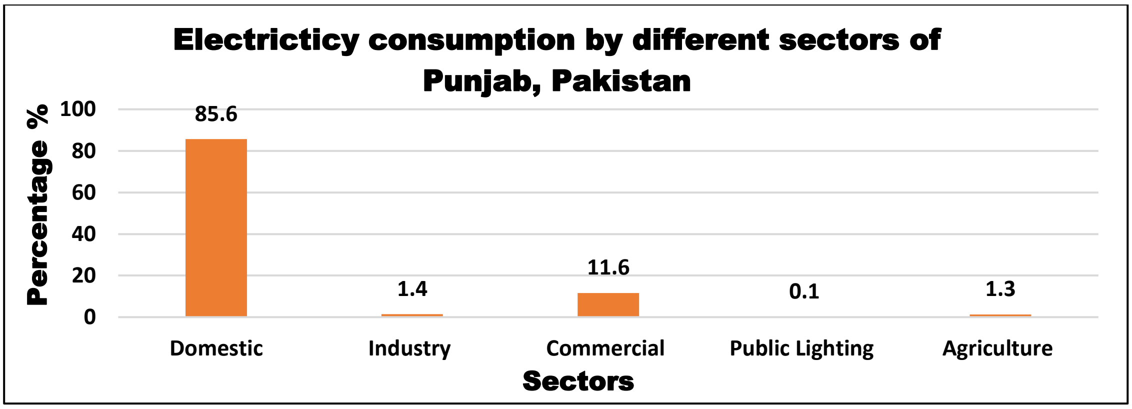


Figure 2.31 Electricity usage in Punjab by different sectors 2012, source: [100] [101]

2.8.2.2 Gas consumption in the domestic sector

Gas consumption in the domestic sector is increased from 140.9k mm cu.ft to 278.0k mm cu.ft from the year 2000 to 2015, which is an increase of 87% in 15 years, and there is a linear trend in the rise of gas consumption (Figure 2.32). This increase is due to the tremendous amount of gas supply to the domestic sector, mainly increased number of housing units and increased access to supply to the remote areas. (discussed later)

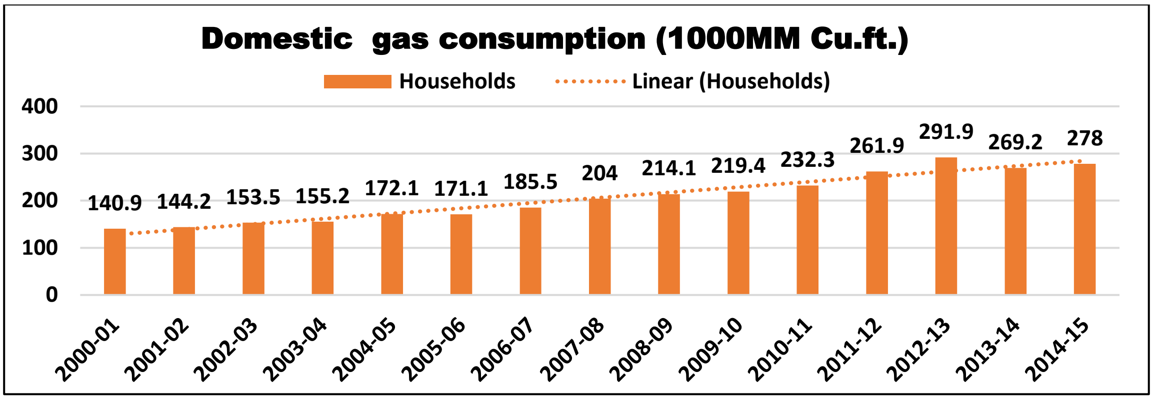


Figure 2.32 Gas consumption patterns in the domestic sector, source: [69], [99], (Author's production)

In recent years during the winter season, gas supply to the domestic sector was cut-down because of shortage, especially during early morning and late evenings, when it is more needed for cooking and heating. There is a shift of gas demand (because of its non-availability) onto the electricity. Resulting in increased demand for electricity and its shortage as well in winter, and an increase in tariff [102]. It is estimated that gas supply would be cut-off permanently in 2030 [19] [102] as the difference in the gas supply and demand would be 16736 Mcu.ft./day and could cause panic in the future Table 2.5.

Table 2.5 Gap between the demand and supply of gas. Source: [103] , Author's production

Years	Demand (MM.cu. ft./Day)	Supply	Net Difference
2004-2005	3173	4033	860
2009-2010	4564	4424	141
2019-2020	9114	3001	6113
2029-2030	19035	2299	16736

Punjab consumes 46% of total gas available in the country and out of which 40% is used by the domestic sector Figure 2.33. We can see in Figure 2.33 below that Punjab only produce 5% of the gas consumed in the country whereas, it is a more substantial consumer of it. This discrepancy in the production and consumption of gas by Punjab province create a supply problem in future when other provinces would be developed and would be consuming or asking for the fair share of the resources available in the country.

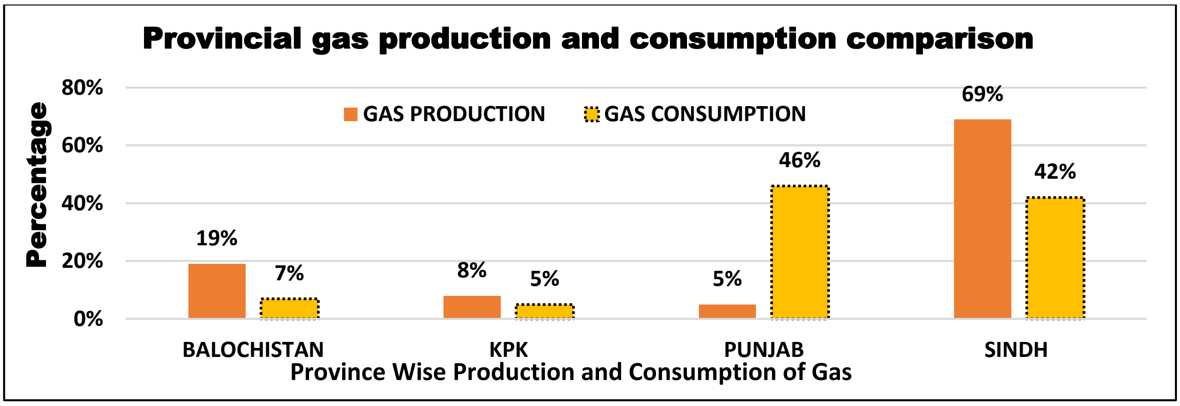


Figure 2.33 Provincial comparison of gas production and consumption

2.8.3 Conclusion

We have found that the domestic sector is the dominant sector of energy consumption in Pakistan, consuming 48% & 33% of electricity and gas respectively. It is also found that the domestic sector of Punjab is one of the major consumers of these two energies and consumes 85.6% (Figure 2.31) & 40%(2.8.2.2) out of total available energy in the form of electricity and gas to the province respectively.

The reliance of the domestic sector on gas makes it vulnerable to meet its future needs as currently gas shortage is seen in the country (Table 2.5). We found that Punjab only produces 5% of the country's gas and makes it more vulnerable to meet its future demand for gas. If gas load would be shifted to electricity, it will cause high carbon emission, as sources of electricity generation are mostly non-renewable. If domestic buildings can reduce this reliability on gas, it would help in the move towards a green future.

Currently, we have understood that domestic energy sources are non-reliable in terms of their availability. We also need to understand what the future demands of energy by the domestic sector would be. In the next section, we would see if, in the future, the need for these two non-renewable sources of energy is going to be increased. Moreover, how hard would it be to meet future demand? We want to know this because we are looking to find a solution or provide a path to achieve a low carbon energy supply system of Pakistan, especially in the province of Punjab. A detailed future energy demand scenario of the domestic sector (particularly Punjab) is presented in the next section.

2.9 Future demand for domestic energy under different scenarios

There is a need to explore the domestic sector in detail for the complete understanding of the future increase of domestic energy demand in Punjab which can reasonably be anticipated based on two proposed scenarios illustrated in Figure 2.34 and interpreted from the available literature.

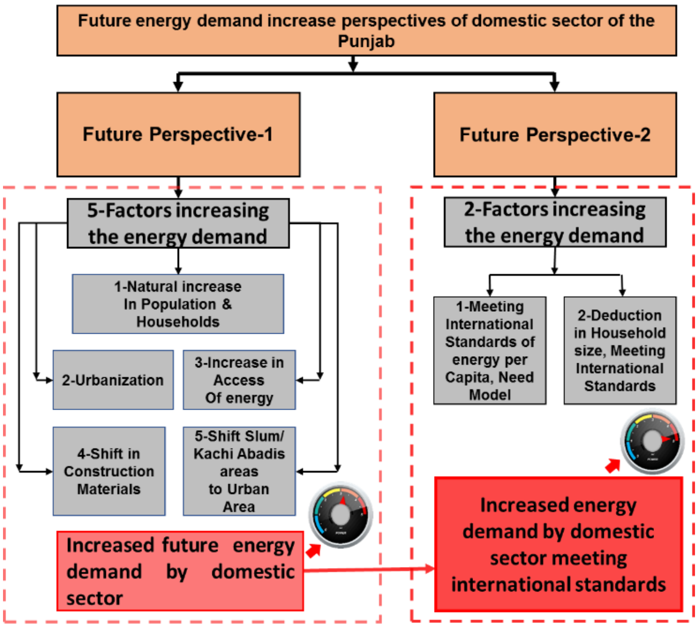


Figure 2.34 Future energy demand increase perspectives of the domestic sector of Punjab

2.9.1 Factors increasing domestic energy demand

For the complete estimation of the future energy demand of the domestic sector of Punjab, we need to understand the factors which are and will be causing an increase in the demand. For this forecasting, some of the factors identified are discussed below based on future perspective -1

2.9.1.1 Population and household growth

The future increase of domestic energy demand in Punjab can be predicted as per the usual business, current usage pattern and growth rates. In Punjab, since 1951, the increase in the number of inhabitants is 88.2M in 67 years, and it would be (based on annual growth rate (AGR) of 1.5 %) (current growth rate of Punjab is around 2%), 177M in 2050, which is an increase of 67M people in 32 years and 60% of the current population. Figure 2.35 below explains the case clearly.

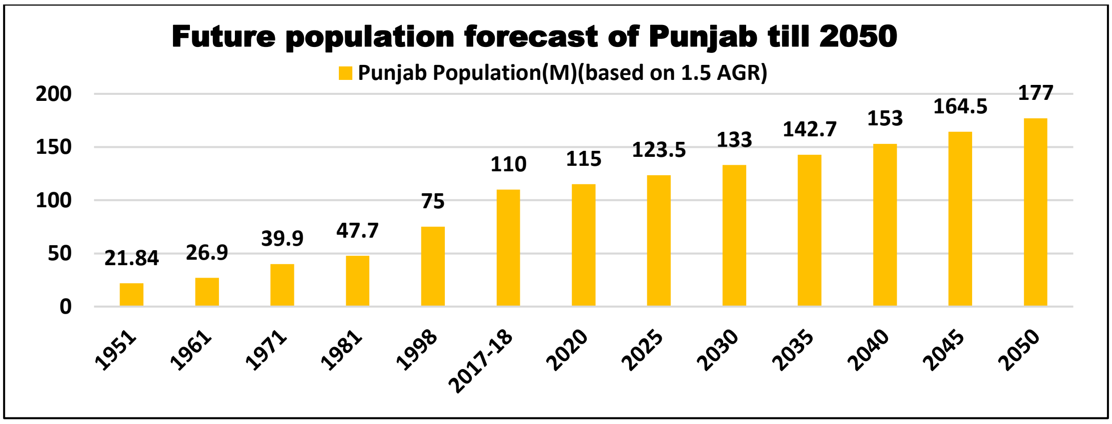


Figure 2.35 Population forecast of Punjab till 2050, source: [38] [39], Author's calculations

Presently, (2017) there are 32.2 M of households in Pakistan out of which 53% (17.1M) are in Punjab. According to the bureau of statistics (BOS) Punjab, it is increasing annually at the rate of 2.13% and with this tendency, it would be 23.3M of households by the year 2030, which would be 40% increase as of its current value in 13 years (Figure 2.36).

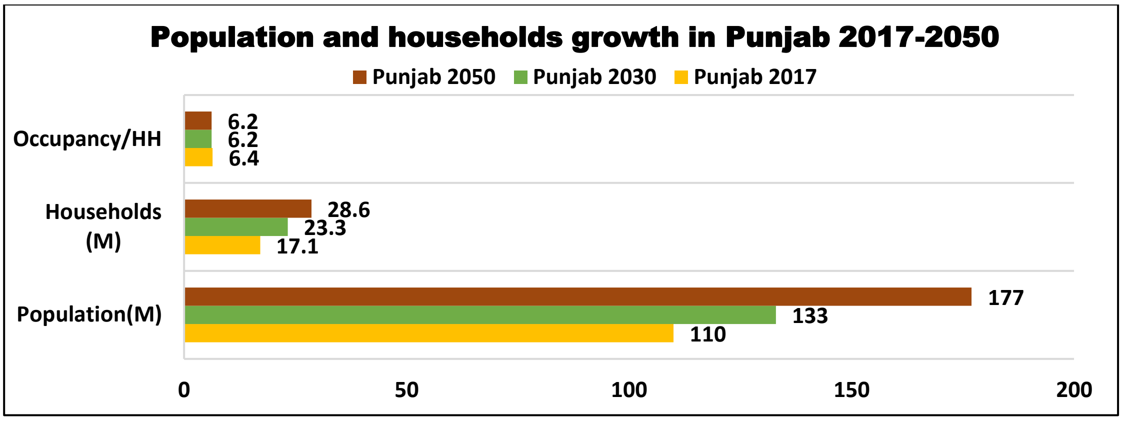


Figure 2.36 Households of Punjab, annual growth trends, source: [31] [104]

In Punjab, the household's growth rate is calculated on the average size of 6.2 people. It is estimated to be 28.6M by the year 2050 as of its current value of 17.1M (Figure 2.36). There is a need of 0.5M new power connections per year in electricity accessed areas of Punjab (Figure 2.37). Figure 2.37 below shows that there is a total of 14.6M domestic consumers in Punjab as of 2014 but looking at the household number of 2017 which is 17.1M indicates that during 2014-2017, 2.7M new connections were needed (0.9M annually) [105]. The increased electricity supply to more households implies that the future need for electricity by the domestic sector of Punjab is going to increase by the natural growth of the domestic sector.

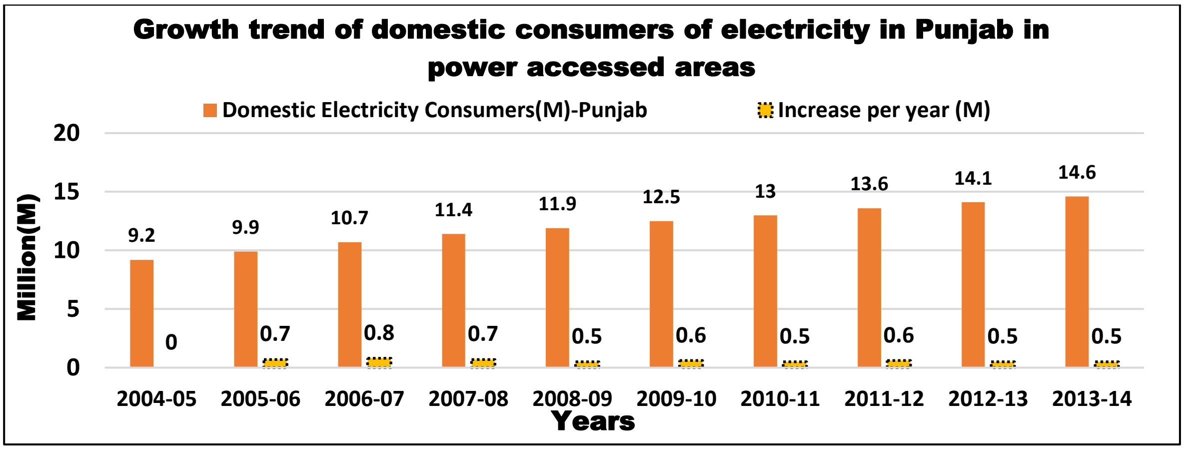


Figure 2.37 Growth trend of domestic consumers in Punjab, source: [106] [105]

Note: The above figure explains the growth in the housing sector power connections in power accessed areas of Punjab.

2.9.1.2 Urbanization

Urbanization trends of Punjab show that it is increasing with rapid speed, as per statistics (Figure 2.38), in the last census of 1998 it had 31.4% urban population. By the year 2017, it has grown to 42.4% as urban population. Because of the rapid trend of urbanization, Punjab will be challenged to meet its supply and demand for resources, as urban power demand is higher than the rural domestic sector (Figure 2.38). Historically Punjab had different rates of urbanization, and it was highest at 1951(5.2%), this happened due to massive migration from India to Pakistan (as a result of the partition of sub-continent), most of the people settled in the urban areas of Punjab. The future estimate is made on the average growth of 1.2% (urbanization) annually, as indicated in the literature by some researchers. At present 46.6M people of Punjab are urbanites, and by 2050 it would be approximately 112M urban inhabitants, about 65.4M people would adopt an urban lifestyle. This increase in the percentage of the urban population would also increase in demand for energy by the domestic sector, as the lifestyle of people would change and would demand more energy.

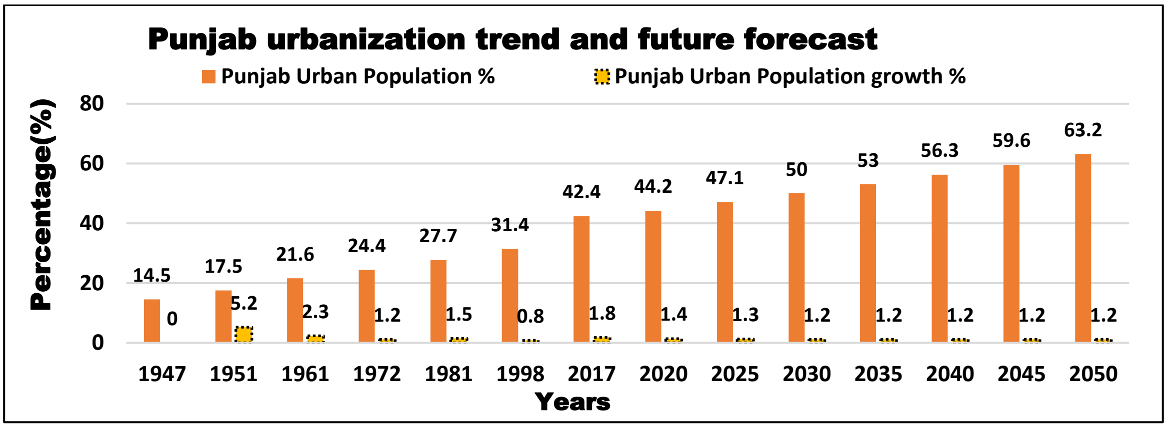


Figure 2.38 Punjab urbanization trends, source: [31] [107] [42] [43] Author's calculations

2.9.1.3 Increase in access to energy

By 2016, 74% of the total population of Pakistan had access to energy (Figure 2.39). Other countries on the list have 100% access to energy, except Bangladesh and India, which has 75% and 82%. Pakistan is the lowest in the region. This access of energy by the remaining 26% population of Pakistan, Punjab is a part of which, would increase its demand.

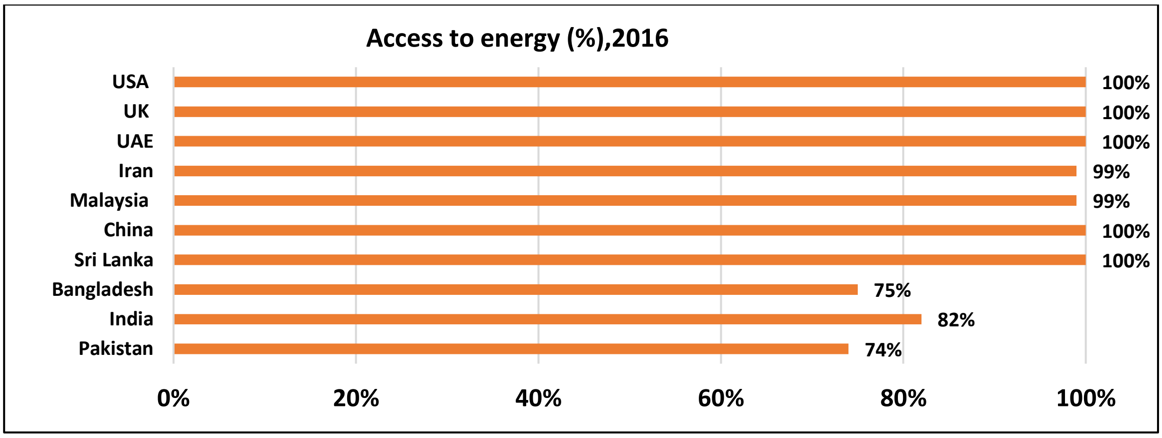


Figure 2.39 International comparison of access to energy, 2016, source: [45] Author's production

As per 1973, only 18% of households had access to electricity which increased to 30% by the year 1980. (54% urban and 5% rural) [42]. Currently, 73% of the population has access to electricity. Approximately **49.5M** (out of 209M) of the population do not have access to electricity [108]. Moreover, 91% of urban and 62% of the rural population have access to electrical energy in Pakistan. Overall, in Pakistan, 71 % of the country is electrified. Nearly 90% of urban areas and 60% of rural areas are connected to the grid. [101]. The urban areas of Punjab are almost electrified whereas **80%** of rural areas are connected to the grid. Overall, there are 20920 villages in Pakistan which are not still connected to the grid out of which **621** villages are in Punjab [109] Figure 2.40.

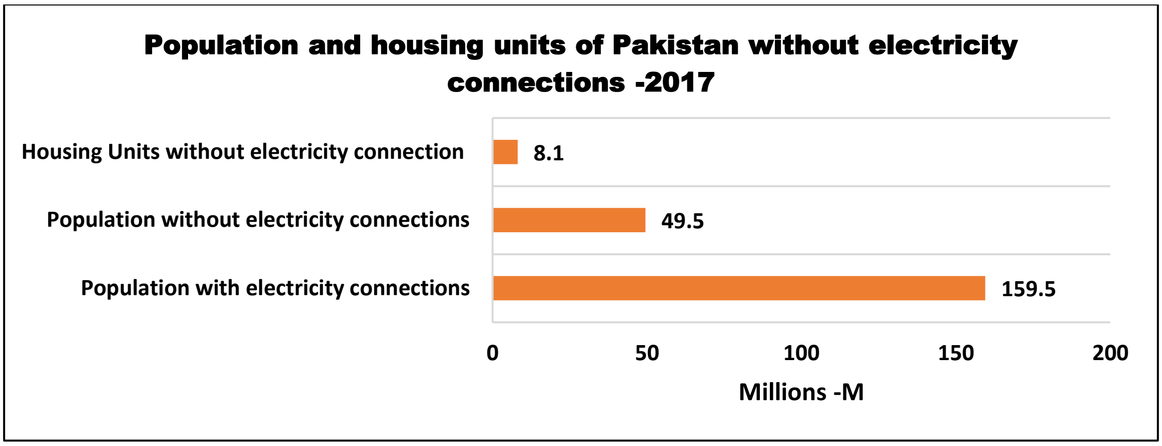


Figure 2.40 Population and housing units without electricity connections-2017, source: [108], Author's calculations

2.9.1.4 Changes in housing construction practice

According to Pakistan Social and Living Standards Measurement (PSLM 2004-5), 95% of new houses in urban areas of Pakistan had brick walls, a considerable change in the construction material over the last 40 years. Kachi abadis (mud houses) are shifting to Pacca (brick) materials [110]. In Pakistan, historically, there have been different types of materials for housing construction, mainly they are categorized under three main types, namely Kaccha (mud), Semi-Pacca and Pacca (brick/concrete) houses. The Kaccha (mud) house (**Figure** 2.41) is more of the vernacular architecture style, and Pacca (brick) (Figure 2.42) house is the modern style prevailing in the country. In Kaccha house, the walls are made of mud or mud bricks, and the roof is made of asbestos sheets, bamboo, and rice thatch. Semi-Kaccha house is made of mud and burnt bricks and roof made of asbestos sheets, bamboo or thatch. Pacca house's wall is made of burnt bricks and cement mortar, while roofs are made of concrete and mild steel bars. The u-values of these three types of construction are different, and as a result, they offer different indoor comfort conditions for the occupants. It is seen that most of the people are adopting a modern lifestyle and shifting from Kaccha houses to Pacca houses. Pacca houses are mainly modern style and consume more amount of energy to make it comfortable, due to higher U-value of construction details.

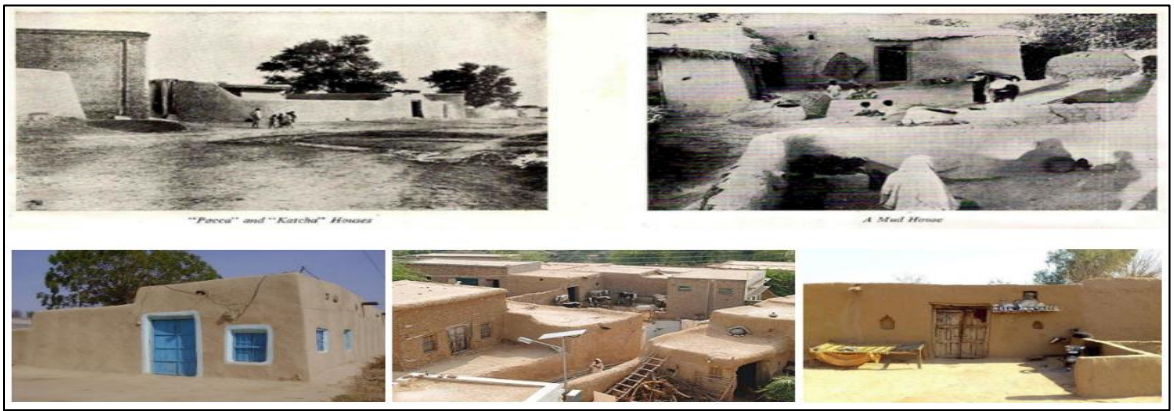


Figure ***2.41 Glimpse of Kaccha (mud) houses in Punjab, Source: Author***

Figure 2.42 Glimpse of Pacca (brick-concrete) houses of Punjab, Source: Author

As per census reports of 1998, (latest available) there are 6.57M Pacca houses, 8.3M are semi-Pacca, and 3.3M houses are Kaccha. Kaccha houses are 31.5% of total house units in Punjab, which tend to shift to Pacca house and may increase the demand for electrical energy by them. (Figure 2.43)

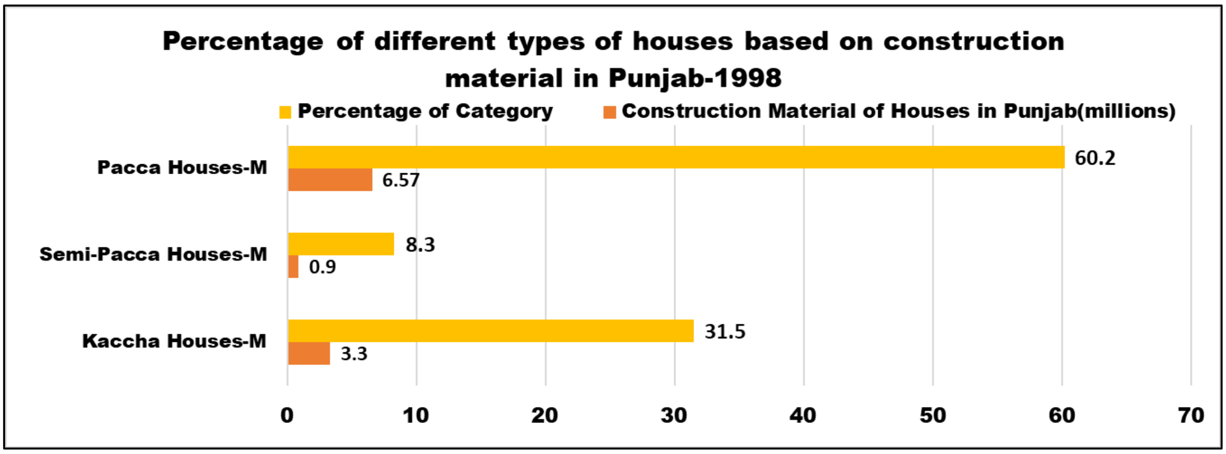


Figure 2.43 Different percentage of house types in Punjab based on construction material used, source: Census report of 1998

Table 2.6 below shows the details of house types in all 36 districts of Punjab. The data is collected from the district reports of all districts of Punjab.

Table 2.6 Details of house types of 36 districts of Punjab

Sr. No.	District	Houses M (1998)	Pacca Houses %(1998)	Pacca Houses M(1998)	Semi-Pacca H. %(1998)	Semi-Pacca H. M(1998)	Kaccha Houses %(1998)	Kaccha Houses M(1998)
1	Attock	0.21	76.7	0.16	5.1	0.01	18.2	0.04
2	Bahawalnagar	0.31	38.06	0.12	10.33	0.03	51.61	0.16
3	Bahawalpur	0.36	46.47	0.17	10.41	0.04	43.12	0.16
4	Bhakkar	0.16	32.57	0.05	8.96	0.01	58.47	0.09
5	Chakwal	0.19	32.57	0.06	9.19	0.02	19.27	0.04
6	Chiniot	0.12	0	0.05		0.01		0.06
7	Dera Ghazi Khan	0.21	28.3	0.06	6.12	0.01	65.57	0.14
8	Faisalabad	0.75	68.49	0.51	14.1	0.11	16.13	0.12
9	Gujranwala	0.45	90.53	0.41		0.02		0.02
10	Gujrat	0.31	91.37	0.28	3.61	0.01	5.1	0.02
11	Hafizabad	0.12	65.69	0.08	1.64	0.00	32.67	0.04
12	Jhang	0.43	37.49	0.16	11.98	0.05	50.53	0.22
13	Jhelum	0.19	84.53	0.16	10.12	0.02	5.34	0.01
14	Kasur	0.34	66.9	0.23	4.64	0.02	28.45	0.10
15	Khanewal	0.29	35.16	0.10	14.25	0.04	50.55	0.15
16	Khushab	0.15	68.99	0.10	4.47	0.01	26.54	0.04
17	Lahore	0.89	92.29	0.82	3.4	0.03	4.31	0.04
18	Layyah	0.15	27.82	0.04	9.36	0.01	63.82	0.10
19	Lodhran	0.16	33.67	0.05	10.69	0.02	55.64	0.09
20	Mandi Bahauddin	0.17	91.28	0.16	2.1	0.00	6.64	0.01
21	Mianwali	0.15	64.65	0.10	6.53	0.01	28.82	0.04
22	Multan	0.43	49.71	0.21	6.92	0.03	43.37	0.19
23	Muzaffargarh	0.36	27.94	0.10	9.54	0.03	62.52	0.23
24	Narowal	0.17	79.11	0.13	6.9	0.01	17	0.03
25	Nankana Sahib	0.16	0	0.06		0.02		0.08
26	Okara	0.37	43.34	0.16	9.9	0.04	46.76	0.17
27	Pakpattan	0.2	33.43	0.07	10.4	0.02	56.18	0.11
28	Rahim Yar Khan	0.42	44.63	0.19	13.86	0.06	41.51	0.17
29	Rajanpur	0.15	16.87	0.03	11.1	0.02	72.11	0.11
30	Rawalpindi	0.52	88.73	0.46	6.1	0.03	5.16	0.03
31	Sahiwal	0.27	32.57	0.09	12.1	0.03	33.38	0.09
32	Sargodha	0.41	77.75	0.32	2.98	0.01	19.26	0.08
33	Sheikhupura	0.45	72.43	0.33	3.41	0.02	24.17	0.11
34	Sialkot	0.37	86.28	0.32	6.65	0.02	7.1	0.03
35	Toba Tek Singh	0.23	45.43	0.10	20.2	0.05	34.36	0.08
36	Vehari	0.3	44.17	0.13	8.86	0.03	46.97	0.14
	Total	**10.92**		**6.57**		**0.90**		**3.30**

2.9.1.4.1 The population shift from Kachi Abadis/slum areas to the urban standards

2.9.1.5 Growth in Kachi Abadis

The term is used for unplanned, illegal squatter development in Pakistan, meaning temporary settlement (Figure 2.44) [111]. A squatter settlement of domestic nature which has no legal status and written permission to build and subsequently no proper infrastructure and access to utilities is term as Kachi Abadis in Pakistan [112].

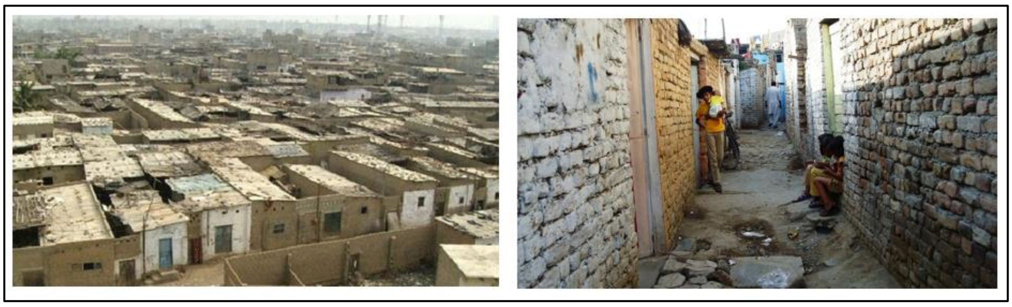


Figure 2.44 Glimpse of Kachi Abadis of Pakistan, sources: Author

It is seen as an informal solution to the housing shortage in any area where people settle as scatter settlers. In 1980 in Islamabad, there were 13K, and by the year 2004 were 50K people living in the surrounding of the city [113]. It is estimated that there are about 3K kachi abadis in Pakistan having a population of over 7M, from recognised abadis of 2302 Karachi development authority (KDA) and as per estimates in 2009 it is about 9.5M [114]. According to one research 10-15 people are living in a single house of two rooms in such settlements. It is estimated that only in Karachi there was 5M inhabitants of kachi abadis, having 0.7M houses up to 2000 [115]. According to the Pakistan national housing agency report of 2001, there is a need for **6-8M** houses. Almost half of the urban population lives in the Kachi Abadis. As per one estimate in 2011 [116], 74% of the urban population of Pakistan lives in urban slum areas and consists of around 36.5M people living in them [117]. About **30M** people are living in the Kachi abadis of Pakistan, as of 2015 (UN-HABITAT) [118]. To overcome the housing shortage problem the new settlements by the name of Khuda-Ke-Basti was introduced in Pakistan, and the idea was to give people land on easy instalments were they can develop their houses in stages, as the resources become available and helping each other [119]. Punjab Housing and town planning department (PHATA) faces the shortage of 3K houses per year due to high land prices, resulting in the development of Kachi Abadis in the suburbs of cities [120].

In Punjab, a full-fledged Directorate General of Kachi Abadis & Urban Improvement is working under the Local Government and Rural Development Department Government of Punjab. At the lower level, there is a directorate of Kachi Abadis working under different development authorities of big cities like, Lahore Development Authority (LDA) Lahore, Multan, Faisalabad, Rawalpindi, which look after the rules and laws governing the kachi abadis. Governing laws of kachi abadis in Punjab works under Punjab Kachi Abadis act 1992.

Slums: Slums (Figure 2.45) can be referred to residential units without necessary access to utilities (like electricity) and infrastructure. People living in them cannot afford to live anywhere else and are forced to live in sub-standard conditions because of poverty and have no legal status (UN-HABITAT) [112]. There are different estimates of dwellers living in slum areas of Pakistan and gives figures 23M to 32M [121]. According to World Bank reports of 2014, there are approximately 32.3M people (45.5% of urban population) are living in the slums of Pakistan with no access to basic needs of life like proper food, clean drinking water, sanitary, electricity and infrastructure (Figure 2.46). In the future, when these people (approximately 32.3M) living in the Kachi-Abadis and slums of Pakistan would shift to the modern lifestyle, with sufficient access to energy, this will cause a huge demand increase.

Figure 2.45 Glimpse of slum areas of Pakistan sources: google, Produced by Author

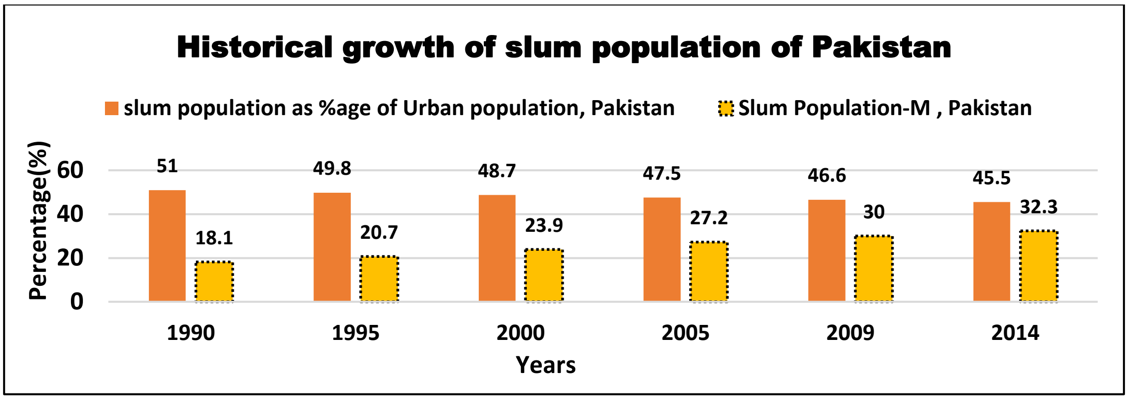


Figure 2.46 Historical development of slum population of Pakistan, source: [122] [123] [124] [125]

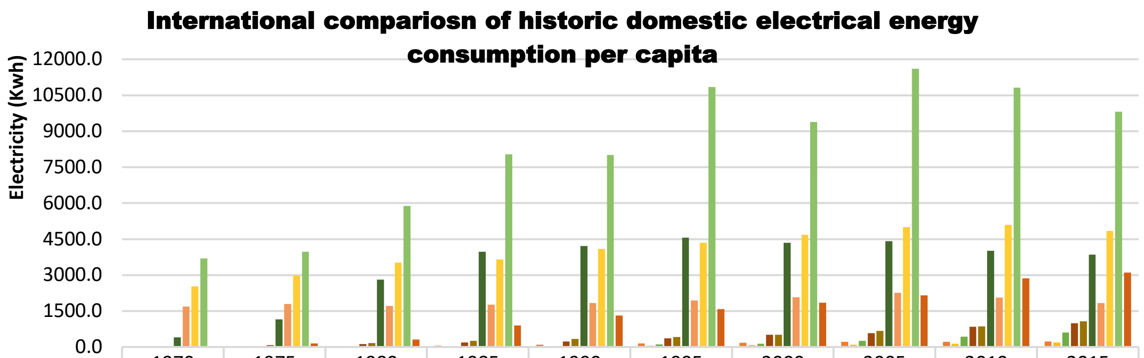
2.9.1.6 Change in energy poverty

In developing countries like Pakistan, there are many classes in society concerning their affordability of commodities like electricity & gas, which is the focus of this thesis. Some people have enough resources to buy facilities of life, making their life comfortable in all respects and especially electricity & gas related visual and thermal comfort in their houses. Nevertheless, at the same time, there is a large population which cannot afford to maintain a comfortable lifestyle, and so is the case of their energy (electricity & gas) consumption. As Pakistan is in the development stage, the energy comfortability by all inhabitants has not been achieved and falls in the category of **energy poverty**. The society as a whole is not sufficiently consuming the amount of energy required to live a life in accordance with international standards, which includes comfortable thermal conditions (of heating or cooling in the space throughout the year), proper lighting, ventilation, in all occupied areas, especially the residences. The future perspective-2 is an effect to investigate the literature to forecast the energy demand of Pakistan, when the society would be developed and would enjoy all domestic facilities related to energy, as per international standards till 2050. Under this perspective, there are two factors discussed which could increase the energy/power demand in the Punjab, Pakistan and are given as: -

2.9.1.7 Increase in demand due to meeting International standards, 'Energy need model'

The next part will consider and would forecast, as per interpreted from literature, the future electricity demand of the domestic sector, based on the concept of '**NEED MODEL'**. In this model, the electricity consumed per capita of the domestic sector of other countries is compared with the electricity consumption of Pakistan's per capita. Note: we compared only electricity use, as we could not find data of gas consumption per capita in Pakistan.

The annual electrical energy consumed per capita of Punjab is lowest (230 kWh) in the region except for India (193.4kWh), Figure 2.47 illustrates the per capita historical electricity consumption of different economies of the world. When it is compared with other developed countries, the data indicates that when the average values of all the compared economies of the world are taken (as of 2015), Punjab's domestic sector should have consumed 2655 kWh per capita. The 2425 kWh annual difference between this value and the current 230 kWh/a domestic electrical energy consumption in the Punjab per capita is used in the thesis as a reasonable indication of the current unmet electrical demand in Punjab (Figure 2.47).



	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
Pakistan	8.8	12.8	30.6	57.7	89.5	145.8	174.6	209.7	216.4	230.0
India	8.2	9.8	14.6	26.3	41.3	61.1	82.7	101.5	141.2	193.4
China	12.7	14.2	13.4	26.9	26.2	105.0	133.9	259.1	436.1	609.2
Malaysia	0.0	0.0	123.0	187.3	235.4	361.6	512.0	580.4	846.8	995.8
Iran	30.4	83.4	158.2	258.4	336.9	414.1	511.5	674.8	855.1	1078.2
UAE	406.7	1148.3	2813.3	3967.6	4211.8	4561.6	4352.7	4409.5	4018.7	3856.5
UK	1680.6	1792.3	1715.9	1772.1	1838.5	1939.4	2074.2	2257.6	2054.4	1834.8
USA	2530.3	2977.0	3514.2	3650.3	4094.5	4348.7	4678.2	4995.1	5094.6	4835.0
Kuwait	3697.2	3971.1	5885.4	8034.7	8008.6	10838.1	9378.9	11610.2	10817.5	9815.1
Oman	0.0	153.1	311.9	896.8	1312.1	1584.0	1845.2	2153.4	2859.9	3105.7

Figure 2.47 International comparison of electricity per capita (kWh) 2015, source: [45] Author's production

The domestic sector of Punjab (having 56% population size) is compared with the domestic electrical energy consumed by developed and developing countries, Figure 2.47, to assess Punjab's potential domestic sector annual electrical consumption per capita assuming an unconstrained supply. Comparing Punjab on a per capita consumption basis with the service-led economies of UK & USA, the domestic sector of Punjab was deficient 162 TWh(Terawatt hours) and 467 TWh annually respectively using 101.4M residents for Punjab (Table 2.7). In 2050, Punjab's domestic sector would need 324 TWh and 857 TWh annually when compared with the UK and USA's 2015 demands respectively assuming a Punjab population of 177M in 2050.

Punjab's domestic sector consumed 972TWh and 292TWh less electrical energy in 2015 when compared with industry-led economies of Kuwait and Oman respectively as per capita consumption of these countries. If it is further compared for future demand of electrical energy in 2050 then Punjab would need 174TWh and 55TWh when comparing with the current (2015) per capita electrical energy consumption of domestic sectors of Kuwait and Oman respectively Table 2.7.

Table 2.7 Punjab's population-based overall domestic electrical energy requirements compared with different economies of the world in 2015 and 2050[1].

Compared Countries	Punjab's adjusted 2015 domestic electrical energy requirement (TWh)	Punjab's adjusted 2015 % increase	Punjab's adjusted 2050 domestic electrical energy requirement (TWh)	Punjab's adjusted 2015 % increase in 2050
When adjusted by Service Led Economies use per capita. Punjab consumed 23 TWh in 2015				
UK	186	695%	324	1288%
USA	491	2004%	857	3573%
When adjusted by Industry Led Economies use per capita. Punjab consumed 23 TWh in 2015				
Kuwait	996	4170%	1738	7353%
Oman	315	1252%	550	2260%
When Compared with Mixed Economies use per capita. Punjab consumed 23 TWh in 2015				
Malaysia	101	335%	177	659%
UAE	391	1578%	683	2830%
When Compared with Neighbouring Economies use per capita. Punjab consumed 23 TWh in 2015				
China	62	165%	108	363%
Iran	110	370%	191	720%

Punjab's domestic sector would have consumed 102TWh and 392TWh of electrical energy if it was compared with per capita consumption of Malaysia and UAE respectively in 2015. In the future, if the per capita consumption of Malaysia and UAE is taken as of 2015, the future need of Punjab's domestic sector than it would need 177TWh and 683TWh respectively.

Comparing Punjab's domestic electrical energy needs with China and Iran show that it was deficient of 39TWh and 86TWh respectively in 2015. The future needs of Punjab domestic electrical energy sector would be 108TWh and 191TWh respectively when per capita current consumption (2015) of China and Iran is projected as a future need of Punjab by 2050 Table 2.7. India is not compared with because its domestic electrical energy consumption is less than current use by Pakistan.

2.9.1.8 The shift in the use of energy source (gas to electricity) by the domestic sector

Electricity provides 34% [126] of domestic energy, of which lighting consumes 35%, space cooling 36% and appliances 29% (Figure 2.48). Electrical energy is not used for cooking in Punjab, and it is mainly done by organic resources like cow-dung, wood and gas(bio-fuel) as discussed in 2.4

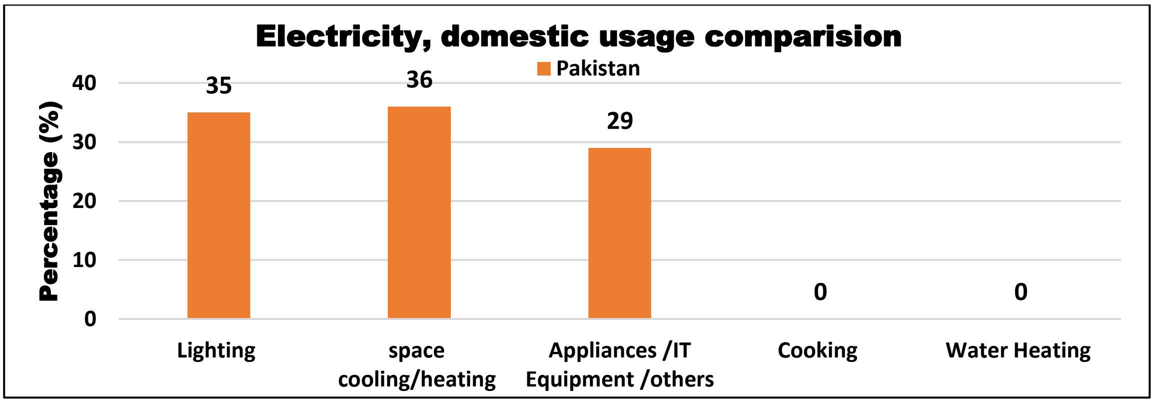


Figure 2.48 Domestic end-use of electrical energy 2015, source: [45], Author's production

[1] While, Punjab consumed 23 TWh total in 2015

Most of the energy (66%) in the domestic sector of Punjab is consumed for cooking, space and water heating. The fuels used are gas (59%), LPG (5%) and oil (2%) (When bio-fuels are not included as an energy source; bio-fuel provides 37.6MToe to the domestic sector, discussed earlier in 2.4). Currently, a shortage of gas during the winter season is observed (as discussed before, Table 2.5) due to its colossal exploitation by domestic cooking. When its load would be shifted to electricity, it would result in the huge demand increase in electricity. In Pakistan/Punjab cooking consumes 44% and space heating consumes 9.5% of overall energy, and this 53.5% of energy is not provided by electricity (Figure 2.49). These two areas have a massive tendency for electricity usage in the future as people have already started using electricity for heating and cooking in Punjab, due to gas shortage.

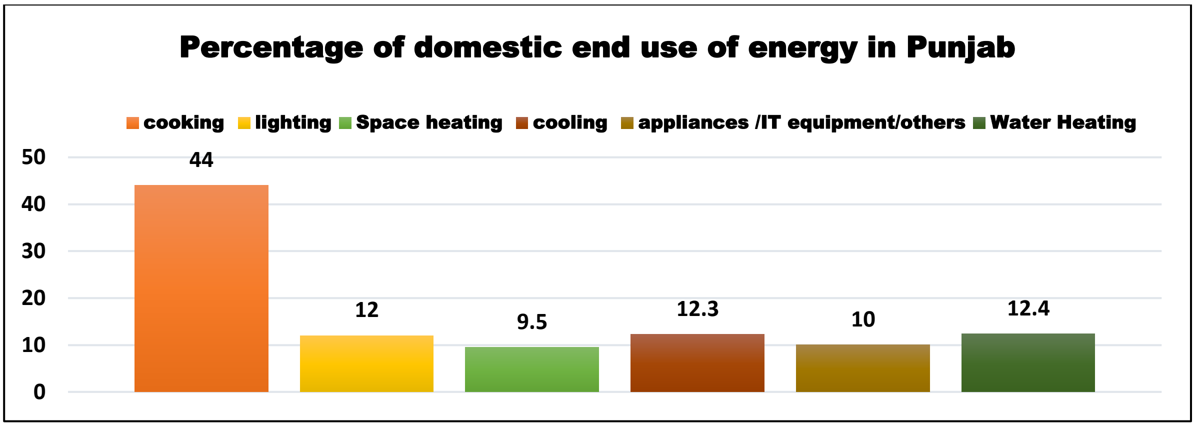


Figure 2.49 Domestic end-use of energy 2015, source: [45], Author's production

2.9.1.9 Shortage of housing units and reduction in the household occupancy size as per international standards

It was estimated that houses shortage of Pakistan was 4M in 2000 [127]. According to one estimate, there was a shortage of 6M houses in the year 2004, and the demand was fulfilled 25% by kachi abadis, 60% through sub-division of land and 15% by densification of existing houses, mainly in the major cities [128]. According to central bank statistics, there is a shortage of 8.8M houses in Pakistan as per 2010, and annually there is a need of 0.7M houses in the country, but it can hardly make 0.3M houses/year [120]. As a result, people are forced to live below the absolute poverty line, and 24% of Pakistan population falls in this category [129] [120].

According to one estimate, 68% of Pakistan's population falls into the low-income group ($0.8K-$3K), which has only 1% of the housing units of the country. Medium income ($3K-$250K) constitutes 20% of the population, occupy 43% of housing units, and high-income group ($250K-above) are only 12% of the population, holding 56% of the country's housing units [130] [131]. In Punjab middle class is 46% [132] It is seen that housing units with one room have declined 1998-2005 from 38.1% to 24.2%, while those with 2-4 rooms increased from 55% to 68.7% [133] [Pakistan social and living standard measurement indices 2004-5(PSLM)].

The occupancy rate of housing units vary from 1-14 in some extreme cases, but average occupancy is calculated as 6.5 persons per house [7]. The occupancy rate (persons per room) in Pakistan is 3, which is higher than the overcrowded level suggested by the UN (1.5-2 person) [134] [135]. If the World's Bank recommended occupancy rate of 6 people per house is followed, by 2018 Pakistan needs 34.8M of houses for the population of roughly 209M. Currently, Pakistan has 32.2M housing units, and there is a shortage of 2.6M housing units. It is just to achieve the recommended standard, but it can be seen from *Figure 2.50*, that 25.7% of houses in Pakistan have only one room. In Punjab 27.5% of the houses have one room, there is a tendency of either increasing the number of rooms in the housing units or making a new house, as occupancy of these room comes out to be 6.5 people per room. These statistics are so depressing, and alarming at the same time, as when the standard of living of these people would be raised, there would be a vast increase in the number of houses. As a result, this would demand a considerable increase in energy supply.

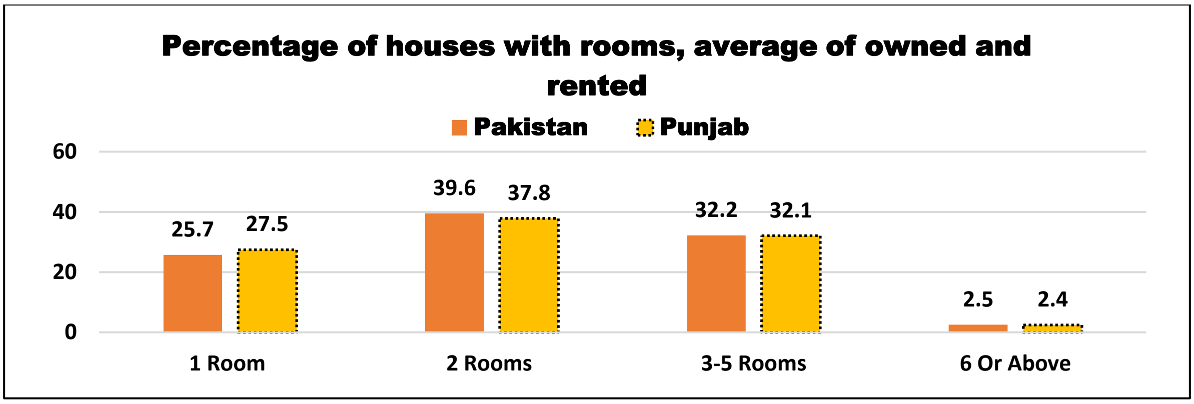


Figure 2.50 housing units with a number of rooms in Pakistan and Punjab, source: household integrated economic survey 2005

2.9.2 Conclusion

As indicated a considerable increase of population in Punjab, would require more housing units or an increase in the size of household; as a result, there would be an increase in the energy demand by the domestic sector of Punjab (Figure 2.35). By the year 2050, adding 11.3M more households in the province will require colossal energy demand. This dangerously high tendency of household growth for Punjab would be demanding immense energy to meet the requirements of households soon (Figure 2.36).

Further, by 2050, 65.4M more people of Punjab will adapt to the urban lifestyle. The energy usage of households will increase due to having more electrical appliances and gadgets, improved living standards of comfort conditions and especially shifting from using bio-fuel & wastes as a source of domestic cooking to modern fuels (like electricity and gas), would result in the massive demand of energy in Punjab Figure 2.38. We have observed that 53.5% of domestic energy (in non-bio-fuel usage areas) is required for cooking and space heating (Figure 2.49), and it is met by gas. Due to the shortage of gas in recent years, this demand would be shifted to electricity.

Even currently, Pakistan is not fully connected to the grid and it has not been able to cope with the energy demands. If the remaining 26%of the population (49.5M) is also given access to energy (8.1M households), the situation will become worse, and access to electricity is the fundamental right of every individual of the country (Figure 2.39 & Figure 2.40). Further, the Kachi Abadis of Punjab and almost 30M people living in them, there is a large number of houses which are either not connected to the main grid or take power from their immediate neighbours with limited use of electricity illegally. When such houses would be legally connected, their usage of electricity will increase and will add load to the main grid. (2.9.1.4.1) moreover, when 32.3M people of slums with the average household size of 6.1 persons per house of Pakistan, having 5.3M households, will be added to the national grid it will increase the overall demand of electrical energy in Pakistan and Punjab (Figure 2.46).

As predicted in Table 2.7, based on the 'Need Model[1], the electrical energy consumption statistics of Punjab (current and anticipated future) show that there is a vast potential of electrical energy demand increase. If Pakistan progresses as one of these economies of the world, the average demand per capita of domestic electrical energy will increase to 2655 kWh (per capita/year) while it is only consuming 230kWh (per capita/year). The statistics (discussed in 2.9.1.9) indicate that there is a huge potential of increasing housing units in Pakistan. As most of the population (68%) have only 1% houses, there lies a future tendency that they would be making their own houses if funds become available as the current government has announced the construction of 5M houses in 5 years (2019-2023). As most of these people (low income), they keep on saving money and make homes in the last age.

When occupancy level per household would be met with an international standard of 6 people per house (currently it is 6.5), it would require more energy to meet the demands of lighting, conditioning and other purposes (2.9.1.9). If the room occupancy would be reduced to 1-2 persons per room, this drive would also require more energy in the country.

In a nut-shell, due to natural increase in population, urbanization increased access to energy, change in construction details, increased housing units, elevated living standards and shift from bio-fuel & wastes to electricity, gas, and oil, as a source of energy. All these factors would insert much pressure on the domestic energy supply system of Punjab. We can also conclude that the future demand prediction of domestic energy is not clearly understood, and this is an area where detailed research is required. As both of demand increase perspectives discussed in this section are based on the statistical numbers available, we need to develop demand prediction models based on actual consumption data, emerging from the usage patterns of Punjab's inhabitants.

In order to meet the aims, set in this thesis, there is a need to explore in detail what the energy demand drivers in a typical house are? When does this demand occur in a year, month and day? Furthermore, what portion of that demand could be met by the exploitation of renewable resources by the incorporation of possible renewable strategies by the domestic sector of Punjab?

To answer these questions, which will provide the information required to achieve the thesis objectives of low impact and resilient energy future of Punjab, we need to know how much of work has been already done in these areas. In the next section, we will explore the literature to understand what efforts have been made to calculate domestic demand drivers and the electrical energy generation potential from the rooftops of domestic buildings of Punjab and Pakistan. It can potentially reduce the future dependency of Pakistan on non-renewable resources.

2.10 **Domestic energy demand drivers**

At this stage, it becomes necessary to explore in detail what causes the energy demand in the domestic sector of Pakistan/Punjab as the domestic sector is consuming 48 % (Figure 2.17) of overall available energy. Literature is reviewed in this section in two parts to explore the efforts made to know the demand drivers.

(i) International studies of domestic demand drivers

(ii) National studies of domestic demand drivers

2.10.1 International studies of domestic demand drivers

Identifying the domestic energy demand factors have been the subject of recent research [136] [137] [138]. They broadly fall into three main categories (i) socio-economic factors, like the number of occupants, family composition, age group, employment status, education, and income level. (ii) dwelling factors, like dwelling types and age, number of rooms, number of floors, floor area, HVAC system for cooling and heating, energy-efficient appliances, (iii) appliances factors, like appliances ownership, usage of appliances and power demand of appliances. In one study, four socio-economic, seven dwelling and nine appliances related factors are identified which have a positive effect on electricity demand. [139]. Some authors had reported occupants behaviour with domestic energy use, with a focus on four topics (i) understanding of occupant behaviour and window opening behaviour, lighting control behaviour and space heating/cooling behaviour (ii) methods and techniques for collecting data on behaviour and buildings energy performance (iii) evaluation of energy-saving potential and occupant behaviour (iv) quantitative building energy modelling and occupant behaviour [140].

Occupant space conditioning behaviour is identified as a significant factor of cooling electricity energy demand [141], heating demand [142] and both demands [143]. Domestic space heating and consumer electronics are found to be the most influential factors of UK domestic energy demand [136]. The literature relating to the impact on energy demand and consumption of the individual variables identified is discussed below.

2.10.1.1 Occupancy

Many researchers found a positive relationship between occupancy level in a household and electricity consumption, i.e. increasing numbers of occupants leads to increased electricity usage.[[144] [145] [146] [147] [148] [149] [150] [151] [152] [153] [154] [155]. One study in Japan found electricity increases by 230kWh/annum for each additional person due to increased use of lighting and appliances [152]. However, research in India [156] found a negative relationship between household area and occupancy w.r.t electricity consumption, suggesting that houses with larger numbers of people had lower electricity consumption. Other research found no significant change in electricity consumption with the number of people living in the house [157] [158]. The conclusions from the literature are that relationships appear to be location-dependent and may vary with time too. It could be due to economic factors, but this has not been assessed in these studies.

2.10.1.2 Per capita relationship

Researchers have looked at the relationship between the size of household and per capita electricity use. A study in the UK [147] found a negative correlation between per capita electrical energy use and household area, suggesting that electricity use is a mix of demands independent and dependent on occupancy numbers. It means more efficient electricity use per capita in larger households. Similar results are found in the USA [159] and Northern Ireland [151]. The overall conclusion is that larger households may use more electricity in total, but per capita consumption is usually less.

2.10.1.3 Floor area

A positive correlation has been found between electricity consumption and the floor area of a dwelling. Research conducted in the UK found that the dwelling floor area has a significant correlation with electricity consumption [160]. Similarly, a proportional increase in electricity consumption with an increase in floor area is found in China [149] and India [156] with different percentages of increase in electricity demand. Per unit floor area consumption was also found to remain constant as the number of occupants increased [156]. A positive association was also found between floor area and energy consumption, but it becomes non-linear beyond a floor size of $100m^2$ in the UK [161].

Other research also found a reasonable correlation between floor area and electricity consumption in different countries, including Portugal [145], Netherlands [146], China [148] [162], UK [154] [163] [161] and Sweden [157]. These researchers also concluded that larger floor areas were linked to increasing electrical use for heating and cooling in line with the seasonal requirements in different parts of the world. It was also observed that this increased demand is more evident in those dwellings where the electricity is the main source of space conditioning. No effect of floor area on the energy demand is observed by Merve [144]. However, some research also found income [164] and weather & location [159] along with floor area, were strong predictors of energy consumption. In conclusion, the floor area is usually found to have a positive correlation with electricity consumption. Demand also changes with location and if electricity is being used as the main fuel for space conditioning.

2.10.1.4 Power rating for appliances

It is found that appliances with lower power ratings had a smaller effect on the overall electrical Power demand [159]. However, the higher efficiency of an appliance often results in increased use, hence overall energy consumption is increased, known as the 'rebound effect' [165]. A similarly high potential for more significant energy usage is found in Ireland [166] in homes having more energy-saving features. The power rating of appliances seems to have a positive effect on decreasing the electricity demand, but it also enables appliances owners to use them more as their affordability increases.

2.10.1.5 Total number of appliances

The number of electrical appliances has a positive correlation with electricity consumption [149] depending on the number [167] , type, power rating and the number of hours each appliance is used [144] on average per day. The effect of a higher number of electrical appliances is reported to be the cause of increased domestic electricity consumption from a study in Japan which concluded that electricity consumption increased by 62 kWh/yr. per unit increase in the number of appliances [152]. Further [144], the number of appliances explained 21% of the variance in electricity consumption in the Netherlands, with a similar trend reported in Portugal [168]. Besides, it is concluded [169] Certain types of appliances use a substantial portion of electricity than others in the USA. We conclude that increasing the number of appliances, and certain types increase the demand for electricity

2.10.2 National studies of domestic demand drivers

No literature was found which explored the domestic demand drivers in the context of Pakistan and Punjab. There is some effort to know the domestic demand drivers, as shown in Figure 2.49. Cooking, lighting, space conditioning and appliances are identified as key drivers of domestic energy demand, the detailed identification of these drivers, including which particular variable is causing the demand, is not done in the context of Punjab. In a recent study, 17 different end uses of electrical energy consumption are identified using 523 survey responses; most of these are individual types of appliances, causing electricity demand i.e. air conditioners for cooling [170]. Overall, Pakistan domestic energy demand drivers and specific demand intensity as per household characteristics or per capita are not well understood.

There are few studies on estimating the time of the year and months when there is more energy demand. Figures are provided by the energy distribution companies as per their records of energy demands and indicate that electricity demand increases [171] [172] [173] during the summer months and gas demand increase [174] during winter months. During the summer, the load increases due to the use of electric fans and air-conditioners in the houses. During the winter, gas's demand increases due to space heating and hot water [171].

2.10.3 Conclusion

The domestic demand drivers are broadly identified internationally, but there are no data-based efforts made to understand the factors responsible for energy demand in Punjab. It is an unexplored area and requires detailed exploration to ascertain these factors.

In the next section, we will see what efforts are made to assess potential energy generation from domestic buildings.

2.11 Timings of energy demands

The approaches used or literature found to answer a similar question are:

- Data collection by smart meters and smart metering analysis to estimate the exact time of peak energy demand has been adopted by many researchers to understand the peak demand and timings of domestic demand [175].

- Non-technical losses (theft, fraud, non-payment) have been detected [175] using consumer's energy consumption data. They were applying linear Regression analysis of residential, commercial, agricultural and industrial consumers by analysing monthly interval data (kWh) using smart meters.
- The hybrid AMI (Advanced Metering Infrastructure) system model is suggested by [176], for the cities of Lahore and Karachi, using smart meters. The model is based on two methods of data communication from the smart meter to the meter data management system (MDMS). One model using Radiofrequency (RF), gateway and data concentrator (DC), and other without a gateway. Communicating data directly to the MDMS using GSM/GPRS (global system for mobile communication/general packet radio service) and suggested the former is better if the load is less than 5kW and latter for the load more than 5kW.
- The electric power demand-side management is studied by [177] , using an AMI based smart grid system, having an energy meter, GSM. In this research paper, they have developed SMS (Short Message Service) caster and graphical user interface. It helps in the management of energy load, as if the load increases above the allowed limit, the message is sent to the user, to take action to bring it within the allocated limit for a particular property. Power stations can also cut down the power supply to any user exceeding the threshold.
- The use of smart meters for the industrial sector of Pakistan is discussed by [178], noticing the potential of conservation of energy by adopting smart grid technology. The research pointed out the areas of improvement and energy efficiency within industries, suggested ways of achieving it using a smart meter. Comprehensive monitoring, management, and billing system are introduced [179] in Pakistan. The application of AMR (Automated meter reading) is made in some house projects, and e-billing and e-management are seen using machine-to-machine (M2M) connectivity by developing a smart meter system. Design and implementation of low-cost electronic prepaid energy meters are done by [180] and found it is useful in the Pakistani context as there are many corruptions in meter reading and billing method.

  Hourly or half-hourly electricity usage profiles are not discussed so far by any researcher for the domestic sector of Punjab.

For the timings of the domestic energy demand, there is much information on the annual energy demand; there is some information on the seasonal energy demand (energy supplies companies up-dates). Still, if we are to move to renewable or low carbon impact, the timing of energy demand is vital to know because we need to know how can renewable systems proposed to meet this demand or do we need to have storage facility? These are essential questions to be answered as the energy demand met by non-renewable like oil and gas; the energy is considered available all the time. Still, when we investigate renewable systems (like solar PV and solar thermal), we need to look for the timing of the energy demand, and battery or storage technologies are not taken out. As they are intermittent, intermittent resources do not guarantee that they would always be there when we need it if we do not store the electricity. So, knowing the timing of demand is very important (monthly requirements or demands within a day, daily profiles).

In the move towards low carbon and resilient economy, what we know is that renewables are intermittent they are not dispatchable resources, they are not predictable resources in the way non-renewables (coal, oil, gas) are because we can predict their availability. We can rely on them being available when we want them. If we are going to rely on a higher percentage of intermittent resources in the grid then the timing of the demand against this intermittency is important, because this would dictate how much storage we need to put in. It will dictate how much traditional generation we need to have. It is also important because if we generate 1kW of solar energy and use it straight away, there are very little losses. Whereas if we generate 1kW of solar energy and store it in the battery, there are losses in putting it in the battery, and then retrieving it back, we may lose 20-40% of the energy in the cycle, in the transformation of its form and change. All these make a case why we need to know when the demand occurs.

When we want to move towards a low carbon economy, there is a difference between this and conventional resources of energy. The difference is that the resources are not predictable, and are intermittent, would need to have some storage. They would be more efficient if they are used at the time of generation rather than stored, a series of things that would change or would have changed, and therefore what this might mean for this thesis. This means it is not the annual use that might be the only driver anymore; it is also important to look for seasonal and time of the day use. Hence the profiles of energy use. Now we will look at the low carbon technologies like Solar PV and would see if the energy generation timings are same to energy demand timings. So, we need to know what the demand profiles are. What are solar generation profiles and to high light the need for storage if generation is more than demands? So, one of the things would seem to be coming in from then is the idea of hybrid-grid. So, we need to have micro-grid locally or in the neighbourhood. The micro-grid requires, is the people operating the national grid, i.e., the countrywide operators are also to dispatch or store energy in the tiny little batteries that each of us have got in our house, and each house can act as a generator. So, we know by now it is not only the scale of demand but also the timing and drivers of the demand, which is important. So, we can now address these as part of a move towards the resilient system, that means we need to know what is causing demand within dwellings.

We need to know and look to see how they can be made more efficient; we need to know timings of this demand on a monthly basis or even day to day basis. We can see when the peaks that occur in each month are and can we overlay on that the production of power from photovoltaics. Furthermore, we can say in the colder months there is minimal power demand/production from PV, and when the demand is great, when heating is on, what is it might need the future grid. In terms of how the domestic sector is contributing, we may look into seasonal storage. How much energy generation over the whole year to meet this demand in winter, but we may need batteries that would store for the entire year. Alternatively, we may look to use the energy in some way that it can be used in more demand period and make it available when it is required. There is no literature available to identify the demand profiles on a daily and hourly basis; this thesis will come up with the answer to these concerns.

2.12 Domestic sector energy generation potential

We have seen in literature that the domestic sector of Pakistan is consuming 48 % (Figure 2.17) of energy, and almost 60% () of this energy is coming from non-renewable sources. It would be helpful to know how much of this energy demand of domestic buildings can be produced from the rooftops of domestic buildings themselves.

This section explores what is already known about this possibility. Broadly, we will explore the potential for the established renewable technologies of solar photovoltaic (PV), solar thermal and wind turbines to generate energy from the domestic situation.

Note: We are not looking at grid level systems; we are only looking at an individual property level.

2.12.1 Domestic solar PV

2.12.1.1 International efforts on solar energy exploitation

Potential: A study conducted in Andalusia, **Spain** showed that 82.3% of the city is suitable for solar PV, out of the 12.3GW of energy consumption by the residential sector, 9.73GW can be met with solar PV, thus fulfilling 78.9% of total energy demand from a rooftop of 265.5km2 with average irradiation of 4.5 kWh/m^2 [181]. It is estimated that 75Wp solar modules in **Dhaka** can produce 1GW power from an area of 10.5 km^2 [182] and the residential rooftop is found suitable to cater 40% annual energy demand in Jiangsu, China [183] [184]. The peak rooftop PV system capacity is estimated to be 5.97GW, and annual potential of energy output is predicted as 5981GWh in **Hong Kong.** It is found energy yield ratio (EYR) between 10.0-15.8, which indicates that rooftop PV is ten times more energy generating during the system life's time [185].

In a larger-scale study to calculate the solar potential over the rooftop, five stepped procedure was adapted. It included the geographical division of the region, sampling using the feature analyst extraction software, extrapolation using roof area-population relationship, reduction for shading, other uses and orientation, and conversion to power and energy outputs. The results showed that it could produce 5.74GW or 157% of peak demand of **Ontario**'s and 30% of Ontario's energy demand can be met by province-wide rooftop PV deployment [186]. In another attempt in the **Slovak Republic**, an assessment of rooftop potential in urban context ensured to achieve 66% electricity demand [187].

Economy: Interestingly, the solar home system (SHS) used in a pilot project for six villages in **Bangladesh** was found more economical (20-30%) than conventional fuel (kerosene oil, batteries). When it is not only used for lighting but also small income generation [188]. Comparison based on the economic viability of stand-alone Solar PV and diesel operated system is checked and found that for the 15kWh load, PV is a much cheaper option for daily usage [189]. The payback period of a large scale solar PV, integrated with the main grid in **Spain** is calculated as 16 years [190]. Still, the economic viability of the domestic building-integrated PV is dependent on the capital cost, efficiency of the system and electricity tariff is found in UAE [191].

Technology: Building-integrated PV (BIPV), as checked-in **Hong Kong** showed that the panel orientation and location on the building are essential for the sustainability of this technology based on the power produced from the 22kW PV system [192]. The concept of the solar city is assessed in Seoul, **South Korea**, and it was found that 30% of the city's annual electricity can be supplied by rooftop PV. Based on their technical potential 66% of yearly daylight electricity need of the city can be met by solar PV [193].In **Greece**, a study conducted to estimate the suitable area available on the rooftop (Statistical calculation model) for the installation of PV, in the city of Thessaloniki, of typical multi-storey multi-family buildings. The results showed that the solar utilization roof factor is only 25-50% in most of the buildings [194]. Further, PV site suitability was checked in **Oman**, found that if solar PV is installed in suitable sites, it can produce 45.5% times the current total power demand of Oman [195]. The stand-alone solar system was checked in **Egypt** and was considered suitable for remote residential projects [196].

Moreover, Stand-alone renewable energy supply from solar and wind was tested for fifty rural houses in **Iran**. It was found that because of the suddenly decreasing wind speed, it was needed that more wind turbine may be attached to the system. However, found that this combination of wind and solar is recommended for the socio-technical feasibility [197]. It is seen that a hybrid system can count for the weakness of one source be fulfilled by other [198].

2.12.1.2 National efforts on solar energy exploitation

A reasonable amount of effort has been made by different researchers to find out the prospects of solar energy exploitation in Pakistan and Punjab. All these efforts can be categorised broadly into four main areas:

(i) Solar Irradiance
(ii) Sunshine hours available
(iii) Solar power generation capacity
(iv) Different methodologies used for Solar energy calculation

2.12.1.3 Solar Irradiance in Pakistan/Punjab

The mean global irradiation falling on the horizontal surface is calculated in the range of 0.2-0.25 kWh/m^2/day and 5-7 kWh/m^2/day [199] whereas, EIA describes that Pakistan has a solar irradiance potential of 5.3 kWh/m^2/day. The maximum solar energy received on earth's surface is from 6-8 kWh/m^2/day, i.e., 1.5–2 MWh/m^2/year close to the equator. In Pakistan, it is 5-7 kWh/m^2/day, and the persistent factor is about 85% [200] ,and it is estimated as 1.9-2.2 MWh/m^2/year [201]. Based on the data collected for thirty years (1971-2000) taken from 58 stations shows that more than 70% of the country area receives global solar radiation average of 5-5.5 kWh/m^2/day [22]. As estimated by the World Bank's Energy Sector Management Assistance Program (ESMAP), it is claimed [202] that Pakistan's location and climate have a high potential for solar energy. The results were based on nine sites (three were in Punjab), and data collected by satellite (met-7) and on-site measurements to ensure the accuracy of data and estimated both global horizontal irradiation (GHI) and direct normal irradiation (DNI) as 2 MWh/m^2/year.

Many researchers measured the solar insolation data of Pakistan, and comparative assessment is done [203]. It states that data of Pakistan Meteorological Department (PMD) and World Radiation Data Centre (WRDC) have a close match and given as 5.30 kWh/m^2/day (19.0MJ/m^2 or 221W/m^2), annual mean daily global horizontal insolation. At the same time, National Renewable Energy Laboratory, USA (NREL) and the Energy Sector Management Assistance Program (ESMAP) of the World Bank in 2015 overestimates solar insolation by 25% in some regions. As per ESMAP, annual mean global horizontal insolation is estimated as 5.67 kWh/m^2/day. So, we conclude that Pakistan has average horizontal insolation 5kWh/m^2/day.

Punjab: Solar radiations in major cities of Punjab are identified between 4.5-5.5 kWh/m^2/day annually. (Ali, Khan et al. 2017). Lahore, the capital of Punjab, is considered to have monthly average solar radiation of 2.8 – 6.3 kWh/m2 [75]. District Multan and Dera Ghazi Khan of Punjab are identified as best sites for the generation of solar energy [204].

2.12.1.4 Sunshine Hours in Pakistan/Punjab

Pakistan is considered to have annual mean sunshine of 7.6-10 hrs [205] throughout the country, 300 days of the sun [206] and 2500 hours/year [207].

Punjab: Daily sunshine hours available in Lahore [208] are estimated at around 6-8 hours in the summer. Sunshine hours are estimated between 1500-3000 in Punjab and considered suitable for the 1GW solar power project in Bahawalpur [209]. Some researchers have looked for the potential of solar energy in Pakistan using Automatic Picture Transmission (APT) satellite images at Space & Upper Atmosphere Research Commission (SUPARCO's) Karachi. It was found that Pakistan is highly sunny, more than half of the areas have ready availability of sun. Lahore, Bahawalpur, Jhang, R.Y.Khan and Multan (cities of Punjab) are identified as having 235, 287, 293, 281 & 277 sunny days around the year, and **October** is identified as the sunniest month while February as most cloudy [210].

2.12.1.5 Solar Power Generation Capacity in Pakistan/Punjab

The total solar potential of Pakistan is estimated approximately to 2900GW [23] [24] [25] [26] [27], and it is estimated that 3000 km^2 land would be sufficient to meet the entire current energy demand of the country by solar PV. By 2050, 85% of forecasted electricity demand, 587,000GWh, could be met by renewable energy potentials of Pakistan, out of which 25-30% can be met by solar PV. By using CPRESS [28] [61], it is argued that the solar generation system is considered expensive from a capital cost. However, if the fixed and running cost are compared to large scale generation projects, it would be efficient, and identifies renewable energy source potential as 167.7 or 169GW in Pakistan [211]. A relationship of **13m^2**/capita of the roof area in Karachi is expected reasonably to meet the electrical energy demand/capita, and with higher efficiency rooftop panels [212]. In another research carried out at NUST (National University of Sciences & Technology -Islamabad) 1.65MWh/m^2/year was estimated from the rooftop [213].

Punjab: Khalil [214] has used 1 kW of solar panel in different cities of Pakistan, using MAT lab, HOMER and RET screen wherein Lahore, Faisalabad and Sialkot (Punjab's cities) were considered suitable for solar PV, and produced between 0.15 and 0.22kWh/m^2/day in Punjab. Off-grid electrification of a single house was tested with PV in Faisalabad Punjab, peak power produced was 1.9kW from an area of 12.82m^2 and total cost estimated was Rs:457k-£3385 OR Rs:14.8/kWh(7.8pence).It was found that this cost was lower than the cost conventionally charged to the domestic consumers [215]. Solar potential is calculated from the rooftop in one of the housing societies in Lahore using GIS and claimed that it could produce 11% more energy than the demand of that society [216]. The period between March-October is found suitable for solar PV and claimed that from an area of 100m^2 45-83MWh/month energy could be generated [217].

Moreover, it is suggested that Pakistan should reduce its carbon emission by adopting greener energy. It can also earn CERs (Certified Emission Reductions), which is a tradeable commodity as defined by the Kyoto Protocol and UNFCCC. It can bring capital flows in the country [29], and estimated carbon emission reductions as 0.606 TCO_2/MWh from wind and solar projects and 0.505 TCO_2/MWh from hydro in Pakistan. Domestic sector energy demand is tested by solar PV, using RET screen software, and recommended that if 5kW solar PV is installed, it will reduce 0.6-0.7T CO_2, in different regions of Pakistan [30].

2.12.1.6 Concluding remarks on domestic solar PV

The facts related to solar generation potential, economy, and technology, found in the literature are very promising and ensuring the vast suitability of domestic Solar PV as an alternate source to generate green energy (2.12.1.1). It is claimed to meet 78.9% (Andalusia-Spain), 40% (Jiangsu-China), and 30% (Ontario) and 66% (Slovak republic) of the energy demand of these areas from the solar PV alone and estimated as more economical than conventional fuels.

Pakistan with mean annual sunshine of 7.6-10 hours/day, 300days/year and 2500 hours/year is estimated that average of 5-5.5kWh/m^2/day and 2MWh/m^2/year (1.9-2.2 MWh/m^2/year) can be produced from solar PV (based on 30 years of data from 58 stations) (2.12.1.2). Overall, Pakistan has the potential of 2900GW as claimed by researchers, which shows the huge prospect of solar energy. Further, from the domestic rooftop areas, it is estimated that 13m^2/capita of an area is enough to meet electrical energy demand in Karachi and 1.65MWh/m^2/year can be generated in Islamabad.

Similarly, Punjab is calculated to have solar irradiance potential between 4.5-6.3 kWh/m^2/day, 6-8hours/day and 1500-3000 hours/year. The period from March-October is identified as a most suitable time for solar PV and from $1kW_{peak}$ solar panel 0.15-0.22kWh or 1.5kWh/m^2/day (with 7 hours sunshine) of energy can be generated and found cheaper than the conventional source (7.8pence or RS:14.8/unit)

The literature review shows that a detailed estimation of solar potential on the roof-top of the domestic sector is not done in any city of Punjab. It is a gap in literature/research to look for the full potential of the domestic sector. So, it is required to investigate in detail the percentage of electricity needed that can be generated from the domestic sector by using solar panels. It should be related to the actual rooftop area available for each house size range in Punjab and evaluating the actual consumption of that house per household and capita.

2.12.2 Domestic solar thermal

2.12.2.1 International efforts on domestic solar thermal

Around the world, 15-25% of energy is going to water heating in the domestic sector [218] Solar thermal with seasonal storage option is calculated to meet overall heating loads without a backup heating system [219]. It is estimated that by combined photovoltaic and thermal roof mounted domestic system can take up to 47.8% and 25% of heating and cooling loads in **Athens** [220].

A huge potential of energy saving and reduction in CO_2 emission was detected in a case study related to **Tunisia** according to typical Tunisian households occupied by 4-5 persons. The results showed that the two types of the flat-plate collector (FPC) and evacuated tube collector (ETC) provided about 8118 and 12032 kWh/year of thermal energy, respectively. The economic potential of Domestic Solar Water Heating (DSWHs) in saving electricity and reducing carbon dioxide emissions showed that the annual savings in electrical energy relatively to the FPC, ETC are about 1316 and 1459 kWh/year, with a payback period of around 8 and 10 years respectively. From an environmental point of view, the annual GHG emission per house is reduced by 27800 TCO_2 [221].

The findings unveiled in one study indicated that Solar water heating has the potential of producing 10.2TWh of thermal energy annually in **Taiwan**, accounting for 127.5% of the total domestic consumption of energy for household water heating in 2009 [222].

Solar hot water (SHW) is an emerging technology in the **UK** with an annual average installation of 4000 units [223] typically taking an area of 2-5m^2 and provides for 90% of summer hot water demand [224]. In one comparative study where the performance of SHW along with other conventional systems like a gas boiler, oil boiler, and electrical immersion heater was investigated. It was found that SHW would break even its embodied energy ‘debt’ in 0.7-2.4 years and will pay back its embodied carbon in 2 years. These results show that the SHW system will provide the carbon benefit for the rest of its estimated lifespan of 25 years. The SHW system can, therefore, improve energy security and decrease carbon emissions by providing a net reduction in the use of conventional energy resources (mainly fossil fuels) [225] [226].

In a controlled study carried out in dwelling in **Canada** using two solar collectors (family of two adults and two kids, average usage of 246l/daily) showed that it could take up to **30.6%** of total DHW heating load of the whole year [227]. In another beneficial study carried out in **France** (2014), where Photovoltaic-thermal (PVT) hybrid collectors were used to convert solar energy into both electricity and heat. The results showed that for a small available roof for solar collector area, the use of efficient PVT collectors in the building envelop can be more gainful than standard PV and solar thermal [228].

SWHS has demonstrated its worth in many developed countries, for example, utilization of SWHS in the **US** has roughly saved 1/4 per year in primary energy sources being used for water heating and about 50-75 million metric tons of reduction potential in CO^2 emissions [229]. The techno-economic analysis of a hybrid solar heating system (for bathing) was done in Shiraz, **Iran** claimed that the optimum ratio between storage tank volume and collator area to achieve 90% solar fraction [230].

Moreover, it was investigated in Seeb District, **Oman** that solar water heaters have energy-saving potential of 335GWh/year from the whole District, with a payback of 7-9 years [231]. Further, it is estimated that if the life cycle cost and winter benefits of solar collectors are taken in to account the payback period of the technology would be only 1.5 years [232]. The field study carried in **Ireland**, representative of a maritime north European climate, the ‘energy payback’ based on the expected energy savings is between 1.2 and 3.5 years by using domestic solar water heating [233].

2.12.2.2 National efforts on domestic solar thermal

Domestic Solar Water Heating (DSWH) is a well-proven technology used to reduce the energy demand for providing domestic hot water, and its potential to largely reduce domestic energy use is frequently acknowledged [234] [235] [229]. Solar thermal technology is currently being used in Pakistan with an annual growth rate of 245%, which is very promising. AEDB (alternate energy development board) of Pakistan has started the awareness campaign in the country, and currently, 55 external and 25 local companies are making solar geysers. It was foreseen that 24k units would be installed in the country by 2020 [236] [237] [238].

It has been reported that nearly 10% of the total primary energy in Pakistan is consumed in water heating and if adopted Solar water heating, under Pakistan’s climatic condition can have a payback period of fewer than three years [239] [240]. The study conducted in Pakistan to calculate the economic performance of roof-integrated solar collector confirmed that it is more cost-efficient than gas and electric water heaters. Further, it was found that the orientation of solar collectors at 15 degrees is most suitable. Another promising benefit claimed in this research was that solar collector could also be used for summer cooling as it can provide up to 50% of the heat required for the desiccant cooling system [241].

Based on the annual cost, annual monetary benefits and payback period, the financial evaluation of SWHS was carried out in the residential sector of Islamabad, Pakistan and found that it is 50% more efficient than conventional electric and gas heaters. Further, it was assured to save £391 and £61.5 of energy cost per annum per household, respectively for each fuel type. Depending on the initial installation cost of SWHS, the payback period found was varied from 1.16 to 1.38 years for electric power and 6.95-8.27 years for natural gas-powered conventional water heating systems. Further, it was assessed that it could save 14.21 MMBtu of natural gas and electric power of 4163.98 kWh annually, which in turn reduces the emission of 2206.9 $kgCO_2$ per year [242].

2.12.2.3 Concluding remarks on domestic solar thermal

Solar thermal technology is widely accepted and being used globally as an alternative to domestic energy for heating. It is proved to be economical than conventional gas and electric domestic heating system, in terms of lifespan performance, and payback time is calculated between 0.7-3.5years in a different part of the world. The energy-saving potentials shown in literature makes this technology a viable solution for domestic heating (2.12.2.1)

Pakistan is also one of the beneficiaries of solar thermal water heating. Attempts made to calculate its financial and environmental benefits assured promising results (2.12.2.2) and found it is 50% more efficient than conventional electric and gas heaters.

The literature review shows that a detailed estimation of solar thermal potential on the roof-top of the domestic sector is not done in any city of Punjab. It is a gap in literature/research to look for the full potential of the domestic sector. So, it is required to investigate in detail the percentage of heating needed energy that can be generated from the domestic sector by using solar thermals, incorporating the actual rooftop area available of each house size range in Punjab, evaluating actual consumption per household and capita.

2.12.3 Domestic wind turbines

2.12.3.1 International efforts on domestic wind energy

A methodology is proposed for estimating the energy yield of a building-mounted turbine from simple information such as wind atlas, wind speed, and building density. The energy yield of a small turbine on a hypothetical house in west London, **UK** is estimated. The energy yield is shown to be very low and suggested that the economic viability of domestic wind turbines in a built-up urban environment needs to be carefully considered [243]. In another study conducted on the house mounted domestic wind turbine showed that the annual energy yield of a 1.5 kW turbine was found to be 277 kWh and 2541 kWh from the two sites investigated. For the high yield site, the simple economic payback of this turbine was found to be 26.8 years, i.e. beyond the likely lifetime of the turbine. The research advises that this technology does represent a possible route for reducing CO^2 emissions, but this is unlikely to be understood unless a satisfactory method is established for more accurately forecasting energy yield at a specific site. A serious issue exists concerning the ability to estimate their energy yields reliably. No robust method exists for determining urban wind speeds. Current methods are solely inappropriate [244] Further, the potential of micro-wind turbines to contribute towards the **UK**'s climate change target is found limited [245].

The effect of the local suburban topology on the wind speed and turbulence intensity fields in a given locality are, therefore, an important determinant of the optimal location of micro-wind turbines. It is found in **Australia** that turbines mounted on flat roofs are likely to yield higher and more consistent power for the same turbine hub elevation than the other roof profiles [246], and in an urban context, the wind speed up at the ridge level is only evident in the single isolated buildings. Further, the multiplicity of factors (related to urban terrain) makes it difficult to generalise a wind resource estimation methodology for the urban environment [247]. It is argued, based on **Australian** data, with currently available domestic scale wind turbines, difficult to generate any appreciable power. Due to the unavailability of reliable local wind data and in general, the payback period of a domestic scale wind turbine is longer. Further, the power generation capacity is limited as it is related to the turbine diameter and available wind regime in the domestic area [248].

In another research conducted in **New Zealand** indicated that the electricity-generating potential of centralised wind farms using large turbines could be as high as 11 times the generating potential of roof-top turbines mounted on urban houses. Roof-top turbines are, therefore, not as efficient as large-scale wind turbines [249].

China possesses more than half of the world wind turbines and produces 18.9GW from domestic scale wind turbines (300K in number) [250]. Small scale wind turbines of 200W, 300W, and 500W capacity are being used in China (Off-grid wind power) as household energy for farmers, herders and fishers [251].

Reports on domestic scale wind turbines available in the open literature suggested that many domestic scale wind turbines do not perform well. Most of such turbines are being developed by wind energy enthusiasts and small companies who generally do not have adequate technological and financial resources to refine their initial designs to perform better by increasing efficiency [252].

2.12.3.2 National efforts on domestic wind energy

According to the report of the National Renewable Energy Laboratory (NREL) of the United States Pakistan has a tremendous amount of wind energy potential around 346GW for power generation. In the year 2002, 14 small wind turbines, six of 500W each and eight of 300W each, were procured from China and installed by Pakistan Council of Renewable Energy Technologies (PCRET) for demonstration purposes. Out of these, eight were installed in the coastal belts of Baluchistan and six in the Sindh. The demonstration project has been concluded successfully [253].

It has been observed that small wind turbines are both technically and economically viable for electrification of the remote communities only. PCRET is now installing 120 small wind turbines in an ongoing project. Efforts are also underway to initiate local manufacture of 500W wind turbines under transfer of technology from China, and 5–10kW turbines under transfer of technology from some European countries [73] [253].

Various news reports inform that 34 international companies from Brazil, Canada, China, Denmark, Holland, Germany, Malaysia, Spain, USA, have been issued letters of interest by the AEDB to invest in the wind power generation projects of about 50MW each aiming to produce 1925.4MW [254]. Wind power projects of total 100MW are being established on a build-own-operate and-transfer (BOOT) basis at Gharo and Keti Bundar in Sindh [255], In Punjab only 50MW wind turbine is going to install soon [256].

It is argued in the literature that solar energy is a more viable solution as a renewable energy option than the wind in Pakistan, as the cost per unit for solar and wind are calculated as 20 US cents/kWh and 77 US cents/kWh. Further, the availability of wind is good for the four months of monsoon only, for the remaining 8 months, it does not cross the economic threshold [257]. As the focus rapidly shifts towards liquefied natural gas (LNG) - based power plants, the government has declared solar and wind energy projects unfeasible because of being expensive compared to conventional electricity production projects [258]. There are no efforts made and research found on the domestic scale wind turbines installation in literature in the context of Punjab.

2.12.3.3 Concluding remarks on domestic wind energy

The research conducted in many countries like UK, Australia, New Zealand and China, showed based on energy yield, economic feasibility, more extended payback periods (even longer than the lifespan of the turbine itself) and non-reliability of urban site winds that domestic scale wind turbines are not a viable solution.

Reports on domestic scale wind turbines available in the open literature suggested that many domestic scale wind turbines do not perform well. Most of such turbines are being developed by wind energy enthusiasts and small companies who generally do not have adequate technological and financial resources to refine their initial designs to perform better by increasing efficiency. There are no national efforts found at domestic scale wind turbines.

2.13 Summary and conclusion of the literature review

We have seen that Pakistan is a rapidly progressing country, and its energy demand has increased 125% in the last 25 years. (2.2.4, Figure 2.4). Pakistan has a responsibility to share and challenges to meet in terms of greener energy production and ensuring the security of energy resources in a competitive world (2.2.7). We found sufficient data in the literature to understand the past, present and future energy demands of Pakistan. The predicted forecast of energy shows that in 2030 energy supply of Pakistan would be less than half of its demand (2.3.2,). In less than two decades, its demand would increase by approximately 400% (as of 2016). Similarly, electricity demand would increase to 181% of its current demand (*Figure 2.9*). Further, we have noted that Pakistan's per capita electrical energy consumption is far less than advanced and neighbouring countries, which could be the future potential of demand increase for Pakistan Figure 2.11.

We found that oil, gas, coal, electricity and biofuels & wastes are the significant resources of energy in Pakistan. These current energy supply resources of Pakistan are mostly non-renewable (Figure 2.12 & Figure 2.13), and their demand has clear growth trends (2.4.1). Not only the past and present sources of energy are non-renewable but also the government's plans of energy supply shows (2.4.2, Figure 2.14) that still there would be a vast dependency on non- renewable resources, and the problem will sustain. It would be improbable to fulfil the aims and objectives set-up in this thesis. Industry, transport, domestic, commercial and agriculture sectors are the primary consumers of the available energy of Pakistan. We found that the domestic sector is one of the larger consumers of renewable (Figure 2.17) and non-renewable sources of energy in Pakistan (Figure 2.18), approximately one-fourth of Pakistan's energy is going to the domestic sector (mainly electricity & gas).

Pakistan should look for a dynamic interacting system which has low vulnerability (to vital energy resources), highly adaptive and innovative capacities—addressing to disruptions (especially resource scarcity and climate change concerns), ensuring capacity building of user's (or user's focussed processes) and all stakeholders, capturing intermittent energies. These measures will bring it close to a low carbon resilient energy pathway as adopted by the UK and EU. A transition to a low carbon pathway for Pakistan's future energy supply system looks to adopt renewable resources and incorporates intermittent energy resources on the principles of **'capture/harvest-when-available'** and **'store-till-required'**. They are ensuring high end-use efficiency and attitude of energy-saving as predicted in Figure 2.25.

It is also found that the domestic sector of Punjab is one of the significant consumers of electricity and gas energies (Figure 2.31, 2.8.2.2). The future domestic demand increase factors (2.9) indicate huge demand increase by the domestic sector of Punjab. International, domestic demand drivers, are broadly understood, what is not known is where the demand is going in the domestic sector of Pakistan? What drives the demand in the domestic sector of Punjab? What are the predictions of this domestic energy demand based on some evidence? So, the work which is now needed to be done would be to understand what individual drivers are, so we can look to see how energy conservation might seem to work with energy demands. We need to develop some mechanism of energy demand prediction of the domestic sector of Punjab.

We found no literature on the daily and hourly demand profiles of the domestic sector. The facts related to solar generation potential, economy, and technology, found in the literature are very promising and ensuring the huge suitability of domestic Solar PV as an alternate source to generate clean energy (2.12.1.1). In Punjab, the period from March-October is identified as the most suitable time for solar PV (2.12.1.2). The literature review shows that a detailed estimation of solar potential on the roof-top of the domestic sector is not done in any city of Punjab. There is a gap in literature/research to look for the full potential of the domestic sector at the city or provincial level. So, it is required to investigate in detail

- ***What percentage of required electricity can be locally generated from domestic rooftops by solar PV by incorporating actual roof area available per house size?***

Solar thermal technology is widely accepted and being used globally as an alternative to domestic energy for heating. It is proved to be more economical than conventional gas and electric domestic heating systems, in terms of lifespan performance, and payback time is calculated between 0.7-3.5years in a different part of the world. The energy-saving potentials shown in literature make this technology a viable solution for domestic heating (2.12.2.1). The total potential of energy-saving and generation from the domestic scale rooftop still needs to be explored, and future research is required, and we need to know,

- ***What percentage of required heating energy for domestic hot water & space heating, can be generated from the domestic sector by using solar thermals, incorporating the actual rooftop area available of each house size range in Punjab, evaluating actual consumption of that house as per household and per capita needs?***

The research into the generation of domestic scale wind turbines and based on the feedback within the domestic sector shows it does not work efficiently in terms of energy yield and payback period (up to 26 years). So clearly, we found that they have not been successful in most of the world; therefore, they have not been considered further (2.12.3). The overall summary of the literature review is mentioned in Table 2.8 below

Table 2.8 Summary of literature review

Aims and Objectives	What is already known?	Findings	What is not known or missing?	Remarks
Pakistan's energy demand (past, present and future)	Government figures and academic publications available	Current -Mtoe: 81.63(2016) Future-Mtoe: 361.3(2030)	On what bases demands are forecasted?	Demands are related to economic and GDP growth
Pakistan's energy supply (past, present and future)	Government figures and academic publications available	Current (2016): Elect. (9.9%-8.08MToe) Biofuel & waste (40.1%32.81MToe) Gas-(21.17-17.28MToe) Coal-(6.26%-5.1MToe) Oil-(22.48%-18.35MToe) Renewable-0.1% Future (2025): Oil-20%, Gas-35%, Coal-10%, LPG-2%, Nuclear-8%, Renewable-10%	-	Future supply given as per government plans
Pakistan's energy Consumption (past, present and future)	Government figures and academic publications available	Transport, industry, domestic, commercial and govt. sectors are the main consumers		Domestic sector identified as the main consumer of energy
Transition towards low carbon and resilient system	Sufficient literature is available at the international level	Achieved by: - reducing energy imports/dependency -diversity of energy supply -increased energy efficiencies -sufficient storage capacity -renewable energy resources approach	Not much literature found at the national level	Pakistan needs to adopt renewable resources and hybrid-grid system
Punjab's Domestic sector Energy demand Current and future	Literature is available	Domestic sector Consumes: Electricity: 85.6% (of Punjab electricity supply) Gas: 40% (of Punjab gas supply)	Indicators of future demand are identified	Anticipated future demand of the domestic sector is very high
-Punjab's Domestic sector demand drivers, -average demand and timing of demand -prediction of domestic energy demand	**No literature is available**	- energy supply companies estimate annual and seasonal demands	-Individual domestic demand drivers and average demand are missing -timing of demand drivers of monthly or daily profiles are missing -no prediction models are available	**Research is required to calculate demand drivers, average demand, the schedule of demand profiles and prediction models of this demand**
Punjab's Domestic sector energy generation potential	**Limited Literature is available**	-solar PV (1 kW_{peak}) produces 0.15-.022KWh or 1.5/m^2/day -Solar thermal results are promising	Large scale domestic rooftop estimation is missing for both technologies, based on actual rooftop area availability, occupancy level and real energy needed	**Research is required to calculate domestic rooftop potential of available measured areas on large scale**

There is no meaningful information available on the evidence-based domestic demand drivers, prediction models for this demand, timings of this demand and how much of this domestic demand we can generate from the domestic rooftops. Using the actual areas available from the different range of house sizes in Punjab, linked with their occupancy level and energy requirement per m^2 by all these houses sizes, in much detail for the whole Punjab.

Chapter 3

Research Methodology

3 Research Methodology

3.1 Introduction:

This thesis aims to understand what impact the domestic sector in Pakistan has on its energy demand, and therefore, what role in a move towards a low carbon energy supply, the domestic sector might play in enabling Pakistan's transition to a low carbon economy. From the literature review, the domestic sector is found to be one of the largest consumers of renewable (Figure 2.17) and non-renewable sources of energy in Pakistan (Figure 2.18). It consumed 48% of the total energy use of Pakistan in the year 2016 when bio-fuel was included as a source of energy and 24.5% of total energy, without biofuel. When we looked at it by fuel type, as a percentage of aggregate Pakistan's energy use, the domestic sector consumes 48% of all electricity, 33% of all gas and 89% of all biofuels. It makes the domestic sector as the largest consumer of energy in Pakistan. Transitioning the domestic sector to zero carbon will, therefore, have a significant impact on Pakistan's overall carbon emissions.

Following the literature review, research now needs to be undertaken to understand the demand drivers, demand predictions and timings of the domestic energy consumption in Pakistan, particularly in Punjab, which is the study area for this thesis. Related research will provide insights into the potential approaches required to reduce this demand and mitigate the future needs, as a part of the move towards a zero-carbon or clean positive energy domestic sector. The research also needed to examine the potential for the generation of renewable energy from the domestic sector rooftops. From the literature review and in-depth understanding of current and future domestic energy demand scenarios, we found the following gaps in the current body of knowledge. We set as the objectives for this thesis, given as,

- To derive the domestic energy demand drivers for Punjab Pakistan
- To produce energy demand prediction models per household and capita
- To derive the timings of Punjab domestic energy demand by day, month and year
- To estimate of the potential for renewable energy generation from the domestic sector

3.2 Research methodology and research process of thesis

Having set up the research questions that we want to answer, the next issue would be what the appropriate methodology is to be used to answer these questions. Our research questions and objectives require quantification on the whole. Therefore, the choice of research methodology to undertake this research will be limited to those who fit into positivistic epistemology and objectivistic ontology frameworks. It has been adopted throughout in the form of a quantifiable survey of occupants and quantification of rooftop area available from the domestic buildings.

The research process chosen for this thesis is shown in Figure 3.1 below. The research methodology diagram [259] shown in Figure 3.1, highlights where the methodology used in this thesis fits. It follows the route of positivism, objectivism, deduction, survey, mono-method, cross-sectional and time horizon in the research process, shown in Figure 3.1

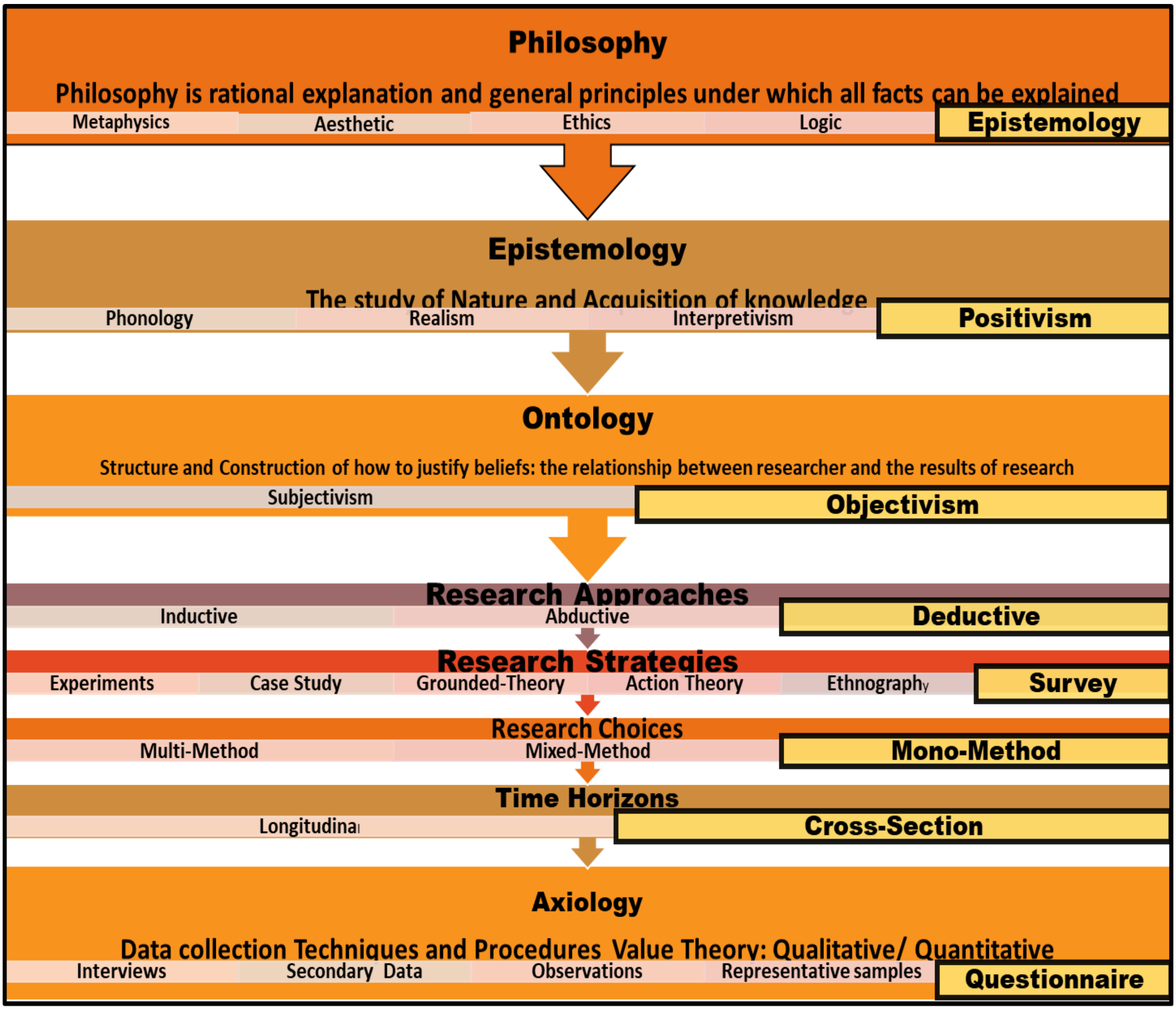


Figure 3.1 Research methodology and the research process of the thesis, source: [259] developed by author

In the next section, we will see how the other researchers have tried and adopted different methodologies to answer the research questions set in this thesis (given above) and what appropriate methodology would be adopted for this thesis.

3.3 Possible research methodologies

In this section, we will discuss the methodologies used by different researchers in different parts of the world. Broadly, the methodologies to answer objectives 1 and 2 of this thesis, are similar in nature and mostly depend on similar dataset. Therefore, they are discussed under one single heading. These methodologies are presented under the titles of the research objectives of this thesis and are given as,

3.3.1 Research objectives 1 & 2 (demand drivers & prediction models)

- Derive the domestic energy demand drivers for Punjab Pakistan
- Produce energy demand prediction models per household and capita

To determine what approaches could be used to answer these questions, summarised methods that researchers had used in similar studies are shown below. Related studies at the national level for Pakistan could not be found, but related studies at the international level do exist. To develop the methodologies of this research, other researcher's examples of data collection methods and techniques used to determine the demand drivers and to develop prediction models in their studies are discussed.

To answer research objectives (1 & 2), the number of studies have been discussed in the literature review (sources: given under different methods). This section classifies these studies into the methodological approaches that were undertaken. Having gone through these approaches, the methods widely used across the world in doing similar studies are the following.

3.3.2 Data collection methods used for demand drivers & prediction models

3.3.2.1 Energy consumption data collection

In this method, the energy consumption data is obtained either from the energy suppliers or from the energy bills of the consumers. In this method most of the meta-data is missing, where we sometimes cannot relate the consumption data with the consumer's details {India [260], UK [261], USA [262]}

3.3.2.2 Physical monitoring

In this method the data is monitored on regular bases of the energy consumption, and noted from the meters of the consumers {Florida USA [263], UK [264]}

3.3.2.3 Published Data Utilization/database

This method utilises the published data available in literature or present in some database or website {China [265], Portugal [168], UK [266]}

3.3.2.4 Physical Questionnaire Survey

In this method, the data is collected using physical questionnaires of the energy consumption of the respondents, along with meta-data. This method helps to better understand the different factors of energy demands. { [267], [268] (Japan), [269] (China), [270] (Ireland)}

3.3.2.5 Energy audits, phone calls, and Smart metering

In this method, the energy consumption is monitored regularly, and factors of demand increase are determined. The data collection method could utilize smart meters and phone calls to note energy demand values. The smart metering is a more advanced technique where the data can be retrieved at any time or in much more details like half-hourly profiles. { [271], [272], Canada [273]}

3.3.3 Analysis procedures used in wider research to answer objective 1 & 2

3.3.3.1 descriptive & inferential technique

Descriptive statistical techniques [274] [275] [276] describes a situation by summarizing information by highlighting and capturing the essential and most relevant aspects of the data. It will include univariate and multivariate measures. [274] [275] [276]. The analysis of dependent[1] and independent variables, (looking for their mean, mode, median, ranges, standard deviation, inter-quartile ranges) combined with a quantitative methodology are used to interpret the numerical results [274] [275] [276] [277] [278] [279] [280] [281] [282]. Using these techniques investigation of the goodness-to-fit correlation between dependent and independent variables is analysed [274] [275] [276]. An inferential statistical technique [283] [284] [285] [286] [287] [288] [289], enabling us to generalize the results to the whole population of our survey area, i.e. Punjab [290] [291] [292] [293].The inferential statistical technique aims to generalize to the whole population that has been observed from a sample [294] [295] [296]. The exploration of the causal relationship between the dependent and independent[2] variables[3]. The forecasting of the dependent variable based on the independent variables from the survey sample to the population at large, with a certain degree of error corrections.

3.3.3.2 t-tests & f-tests

To check the goodness of fit and significance ($p<0.001$) of the models and independent variables, f-test, and t-test checks were used. In all models presented in this thesis, they were significant (only presented significant models in the analysis part)

For the **f-test**, the null hypothesis is $H_0 = 0$, (all coefficients are 0), i.e., it cannot predict the dependent variable from the Mean. Zero value means the model has no explanatory power, and none of the independent variables helps to predict the dependent variable. If $Ha \neq 0$ (at least one coefficient is different from 0) then the model has explanatory power. The f-test tells us the predictive power of the complete model as a whole.

For the **t-test**, the null hypotheses are $H_0 = 0$, (all coefficients are 0), i.e. the true population value of the coefficient is equal to 0. It means independent variables do not help to predict dependent

[1] Dependent variables, these are the variables whose values depends on other factors, and being studied

[2] Independent variable, it is a variable that stands alone, and has no effect on other variables, when we are doing a measurement in any study.

[3] A variable is an object, idea, time or any other category which we are trying to measure.

variables. If $H_a \neq 0$ (at least one coefficient is different from 0) then independent variables do help to predict dependent variables. In all model cases, the null hypotheses were rejected.

The f-test and t-test are valid when the diagnostic or residual assumptions are adequately met. The f-test is used to know the significance of each model, whereas t-test used to determine the significance of each variable. [267].

3.3.3.1 Analysis of variance (ANOVA)

It is a test used to see whether there is a significant difference between the means of two groups in the statistical data [267].

3.3.3.1 P-value and correlation analysis (procedure)

P-value: In statistics, the p-value is the likelihood of getting results as extreme as the observed results of a statistical hypothesis test, assuming that the null hypothesis is correct. The lower value of p suggests that there is greater proof in favour of the alternative hypothesis.

Correlation analysis (procedure):

Pearson's Correlation coefficient (r) is used to determine the energy '***Demand Drivers'*** of the domestic sector. Correlation is the measure of association between two variables, the relationship of bivariate variables, enabled us to know the strength of the relationship between them. We are interested to know which independent variables have the highest correlation with the dependent variable (energy consumption per year-kWh). Pearson correlation test broadly used as,

- It is the measure of association between two variables
- To understand, the demand drivers of energy consumption in a typical household it was required to know the degree of relationship between the energy demand (dependent variable) and other factors like house size, occupancy level, appliances and lighting luminaries, being used (independent variables)
- The sample size was more than 100, so correlation was an acceptable analysis
- Correlation values may be between -1 to 1, (if it exists) as a rule of thumb, r = 0-0.2 shows weak association, r = 0.3-0.6 is moderate, and r = 0.7-1 is a strong relationship between the two variables.
- We could find out the factors(drivers) which produce the energy demand in a typical house by analysing to what extent each variable is associated with it.
- R-squared measures the degree to which the dependent variable(Y) is related to the independent variable, the R^2 values tells us the goodness-to-fit, in the linear regression model {Portugal [168], UK [266], [297]}

3.3.3.2 Regression (simple and Multiple)

Multiple Linear Regression analysis is adopted to develop the '**Prediction Models'** of energy consumption per household and capita, as there is more than one independent variable to predict the dependent variable.

Multiple linear regression allows for more than one predictor variable

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \varepsilon$ (1)

where, Y is the response variable, and $X_1; X_2; \ldots X_p$ are the predictor variables, p is the number of variables, $\beta_0; \beta_1; \ldots \beta_p$ are the regression coefficients, and ε is an error value to account for the discrepancy between predicted data and the observed data [298]. This errored value must be added to predict future energy demand. The predicted value-form of Eq. (1) is:

$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \cdots + \hat{\beta}_p X_p$ (2)

where, $\hat{Y}$ is the fitted or predicted value and $\hat{\beta}$ are estimates of the regression coefficients [298].

In this analysis, the dependent variable (outcome) is the annual energy consumption (kWh/year), and the Independent variables are the predictor variables. (discussed in detail in chapter 5)

The regression equations developed to enable us to calculate potential changes in the dependent variable from changes to the independent variables, helped us to estimate the energy demand.

Broadly Regression is,

- In correlation, the variables are not taken as dependent and independent, in regression we do
- The dependent variable is the outcome variable, and this is what we want to predict.
- The Independent variable is the predictor variable; this we use to predict the other variables' values if independent variable values are known.
- Regression goes beyond correlation because it has prediction capabilities.
- In our data set energy demand (kWh/year) in the dependent variable, while other factors like size of the house, occupancy level, type, number and usage of appliances, are the independent variables
- The regression equation developed from coefficients of dependent and independent variables enables us to predict the dependent variable (energy demand) for the larger set of the population (parametric estimates)
- This equation calculates the future energy demand forecast
- The results of the regression models would be applied to the population at large

The researchers who have used this technique have applied it in the following countries: The Netherland [299], USA [262]. [271] [272], China [300], USA [301] [302], Ireland [303], Italy [304], New Zealand [305], Turkey [306], Iran [307], Jordan [137], Palestine [308], UK [138] [309], China [310], [260].

Now we need to see which one of these techniques might be best applied in the Pakistan situation. When we look into the Punjab, Pakistan, the unique characteristics where the author might have access to. One of the advantages of conducting a survey in Pakistan is culturally the following exists:

- People are used to answering questions when asked by some surveyor at their doorsteps

- People are used to being clear about and engaging properly in consultations, which may not exist in all cultures around the world.

  This meant that the author was aware of the fact, being a part of the academic sector (assistant professor at University of Engineering and Technology Lahore) in Punjab, it would not be difficult to have access to the people with whom the survey is being undertaken. The physical monitoring or smart metering data collection was not a viable method to collect data due to economic, social, and political constraints. The other method like utilising the published data or datasets were also not useful as the data is not available along with the relevant meta-data and was useless for the author to determine demand drivers and produce prediction models.

Therefore, this thesis will attempt to undertake similar studies to those conducted by [260], [261], [297], [299], [262], [269] and [268] in the literature review. A similar **statistical questionnaire-based domestic survey** methodology approach will be used to understand the demand drivers and to produce prediction models, in the domestic sector of Punjab, Pakistan, aiming for a sample size sufficient to achieve a confidence level of 95% and confidence interval between 1-5(along with meta-data). Further, to find answers to objectives 1 and 2, similar techniques and procedures like Descriptive statistics, p-value, R-value, ANOVA, t-statistics, f-statistics, R-squared and regression will be employed, as these are the most acceptable procedures for a similar type of data analysis.
{ [267], [168], [266], [311], [273], [297], [312], [269], [313], [311](Hong Kong) [273] Canada, [297](Sweden) [312] (Austria), [269] (China), [313] (Norway)}.

3.3.4 Research objective 3 (timings of demands)

- Derive the timings of Punjab domestic energy demand by day, month and year

3.3.4.1 Data collection methods used to know timings of energy demands

3.3.4.1.1 Energy consumption billing data

The data is extracted from the energy bills of consumers either taken from the energy supply companies or taken from the individual residences of the respondents. This method is largely used to understand when does the energy demand occur over the year. The data obtained in this method have details of annual and monthly consumptions. However, this data does not inform about the weekly, daily and hourly demands (profiles) [175], [178], [179].

3.3.4.1.2 Smart metering data

Smart metering data provides more up-to-date consumption values. This data contains detailed information on monthly, daily, and hourly profiles. The other researchers who have used the smart metering data to understand the timings of energy demand are [175], [176], [177], [178], [179] & [180].

3.3.4.2 Analysis procedures used to know the timings of energy demand

3.3.4.2.1 Descriptive statistics

The descriptive analysis procedures like averages, median and inter-quartile ratios are used to understand the timings of energy demand, using analysis tools like Excel or SPSS etc. [176], [177], [180].

3.3.4.2.2 Correlation and regression

In some research, the data is analysed using correlations and regression techniques; these techniques are explained in detail in 3.3.3 [175].

In the context of Pakistan, it was easier for the author to collect data by a physical survey of the households, along with meta-data. This type of data is not available at any government agency, as from the energy supply companies, we can only get the energy bills information along with their addresses, without any link of these bills with the households' characteristics. As the physical survey was decided to collect data to answer objectives 1 & 2, the same survey questionnaire was used to get the answer for objective 3. Broadly, this thesis will use data, collected by two methods, i.e. (i) conducting a physical survey of the domestic sector by utilizing the energy bills values, to understand the timings of energy demand throughout the year. (like months of low and high demand) (ii) using smart meters (case studies) as utilized by [175], [177], [180] to understand the load profiles of the domestic buildings on yearly, monthly and half-hourly bases for the domestic sector of Punjab. The analysis procedure that would be adopted, would be similar to [176], [177], [180] ,i.e., descriptive analysis technique.

3.3.5 Research objective 4 (estimation of generation potential)

- Estimation of the potential for renewable energy generation from the domestic sector

The generation potential of solar PV and solar thermal would be explored in this thesis. The domestic roof-mounted wind energy will not be exploited as it has limited potential as found in the literature.

3.3.5.1 Methods used to calculate generation potentials by solar PV

3.3.5.1.1 Epply and Kipp Pyranometer data

This system takes into account the local conditions on-site, which may differ from the calculations done with weather stations ignoring the local site factors, like clouds, rivers, mammoth lakes and coastline [314], [315]. Further, solar maps can be developed using Geostationary operational environmental satellite (GOES) [316].

3.3.5.1.2 GIS and object-based image recognition/ satellite measurements

GIS is a computerised tool used for mapping and examining features or happenings on the earth. GISs are very helpful in spatial and temporal analyses of solar assets while applying location-specific technologies. GIS maps assist the evaluation of radiation at different locations and times without measurement equipment. Because solar data are not available for all potential sites, possible links among the radiation-related constraints can be used to map the global solar radiation at sites where data are not available [317]. GIS-based image analysis is used to determine the building footprint area (BFA) Ratio, the photovoltaic available roof area (PVA) ratio [318], [319], [216], [320], image recognition, spatial analysis **Brazil** [321], physical capacity **UK** [322], {Germany [323], [324], IEA (International Energy Agency) [325], **Malaysia** [326], ATM (atmospheric and topographic model) [324]} using satellite measurements technique solar maps can be developed [327] (The World Bank's Energy Sector Management Assistance Program (ESMAP) [328] used **satellite (met-7)** for Pakistan)

3.3.5.1.3 Digital surface model (DSM)

A DSM expresses digital representation of the elevation of all objects within an area of interest. Digital surface model (DSM) is used to calculate local inclination and orientation of roofs, employing the shadow effect of the various components { [329], (Ulfat, Javed et, al. 2012) [216], [330], [322], Solar 3D urban model [331], 3D urban massing [332]}.

3.3.5.1.4 Area solar model (ASR)

In this method, the area required by the solar panel to meet the demand is calculated utilizing the data of energy required from the solar panel. The overall area requirement is calculated based on the demand/m^2 of the floor area of the house, incorporating all factors like efficiency, losses, solar irradiance values etc.{ [213], [214], [216]}

3.3.5.1.5 Statistical calculation model

This method is used to estimate the suitable area available on the rooftop for the installation of PV. It is based on a statistical calculation model for the solar potential that has been validated by analysing actual measurements carried out on-site in Greece [194]. In this method all actual data regarding occupancy, demand/m^2 or per capita, roof and floor area availability is incorporated in the final calculations or simulations.

3.3.5.1.6 roof area-population relationship model

The method includes the geographical division of the region, sampling using the feature analyst extraction software, extrapolation using reduction for shading, other uses and orientation, and conversion to power and energy outputs. **Ontario** [186]

3.3.5.2 Analysis procedures and tools used to calculate generational potential by solar PV

3.3.5.2.1 Utilizing software(simulations) and procedures

RETScreen software [333], [30], [334], [214], [216]

MAT lab, **HOMER** [213], [214]

PVSyst software [320]

Light Detection and Ranging (LIDAR): [330], [322], [335], [336], [326], [331], [337], [316], [332]

Orthophotos: [335]

3.3.5.2.2 Correlations

The method is explained in 3.3.3.1

[322]

3.3.5.3 Concluding remarks and justification of methodology adopted for solar PV in the thesis

Justification of methodology adopted: The most used methods involved are **GIS**, **LiDAR**, **DSM** and **statistical area model**. Whereas this thesis will use 'Statistical area solar model' approach. Whilst it is acknowledged that some of the newer technologies are likely to be more accurate in terms of working out roof areas. It is felt this approach is more appropriate to this study as when it is attempting to give an estimate rather than giving actual yield. This thesis is going to undertake a physical survey of substantial sample houses of all representative sizes within the Punjab region. One of the questions in the survey would be ***'how much roof area do you have available that can be used for photovoltaics and solar thermals?'***

Given that this is one of the questions which is going to be asked, it was felt that the most appropriate approach to estimating the available area, was this approach. This ***'Actual Available Area'*** cannot be found by using any other techniques like satellite imagery as the willingness of the householder is not involved, and it depends on how the occupants choose to use the roof. The use of physical surveillance techniques without knowing the occupant's choice of how to use their roof is highly inaccurate, especially in the context of Punjab, where the rooftop is also a social space for various activities. Calculations based on satellite imagery will only give maximum yield from the roofs without any real understanding of the reality of *'what actually is available in practice?'*. Each of the above techniques has inherent advantages or disadvantages. Depending on the resources available to the author (in this particular instance), rather than going down to the route of attempting to obtain satellite imagery, and through the knowledge of local situations in Punjab in the first place. The author is aware of one of the critical issues to address here is *'What percentage of the area of the roofs the residents are ready or willing to give over to the generation from solar PV*, and therefore we have not gone for detailed physical satellite-based calculations.

Further, one of the advantages of this approach is that it will not only provide the actual available area but also provide information about the occupancy and demand/m^2 of each residence. This method will enable us to link the generation capacity with the requirement of occupants of particular house sizes, which cannot be achieved by satellite imagery. So, given the importance of occupant's willingness to give up the part of their roofs for Photovoltaics, the following approach is being adopted.

This thesis will calculate the solar PV domestic rooftop potential by adopting somewhat similar models of the '**Statistical calculation model**' [194], and **Area solar Model(ASR)** [213]. It will calculate the available rooftop area of different house sizes, along with its occupancy level and demand per m^2 of each house size, by physical questionnaire survey, as discussed in the literature review. Further, the final potential will be calculated by using solar simulation software like PVSyst [320] , RETScreen, PVGIS, PVWatts and Valentin, as this software are validated, and largely accepted in published research, and are easily available to the author. This method is more practical for the author to adopt, as installing the modules on the rooftops of all house sizes in all ten divisions of Punjab was not possible due to economic, social and time constraints.

3.3.5.4 Methods used to calculate generation potentials by solar thermal

3.3.5.4.1 Domestic scale water heaters (roof-mounted) performance model/monitoring

Some of the researchers installed solar thermal on the rooftop to estimate the potential of energy savings from this technology. In this method actual solar thermal units are installed on the rooftop of some experimental house or case study, the regular monitoring is carried out and noted to calculate the generation potentials.{China [338], [339],UK [225], Canada [227], China [340], Ireland [233], Rome, Madrid, and Munich [341], Tunisia [221], Pakistan [241], [242]}.

3.3.5.4.2 Meteorological data

In this method, meteorological data is used either in some simulation software or in numerical equations. The solar thermal units specifications are used to calculate the generation potentials utilizing data like NASA(National Aeronautics and Space Administration) {Ethiopia [342], UK [225], Iran [230], Tunisia [221]}.

3.3.5.4.3 Computerised simulations:

In this method the required data is put in the simulation software. The standard values are used from the literature of hot water requirements, space heating needs, occupancy, floor areas, and other conditions are taken from published research. Sometimes these values are taken utilising the site data.{Spain [343], China [340], France [228], Iran [230], UK [226]}

3.3.5.4.4 Statistical solar area model

In this method the actual area availability of the rooftop is measured, all other requirements of simulations are taken from the reality on the ground like occupancy, floor area, climatic data of site etc. this method links the simulations carried out using software with the actual conditions on the ground, Taiwan [222].

3.3.5.5 Analysis procedures and tools used to calculate generational potential by solar PV

3.3.5.5.1 Utilizing software(simulation) and procedures

HOMER: [342],

TRNSYS(Valentin): [343], [228], [221]

GaBi v.4.4: [226],

Manual calculations (using equations): [241], [242]

3.3.5.6 Concluding remarks and justification of methodology adopted for solar thermal in the thesis

Open literature shows a large number of studies where solar thermal potential and performance are described employing case studies utilizing roof Integrated solar collector, experimental and monitored data are used. Most of the studies conducted used simulation models for theoretical or numerical equations. Some of the studies have performed simulations using simulation programs like HOMER, TRNSYS, CR-3000, GaBi v.4.4. **Statistical solar area model**, where the available rooftop area is measured, and the generation potential calculated by using **simulation software**, has also been the methodology of some researchers. We will adopt a similar model for this thesis to calculate the solar thermal potential for the domestic rooftop. We will find out the actual available rooftop area of different house sizes of Punjab. The solar hot water and space heating requirement data will be taken from literature; the occupancy level of each house size would be obtained from the physical questionnaire survey. The software that would be used for solar thermal generation potential would be RETScreen, PVGIS, PVWatts and Valentin (TRNsys) (all validated software, the average values of all these would be presented in the result section). The justification for using this methodology is similar as we provided for the solar PV in (3.3.5.6) and related questions would be part of the physical survey. This method is more practical for the author to adopt, as installing the modules on the rooftops of all house sizes in all ten divisions of Punjab was not possible due to economic, social and time constraints.

3.4 Summary of methodology section

The overall summary of the possible methodologies adopted by other researchers and adopted for this thesis is given in Figure 3.2. We will primarily conduct a physical questionnaire survey, smart metering data collection for some case studies, and a statistical area solar model will be used to estimate the clean energy generation potential.

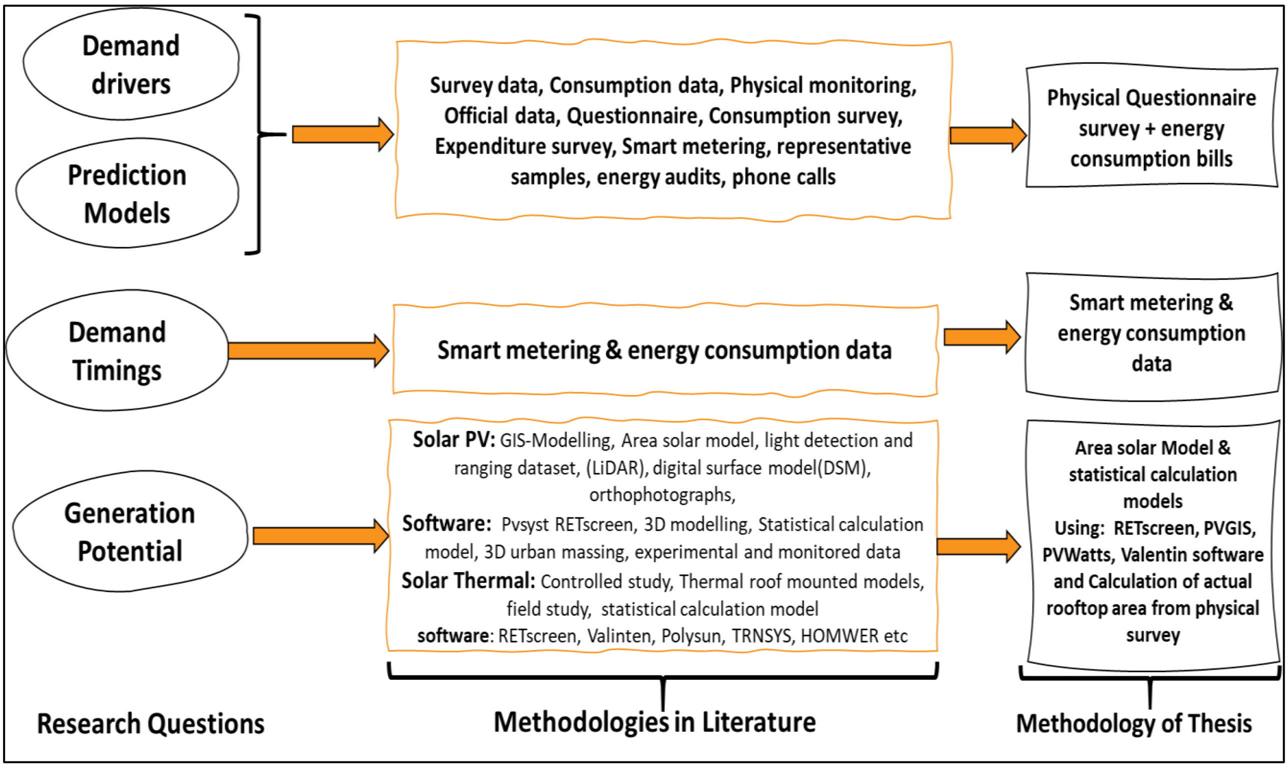


Figure 3.2 Methodologies to answer research questions, and methodologies adopted for the thesis

This Chapter has shown why the methodology chosen in the thesis has been used. Conducting a physical questionnaire-based survey seemed culturally accepted method to get data to answer thesis objectives because this method is usually used in Pakistan for all types of social surveys. Statistical Area solar models for solar PV and solar thermal will be used, utilizing the actual data of the respective household.

The stages covered up till now, and the next stage is shown in Figure 3.3 below. We have set the research aims and have looked for answers to the questions we raised in the introduction chapter. We have conducted an elaborate literature review and came up with the research objectives, where we identified the research gaps. In the next stage, we looked for the possible methodologies adopted by other researchers in the literature who have tried to answer the objectives set for this thesis. At this stage of this thesis, we have identified the do-able methodologies which we will use to conduct this research. In the next section, we will discuss in detail how the research was conducted to look for the answers to the questions set in this thesis, Figure 3.3.

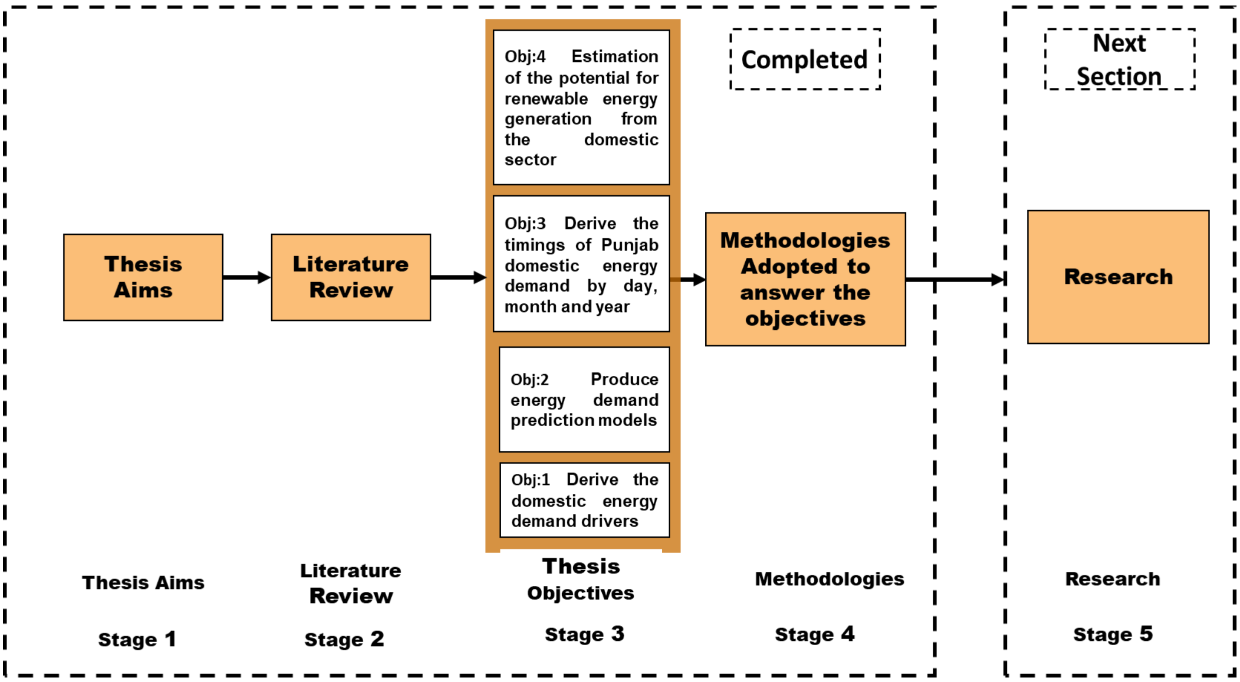


Figure 3.3 Research Stages of the thesis 1-4

Chapter 4

Research

4 Research

This chapter presents the research undertaken, showing methods used, caveats to the data and presents the datasets obtained. We have seen in the research methodology chapter 3, how different research questions developed from the literature review are linked together to develop the research methodology for this thesis to answer the aims and objectives set.

In this chapter, we will present how actual data, to answer each research question, is collected and what type of data we have obtained to address each question. The exact methods used, data set obtained, and its limitations are presented below as per each research question.

4.1 The physical survey underpinning all four objectives of the thesis

A quantitative survey was needed to be set up following some strict guidelines, to avoid leading the people completing the questionnaire in a certain way, to prevent biased results. Before starting the physical survey to be executed in the whole Punjab region, we came up with the following questions which should be answered from the survey data:

- Q1: What is the average energy (electrical and gas) demand and demand drivers of per households and per capita of different house sizes and occupancy?
- Q2: What is the nexus between energy consumption and metadata of the respondent's households to obtain sufficient information to develop energy prediction models in a typical house?
- Q3: When does this demand occur in a year, a month and within a day?
- Q4: how much socially acceptable rooftop area is available to generate renewable energy from the houses?

Based on the questions (mentioned above) to which we were trying to find the answers, we were needed to ask the following questions,

- ➢ To find the answer to ‘how much energy is being consumed per capita or household? We needed to know:
  - ✓ The occupancy of each house type
  - ✓ The amount of energy which is being consumed by each house type (electrical and gas)
- ➢ To know the average energy consumption of each house size, we needed to know:
  - ✓ What is the size of the house?
  - ✓ What are the monthly and annual energy consumptions of each house size?
- ➢ To understand the demand drivers per household and capita, we were looking for:
  - ✓ The occupancy of each house size
  - ✓ The energy consumption of each house size

- ✓ The number, types and usage hours of different light luminaries and appliances of each household of different house size
- ✓ We were also interested to know the power rating of all these light luminaries and appliances

- ➢ To understand the link between the energy demand and different factors causing this demand to develop prediction models, we needed to know
  - ✓ Actual energy consumed under the different scenario of house size and occupancy level
  - ✓ Meta-data of individual respondent's household
- ➢ To calculate the renewable energy generation potential from the domestic rooftop, and to establish a link between the energy demand/m^2(in kWh) and possible generation/m^2 of each household of different house sizes, we were interested in finding out,
  - ✓ How much socially acceptable actual useful rooftop area is available of the different households having different ranges of house sizes
  - ✓ How much is the average energy demand of individual households of different house sizes, like demand per m^2
  - ✓ What is the occupancy of each household of different house sizes?

In this way, different questions started to become part of our questionnaire, and we asked a specific question to get the small bit of the answer for our objectives.

4.1.1 Questionnaire

As we discussed, each question that appeared in the questionnaire had the sole purpose of serving the overall objectives of the thesis. Before conducting the elaborate survey in the field, the questionnaire was validated with the prior pilot survey (DELPHI[1] analysis was done). It was refined many times; if any of the questions were misunderstood by the respondent, it was clarified using more appropriate language, and terminologies used were explained either in written form or supported by illustration/picture. The questionnaire was prepared in two languages, i.e. English and Urdu (native language) to make it easy to understand by the respondents of different educational backgrounds. The final questionnaire had the following questions with the reasons for asking given below, (apart from the necessary name and address questions)

1. How many people are usually living in the house? (Also include house worker(s)/servant(s) who live(s) in the same house?

   Reason to ask: to answer objective 1, 2, 3 & 4, to link occupancy level with each objective
2. What is the total covered area of your house? (Including each floor covered area of the ground floor, first-floor basement, and excluding outer spaces? Or Gross internal floor area (GIFA)

[1] The **Delphi method** is a forecasting process framework based on the results of multiple rounds of questionnaires sent to a panel of experts. Several rounds of questionnaires are sent out to the group of experts, and the anonymous responses are aggregated and shared with the group after each round to see if the objectives of the questionnaire are properly achieved after many refinements.

Reason to ask: to answer objective 1, 2, 3 & 4

3. What is the total number of conditioned rooms (rooms which are heated and cooled) in your house?

   Reason to ask: to answer objective 1& 2

4. What is the total combined area of conditioned rooms? (sq.ft. m^2, Dimensions)

   Reason to ask: to answer objective 1& 2

5. How many rooms would you like to condition in total if you could afford it? (heating or cooling)
   Reason to ask: to answer objective 2, and to understand future demand increase

6. What would the new total combined area of conditioned rooms then be? (Sq. ft., m^2, Dimensions)

   Reason to ask: to answer objective 1& 2

7. How much electricity do you use per month (kWh)? Also, the number of power cut hours /day in each month?

   Reason to ask: to answer objective 1, 2 & 3

8. How much Gas do you use per month (hm^3)? And, the number of Gas cut hours /day in each month?
   Reason to ask: to answer objective 1, 2 & 3

9. Are you aware of the use of solar cells (PV) to help supplement the electrical energy you purchase from the national grid?

   Reason to ask: to answer objective 4, and to support the outcomes of objective 4

10. Would you be willing to install Solar cells (PV)?

    Reason to ask: to support the out-comes of objective 4

11. How large is your rooftop area?

    Reason to ask: to answer objective 4

12. Please list all the lights in your house by type, wattage, and average usage per day, and additional required if you can afford it?

    Reason to ask: to answer objective 1 & 2, and to understand potential future demand increase

13. Please list all the electrical appliances in your house by type, wattage and average usage per day, And, additional required if you can afford it?

    Reason to ask: to answer objective 1 & 2, and to understand, potential future demand increase

We asked different questions to get an answer to the small part of each objective. To support the outcomes of the research objectives, for example, a question like ‘the willingness to adopt solar PV’ was asked. Because we were interested to know if the substantial generation potential were found later in the thesis, would there be any resistance by the respondents to adopt this new technology and vice versa? The detailed questionnaire sample is given in **Appendix B**.

4.1.2 Survey samples, hurdles, lessons learned and outcomes

To get a reasonable response, and achieving a confidence level of 95% and a confidence interval equal to less than 1, we were aiming to get 10 thousand responses out of 17.2M [31] [104] households(**households** are our Survey Population for this thesis) in Punjab. The possible methods to obtain the required response were:

- Online survey
- Social media, like Facebook, Twitter, WhatsApp
- Electronic and print media like TV, radio, news channels, newspapers
- Door-to-door or face-to-face surveys

Survey Samples: We faced many obstacles in conducting this extensive survey in the context of Punjab. The possibility to exploit the electronic & print media could not be possible for us. As it could have cost us a considerable amount of money and there was no such precedent or modus-operandi available, so with our limited finance and time constraints, this option was not adopted.

We started our survey online using social media by contacting many respondents by ourselves. The methods used were telephonic calling, sending emails, spreading the survey links online. The follow-up reminders and emails were sent to the respondents, and we waited for more than a month. Unfortunately, this method was not successful, and we hardly received 15-20 responses in a month, even after sending many reminders. We also tried to link the '**response**' with some **'incentive'**, like every respondent's name would be included in the raffle/draw to win mobile phones. This method also could not be fruitful. Whilst there were limitations about the possible ways of conducting such a large scale survey, and knowing the more comprehensive nature of the society, it was decided, we need to go out for door-to-door survey method. Due to the personal social links of the author with public sector universities in different cities of Punjab, we also approached university students in the whole province. One of the questions that were explored in detail before going out for the survey was just how many questions, we might get answers to? How much we might be able to ask before the survey fatigue might set in when people are answering it.

University students survey: The author contacted various public sector university teachers (being a teacher himself) and discussed the nature of the survey. After this decision was made, the helping teachers were contacted. Mainly the university students were approached in two ways; (a) the questionnaire was given to the class teachers or the class representatives for the distribution, and the students were given a couple of days to bring it back as per their convenience. It was also required that each respondent must provide the picture or photocopies of their energy bills. To make it possible the WhatsApp number of the author was provided on the bottom of the questionnaire so that respondent can send their energy bills, and, in some cases, the survey forms through WhatsApp messages with their names and roll numbers written on forms as well as on energy bills. We received the survey responses in both hard and soft forms by applying this method. (b) the other way used was that the university students were asked to gather in big conference/seminar halls, hard copies of the questionnaire were distributed, and the author himself explained the purpose and nature of the survey and discussed every question with them while addressing the students. Even in this method, the students could take the questionnaire home with them and answer the questions related to energy bills, after taking monthly and yearly values. In this method, the pictures or photocopies of the relevant energy bills were taken and coded with the same name and roll number of the students. The author received a large number of responses (2580) through this method, and filled survey forms were received by postal mails, sent from different cities of Punjab. In the end, all samples collected either in the hard or soft (digital) forms are digitally archived, and responses were uploaded on the online software for analysis.

Field survey by the survey staff: The other successful method utilized was hiring the field staff or surveyors. The advertisements were given in the mainstream newspapers of all cities of Punjab. The author received a quite reasonable response, and a large number (107) of surveyor personnel contacted the author and showed their willingness to conduct this survey from all most all cities of Punjab. The surveyors with previous experience of conducting the domestic survey were shortlisted based on their speaking skills and education level. All of the surveyors hired for the task were 12 standards passed (HSSC-higher secondary school level or A level's equivalent) and had excellent communication skills and were paid @Rs 30/form (Pak Rupee). After the selection of the appropriate surveyors, they were all invited to the home city of the author (Lahore) for the necessary paper works. Proper training on how to conduct the survey was given to them by the author himself. It included clarifying the purpose of the study, adequate understanding of each part of the questionnaire and knowing the ethical restrictions involved. Both male and female staff was hired as considered appropriate understanding of the nature of the local culture and norms of each city. To prevent unforeseen situation, all the surveyors were provided with the stamped[1] official letter of the author (being himself part of public sector university). The letter informed the purpose of the study, who and why the study is being conducted. The contact number of the author was provided on that letter for any further inquiry if required. The survey staff themselves filled the questionnaires. It ensured the accuracy of the responses and avoided misunderstanding of any question. The completed survey forms were then posted back to the author by the surveyor along with, either the photocopies of the energy bills or pictures of them, well coded with the respondent's numbers on each form[2].

[1] In Pakistan, faculty members of public sector universities are authorised to issue such authority letters to the official departments and the people concerned. Their official stamps are the proof that the letter is authentic, and no fraud or any kind of deception is involved.

[2] each surveyor was also assigned with specific code number, to ensure that the survey forms should not mix, when they are received by the author. These code numbers consisted of initials of the surveyor's name, city code and surveyor's number etc

Hurdles:

Within Pakistan the following are the main obstacles to be overcome in undertaking this survey:

- There are several regional dialects and languages spoken within Punjab.
    - This survey addresses this through using both English and Urdu on the questionnaire, supported by local surveyors who understand local dialects in the neighbourhood they surveyed.
- How to address administering the survey over a large geographical region?
    - This issue was overcome by proper administration of survey being conducted by the author via;
    - University Students administration: the public sector universities students of different divisions were approached by the author, using his social links (and being a part of one such university, it was not so difficult for the author to achieve this task), the students were properly explained about the survey, hard copies were distributed to them, and author was able to get hold of at least one representative (administrative staff, mainly a clerk from admin office) from each university to contact and send reminders to the respective students. Later they collected the survey copies and pictures of energy bills, etc., and sent these back to the author. Author was constantly in contact with those representative (administrative staff) members for any type of updates or clarification required by the respondents. The hard copies collected were finally sent to the author by postal mails.
    - Field staff Administration: Between 2 and 3 field staff members were hired from different districts of Punjab. They were provided with the author's stamped letters for any query if required in the field for any explanation of the survey. The author personally monitored the survey on a daily basis. The field staff were frequently contacted by author discussing any issues or hurdles they might have. The field staff were properly motivated and were kept engaged in the survey by the author via phone calls, text, voice and video messages. The survey samples collected from different districts were recorded daily, and pictures of the hard copies were sent to the author every day, this ensured the steady progress and success of the survey.
- How to identify which neighbourhood and area to be surveyed in order to provide an unbiased sample representative of Punjab as a whole?
    - The reason to approach the public sector universities was to have unbiased samples. The students at these universities belong to different economic classes of the society in Punjab because the admission criteria of these universities are strictly on merit and they charge very nominal tuition fees and get students from all levels of the community. This reduced the risk of sampling only one class of the society, e.g upper, middle or lower class, and ensured the respondents in our survey could come from all three classes, helping to minimize bias.

- Before starting the door-to-door field survey, different areas of each society/city were identified (having different house sizes and apparent social classes and economic status), and it was ensured to include them in the survey. This helped the inclusion of all representatives of the society.
- Within Pakistan there is no published data defining the class a person belongs to in the society of Punjab. So, it is not possible to claim that this survey is representative of all classes in the proportion we need in each class. However, in the absence of this statistical information for the Punjab, this survey ensures that the proportions of the surveyed occupants reflect the proportions of different house sizes in the Punjab. The author considers house size to be the best available proxy for social status in Punjab. If future work supports this assumption then the survey could be seen to be significantly representative of Punjab society.

Lessons learned:

- Conducting an online survey of this nature is not a viable solution in the context of Punjab, may be due to limited internet facility or casual attitude of the respondents using technology
- Using social or print media is very expensive and do not have many such practices or precedents, except few government levels surveys
- Approaching physically to the respondents is the most useful way to have a good response
- Follow-up of the respondents is essential, sending text messages are not helpful, the phone call is a better option to follow-up
- If, we are using our links or social contacts, keep telling them we need to have this survey done in limited time, if we provide un-limited time, respondents will forget to fill the form or may misplace them
- When we are hiring field staff, we need to push them on daily bases, and always give them a target, and ask them to meet it occasionally
- Field staff should be timely paid, and we should always be available to answer any query they have, this boosts up their morale and confidence.
- Always, upload data on the software, do not wait for the survey to finish, and then shift data on some analysis software; it should be done side by side. Data entry will help to clarify any ambiguity timely, and would also safe time in general.
- There should always be someone who is looking after the survey on daily bases as a full-time job, and contacting the respondents and the survey staff on the field, this will ensure the timely completion of the survey

Outcomes: The data set consists of primary data collected by the researcher in 2017-18 through conducting a domestic field survey covering the whole Punjab. Using a probabilistic clustered sampling method and random sampling principles, in which Punjab was divided into clusters consisting of 10 divisions, and a representative sample from each division was taken as per household population in each division. Within each division, a stratified (as per house size) random samples were collected. By using these methods (mention above), we were able to receive approximately the following responses,

Online survey: **14** samples received (in 40 days), Valid =14

Social media: no response received (in 90 days)

Electronic and print media: we did not use this method

Hired field staff: **3200** samples received (in 90 days), Valid =2619

Approached university students: **2580** (50 days), Valid =1973

Overall, we received approximately **5800** samples, and after data refining process (discussed later) we were able to achieve a confidence level of **95%** and a confidence interval of **1.45** from gathering **4597** valid[3] samples (Figure 4.1, Table 4.1) from the whole Punjab for electricity consumption. For gas consumption, **2901** valid samples were obtained, achieving a **95%** confidence level and **1.8** confidence interval Table 4.1. We were looking to achieve a confidence level of 95% and a confidence interval less than or equal to 5. The confidence interval obtained in each division for electrical consumption is shown in Figure 4.1, wherein, we met the target in 7 out of 10 divisions.

The robustness of the data is ensured by taking,

- Consents of the respondents were taken, either by clicking **'online option'** provided or by putting **signatures** at the bottom of the form. Space was provided in hard as well as in the soft types of questionnaires. In some cases, even the **audio recordings,** confirming their consent, were recorded, especially if the respondents were reluctant to put their signature, due to having some fear of fraud or privacy.
- Either electricity or gas bill's pictures and photocopies were taken for validation of the valid respondent and consumed energy.
- While conducting the survey, the principle of random sampling was applied to incorporate the maximum variety of the house sizes and different areas within the city to eliminate the biasedness of samples. The oversized houses (like more than 12 Marlas (250M^2) were not surveyed in large numbers. These house sizes make less than 1% of total households in Punjab. Our survey data is mostly concentrated on that house sizes, which have the highest percentage in the population, somewhat proportionately stratified data were collected as shown in Table 4.1. By adopting the above methods to ensure valid respondents, the author was also able to have a check on the hired field staff, that no fake entries were added. Moreover, all field staff submitted the hard copies of the survey conducted, ensuring a valid response.

[3] Valid sample: we defined valid sample as, the sample which enabled us to answer all four objectives set in this research. Any sample which did not have sufficient information was rejected.

Table 4.1 Stratified valid samples from the whole Punjab

Divisions of Punjab	Districts	Households Population M (2017)	Electric energy Valid Samples Received	Gas energy Valid Samples Received
Lahore Division		**2.29**	**785**	**441**
	Lahore	1.76	562	290
	Kasur	0.53	307	124
Sheikhupura Division		**0.74**	**396**	**64**
	Sheikhupura	0.52	334	55
	Nankana Sahib	0.22	62	9
Gujranwala Division		**2.44**	**853**	**655**
	Gujranwala	0.75	419	325
	Gujrat	0.44	182	144
	Hafizabad,	0.18	11	5
	Mandi Baha-ud-Din	0.25	13	7
	Narowal	0.24	18	9
	Sialkot	0.58	210	165
Faisalabad Division		**2.23**	**432**	**207**
	Faisalabad	1.23	174	104
	Chiniot	0.22	12	3
	Jhang	0.44	233	98
	Toba Tek Singh	0.34	13	2
Sargodha Division		**1.32**	**327**	**313**
	Sargodha	0.6	282	276
	Bhakkar	0.27	12	11
	Khushab	0.21	16	12
	Mianwali	0.24	17	14
Rawalpindi Division		**1.68**	**179**	**125**
	Rawalpindi	0.89	130	94
	Attock	0.31	7	4
	Chakwal	0.27	17	11
	Jhelum	0.21	25	16
Sahiwal Division		**1.19**	**255**	**147**
	Sahiwal	0.39	103	74
	Okara	0.49	136	67
	Pakpattan	0.31	16	6
Multan Division		**1.95**	**520**	**323**
	Multan	0.76	386	244
	Khanewal	0.47	48	23
	Lodhran	0.26	46	29
	Vehari	0.46	40	27
Bahawalpur Division		**1.77**	**458**	**421**
	Bahawalpur	0.59	313	297
	Bahawalnagar	0.48	130	113
	R. Y. Khan	0.7	15	11
D.G. Khan. Division		**1.66**	**392**	**205**
	D. G. Khan	0.35	9	1
	Layyah	0.28	14	4
	Muzaffargarh	0.77	364	196
	Rajanpur	0.26	5	3
Total	-	**17.27**	**4597**	**2901**

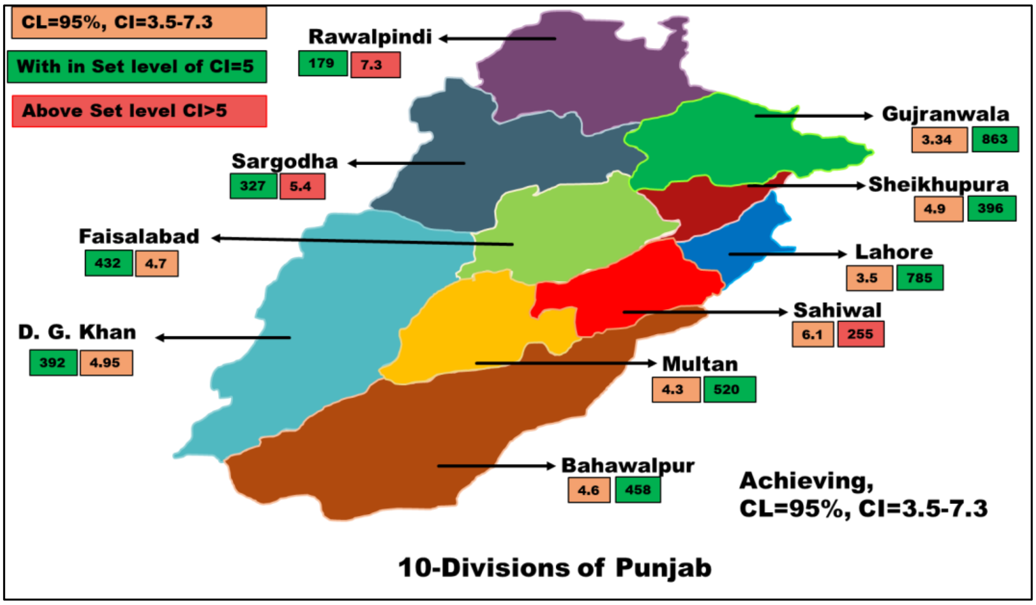


Figure 4.1 Confidence interval achieved (electric) in each division of whole Punjab

4.1.3 Tools used to design questionnaire and data preparation for analysis

- The questionnaire was designed using 'online survey' software provided by Cardiff University, UK, previously called 'Bristol online survey.'
- The field data collected was either in the form of hard copies or entered online in 'Bristol online survey software' [344] [345]. The data in the form of the hard copies were later entered into the same software online. Pictures were taken and archived of the hard copies of survey forms and energy bills. The excel files were generated from each district data, from the online software for the sorting process. Then Sorting of data related to each division was done using excel sheets. The different district's data was added to the relevant divisional data files. We had roughly 72 online data files (of 36 districts) from the whole Punjab, which were later concentrated into ten divisional data files.
- Data files of each division (consists of districts) were carefully checked against the district's codes, and responses were counted from each district and noted in the master data file.
- Data cleaning included removing irrelevant response, wrong values or units added, extreme outliers, wrong decimals positions, blank spaces, converting text data to numeric, removing duplicates, removing all formatting. The researcher personally did cleaning by using excel software. Approximately 1200 responses were rejected because of either incomplete or wrong answers. These were counted as '**invalid sample'**, i.e. any response missing energy bills, house size, occupancy, types and number of appliances and usage hours, was not included in the final data set. Further, a sample which does not provide a required number of answers to the objectives of this thesis were counted as invalid. The data preparation and cleaning process was the most tedious and time-consuming part of the research, it took roughly 4-5 months before the first file was ready for analysis, and even after the initial analysis, the data were further refined.

- Excel-2013 and IBM SPSS statistics-25 software were used for data preparation and analysis.
- New variables like total energy demand and overall power rating (kW) of appliances, average usage of appliances (kWh), the total number and types of appliances, were created in the Excel software

4.1.4 Data accuracy and limitations

- Quantitative data obtained from such surveys would have different levels of accuracies associated with the data for each variable. The energy consumption values are considered accurate within a few percentages of error, less than 1-2%, Published accuracies for most electricity fiscal meters are better than 2% for many meter manufacturers. We have assumed these accuracies also apply in Pakistan [346] [347] [348] [349], and these are taken from official electricity and gas bills[4] and were cross-checked. We have similar confidence in the gross internal floor area (GIFA) calculation values. The occupancy of the house is considered accurate. For appliances and light data, the general accuracy is likely to be slightly less but could not be verified. The physical presence of field surveyor during the questionnaire completion, known to have improved the accuracy with which these values were reported. The surveyors made it possible to clarify any ambiguity that occurred in the understanding of any part of the questionnaire. Overall, the data on which this analysis is undertaken is consistent, accurate and of high quality.
- To get the accurate response ample time was given to the respondents (were allowed to take hard copies home) there may be some responses where the respondents have filled the questionnaire without actually noting the energy consumption values (but this was ensured to be correct as their utility bills pictures were requested and widely received)
- Any response not supported by the energy bills pictures or photocopies was considered invalid.
- Though the data was precisely entered from the hard copies of the questionnaires to the online software for the preparation of the excel sheets, there are possibilities of human error, in little percentage. Still, it was made sure to be as accurate as possible by multiple cross-checks.

4.2 Research on objectives 1 & 2 (demand drivers & prediction models)

- Objective 1 determining domestic demand drivers
- Objective 2 producing energy consumption prediction models

Rationale: The domestic sector in Pakistan is responsible for 24.5% (without biofuel) and 48% (with biofuel) of Pakistan's total energy consumption. Addressing this consumption is a crucial task in the transition to a low carbon economy and achieving resilience. The predominant domestic fuels in

[4] In Pakistan or Punjab, the hard copies of energy bills(electricity and gas) are posted to consumers postal address for the payments, and the bills are paid at various outlets like banks, shops, online etc, this made us possible to take the pictures or photocopies of the bills.

Punjab are electricity and gas. As of 2016, Pakistan is consuming 81.63 Mtoe of total energy, out of which 9.9% & 21.2% is provided by electricity and gas, respectively [8]. Punjab's domestic sector consumes 40% and 23% of total electricity and gas energy produced in the entire country [5].

We need to understand what causes this energy demand in the domestic sector. From the literature review, the following findings have been identified in other studies as the main drivers of domestic energy demand to put our findings in some context. These are occupant's behaviour, space conditioning, electronics, occupancy, floor area, power ratings of appliances, the total number of appliances**,** usage hours of appliances, ownership of appliances, as primary drivers of energy demand (for details see section 2.9 of literature review). These drivers are also part of the prediction models for the energy consumption found in other countries. To know these demand drivers and to develop prediction models for the context of Punjab, we needed to conduct a comprehensive research. It became more important to find out the demand drivers and to know the predicted forecast of the energy demand of Punjab. When we compared the current electrical energy consumption per capita of Punjab with other countries, we found that the ranges of domestic per capita consumption of electrical energy of undeveloped and developed countries go from 194kWh to 9815kWh with an average value of 2655kWh. At the same time, Pakistan/Punjab only consumes 230kWh (2016). Further details can be found in Figure 2.47, where it is dealt with more information in section 2.8.4.1.1 of chapter 2, in the literature review.

Research: The research is designed to produce quantitative data of main demand drivers, average demand, and to produce prediction models per household and capita of energy consumption. The theory behind the data to be collected to achieve this understanding is based on well-established building energy modelling principles [10] [11] which show that a building's energy demand is determined by fabric, area, location, and climate. In contrast, occupant energy demand is considered [12] to be driven mainly by the number of occupants, activities undertaken in the building and economic strength. What is often unknown is how these parameters combine across given communities to create overall demand. This thesis fills that gap for Punjab. The theory leads to a holistic research approach based on a positivist paradigm for this work.

Objectives 1& 2 of this thesis presents, how the data collected from an extensive scale survey of these factors, have been combined with the recorded monthly and annual energy use at individual dwelling level. Energy usage compiled from actual energy bills of each respondent to produce models which clarify the drivers for current demand in Punjab, as well as enabled the estimation of future energy demands based on changes in these drivers and provide the average energy usage per household and capita.

4.2.1 Approaches for objectives 1 & 2 (demand drivers & prediction models)

The physical questionnaire survey is conducted to get the relevant data to answer objective 1 & 2. The problem to be solved is how to predict energy demand drivers from energy consumption data, along with meta-data. This type of problem requires the use of regression techniques that allow the correlation of independent variables with dependent variables. This approach is an established method found in the wider research when undertaking energy prediction and estimate analyses. A quantitative field research methodology [274] [275] [276] is appropriate based on the positivist research paradigm adopted to answer Obj: 1 & 2 of this research. Descriptive and inferential statistic techniques are used (discussed in detail in 3.3.3.1)

The data is initially analysed using **correlation coefficients** (Pearson) to understand demand drivers (Obj: 1), the descriptive statistics are used to know the average demands (addition outcome of the study) and **regression analysis** is used to produce prediction models (Obj:2). The detailed methodology adopted is provided and discussed in chapter 5, along with the results and analysis. In chapter 3, we have discussed in detail what are these analysis procedures.

4.2.2 Regression assumptions (fulfilled) & data reliability (checked)

The quality of the regression models produced, and the reliability of data was confirmed by checking if the following criteria are met,

- The dependent and independent variables are continuous, level of measurement is the scale in all variables
- There is a linear relationship of some degree in the dependent and independent variables
- The ratio of participants to independent variables is above 1:20. The confidence interval is the predictability of the independent variable to predict the dependent variable, how well the independent variables predict the dependent variables
- R-squared change is the change in the prediction of the dependent variable by adding another independent variable
- Independent variables are not highly or perfectly correlated if they are highly correlated it is called multi-collinearity ($r>0.90$), and if $r=1$ it is called the singularity
- To identify outlier in data, Mahalanobis is the measure of distance that how much the value of a case is different in the independent variables from the average of all other cases. Cook's distance would suggest how much of the regression coefficient will change if a particular case is removed. Cook's distance > 1, it should be removed as it will affect the values. Leverage values measure the multiple outliers, with higher values indicating potential outliers,
- Residual is the difference between the observed value of a variable we measured, and the value suggested by the regression model.
- Homoscedasticity is the assumption that variance in our variables is roughly equal.
- **Cronbach's alpha:** Cronbach's alpha is the measure of internal consistency, which shows how closely related are the questions within the group. It is also the measure of the reliability of the responses we received, which means that if we ask the same questions from the respondents, we will receive similar answers. The higher the value of alpha(α), the better it is, it is measured between 0-1, 1 being excellent, and can never achieve in reality, but its value above 0.7 is considered acceptable. We checked Cronbach's alpha and found its value as 0.77, which is acceptable and shows good reliability.

The prediction models presented in chapter 5, fulfil all the required assumptions of regressions. The most refined models are presented in the thesis, after meeting all regression assumptions.

4.2.3 Validation and diagnostic criteria used in the thesis

4.2.3.1 Coefficient of determination

The coefficient of determination is used to show the percentage of the variation in the dependent variable explained by the independent variables. It is given as $R^2 = \frac{SST}{SSR}$,

where:

SST= sum of squares total

SSR= sum of squares regression

4.2.3.2 f- test & t-test

Explained in methodology chapter 3

4.2.3.3 Root mean square error (RMSE)

The **root-mean-square deviation (RMSD)** or **root-mean-square error (RMSE)** is a normally used measure of the differences between values predicted by a Regression model and the values detected. The RMSD denotes the square root of the second sample moment of the differences between anticipated values and detected values or the quadratic mean of these differences. These deviations are called **residuals** when the calculations are performed over the data sample that was used for estimation and are called errors (or prediction errors) when computed out-of-sample. The **RMSE** tells us on the cumulative scale the extents of the errors in predictions into a single degree of predictive power. It is a measure of correctness, for the different models of the same dataset not between different datasets. A '0' value of RMSE means a perfect fit of data, and it never happens in practice. Usually, a **lower RMSE** is better than a higher one [350].

The square root of the sum of the square of differences between predicted and observed value divided by the number of observations. It can be expressed mathematically [286] as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Et - \hat{E}t\right)^2}$$

Where Et = observed energy consumption and $\hat{E}t$ = predicted energy consumption

4.2.3.4 Cross-validation

To check the validity of the models that are produced from the full data sample, we also performed a **cross-validation** procedure to see if our models produced are not over-fitted. To do so, we have randomly separated the data into two halves (training data set and validation data set). We produced Models and rerun the analysis to see if the models are similar and have tested the model predictions against a sample of the validation data-set to prove applicability. The cross-validation is done using the Holdout method, and the predictions are made for the validation data set using models produced from the training data set. The errors it makes are aggregated to give the **mean absolute test error**, which is used to evaluate the model. The MAE (Mean Absolute Error) analysis shows similar results as did our predicted models, so it validates the models.

4.3 Research on objective 3 (demand timings)

- Timings of energy demand in a day (daily profiles), month and within a year

Rationale: As we are trying to understand what role domestic buildings could play in the move towards a low carbon future, we were interested to know what causes the energy demand in the domestic sector. To justify a low carbon energy generation from the domestic building's rooftops, we were interested to know when does energy demand occurs in the house. What are the timings of high and low demands within a year, month and even in a day? We wanted to know this because we needed to see if the timings of energy demand coincide with the timings of energy generation. By knowing this, we would be in a better position to size our clean energy generation technologies. This will also help us to know, do we need to have a storage capacity, like in the form of batteries? Alternatively, even this would help us to design the size of storage capacity. For instance, if the demand and generation occur at the same time, maybe we do not need storage batteries, or we may need to have a little capacity, and vice versa, for the yearly, monthly and daily need profiles.

Research: To know the timings of domestic energy demand, we were required to have a representative sample of yearly and monthly energy consumption data from the actual energy users, i.e., energy consumption household data. To achieve this objective, we added some relevant questions in the questionnaire like, what are their annual and monthly energy consumptions. By adopting this method, we were able to get the monthly and yearly energy demand values (kWh) of every respondent's households from actual energy bills. We were able to get approximately 4597 for electrical and 2901 of gas energy usage valid samples, obtained by a physical survey of the houses. By this method, we were only able to get the data that could tell us the timings of monthly and yearly demands.

Nevertheless, we also needed to know the daily consumption profiles, so the other method we used was to get data by using **'smart meters**. Initially, we were planning to install our smart meters in domestic buildings. We had taken a couple of quotations from the vendors and analysed the cost of smart meters for our study. We rejected the idea of buying and installing our meters, firstly, because of the cost of these meters was very high. Secondly, the willingness to permit to install smart meters by the owners of the residences was limited, as it might have caused compromise on their privacy, so they were reluctant. As a result, alternatively, smart meters data was obtained from the smart meters Supplier Company ([5]**Creative Group of Companies**) for ten houses in Lahore [351], already installed with smart meters. Real-time metering and monitoring, automatic meter reading and reliable

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[5] Smart metering is a new technology in Pakistan, the creative group of companies is a local manufacturer and supplier of smart meters. In our case study houses, they have installed smart meters on the behalf of local electricity distribution authority (LESCO) and were authorised to retrieve data for study purposes if required. The company took permission from the residents of the 'case study houses' to use their load profiles for analysis. The author acquired this data from the company with the clear understanding that it would be used in the thesis and will not be shared with any third party (the residents were also made aware of this understanding).

meter data retrieval method was used to obtain the data from 1-09-2017 to 31-08-2018 (12 months data) for every 15 minutes interval. 'Energy(kWh)' data is used for the analysis. The energy consumed is often very significant since it can point out the problem areas within a process of electricity supply and can provide real-time information of power being drawn from the supply system. By using smart meters this instantaneous energy consumed (15 minutes energy usage) can be easily captured in the form of load profiles, such daily, monthly or annual load profiles are used to understand the timing of this electrical energy demand of 10 sample houses, (as a case study)

How does it work? Advanced metering infrastructure (AMI) used for data collection, is the alternate solution to meet the current demands and challenges of the manual metering system. AMI system comprises the smart meter, gateway (i.e., data concentrator (DC)) and meter data management system (MDMS). The key part of smart metering consists of GMS based smart energy meter, which shows readings on LCD, the instant power consumption at the user side, sends and receives information from Grid through GSM modem. The energy consumption on-grid station of each user is continuously monitored and recorded through SMS caster and C- based Graphical User Interface. This periodic recording of data offers a more comprehensive understanding of the energy demand when it happens and helps develop an excellent visualisation of load use patterns.

4.3.1 Approach for objective 3 (demand timings)

To understand the timings of electrical energy demand, the data used is obtained in two ways. Firstly, electrical energy consumption data is collected from the houses in the whole Punjab by physical survey along with meta-data. Secondly, by using the smart meters in 10 sample houses and related Meta-data of the same case study houses was obtained by a physical survey of the metered houses, by the author himself. Both sets of data are used to understand the descriptive statistics at per household and as per Capita levels.

Briefly, to get the answer of the timings of energy demand, we used two data sets and given as,

- '**Survey data set'** obtained from the actual energy bills for monthly and yearly values, both for electricity and gas
- '**Smart meters data set'** for monthly, yearly and daily (up to sub-hourly profiles,15 minutes interval) profiles, only for electricity

In both types of data sets, the data was entered in the Excel sheets for analysis and interpretations. Their average values would be used for the analysis of similar statistics. The smart metering data we have is very limited only for ten houses. We will see in the analysis chapter if the smart meter data we have, is the representative of the similar house sizes we have in the survey data for yearly and monthly values? The daily profiles analysis of these case studies houses would be a small representation of the households on the ground. So, we will be comparing it and showing where the smart meter data fits in our main set (of similar size houses).

4.3.2 Data preparation and cleaning process used for objective 3

- Survey data: we followed similar data cleaning and preparation process as we did with the data for objective 1 and 2.

- Broadly, inappropriate responses which were not complete enough to answer our objective were removed, like if the energy bills values of each month were missing it was considered as an invalid response.
- We have achieved similar confidence levels and confidence intervals for electricity and gas, as we have achieved for objective 1 and 2, i.e. 4597 and 2901 responses for electricity and gas respectively
- The smart meters data was received in excel sheets from the supplier company (our source). There were few missing values in the data set for several numbers of hours due to the load-shedding happened locally in the case studies houses. These missing values were identified correctly, and relevant matching values were added, taken from the average values of the similar hourly profiles. The data used for the final analysis was carefully prepared and was cross-checked multiple times to avoid any error.

4.3.3 Validation and limitations

- The energy consumption data obtained by the physical survey is highly valid as it is taken from the actual energy bills of the respondents along with meta-data
- The smart metering data is also highly valid as it is taken by using smart meters, and the metadata is obtained by conducting a physical survey of monitored houses by the author himself.
- The smart meters data is gathered from the energy Supply Company. They provided the annual data and house addresses of installed smart meters of relevant houses. The author was not able to collect the data by installing his smart meters because of financial, temporal, and social issues (like privacy).

4.4 Research on objective 4 (estimation of energy generation potential)

- Renewable energy generation from the domestic sector

Rationale: we are interested in estimating how much clean energy we can generate from the domestic rooftop. We want to link this domestic generation potential with the energy demand of the same household or demand per capita of the resident of the same house. The generated energy will enable us to know how much of the required energy demand of domestic buildings can be met by the energy generation from their rooftops. By doing this, we would be in some position to tell the policymakers or government authorities, that they need to exploit renewable energy generation possibilities from the domestic sector, which is the major consumer of energy in Punjab. When the domestic buildings would generate their energy, they would not draw energy from the main grid. That amount of energy would be available for the other sector to consume like agriculture, transport, and industry. The rooftop energy generation would be the decisive role of domestic buildings that they can play in the move towards the low carbon energy supply system of Pakistan, by not drawing partially or wholly their demand from the central energy supply system. In doing so, some of the domestic buildings would also be able to transfer some of the energy to the main grid if they were able to produce more energy than their demand and vice versa. It will be a step forward to achieve a resilient supply system, owing to the minimum inherent distractions. It must be noted that the generation potentials measured are there to give the feel of what we can produce. They are not claimed as the actual generation values as some of the factors are not taken into account while doing the simulations, like overshadowing of the rooftops from neighbouring buildings, trees or any other obstacles that might be there on site.

Research: In this thesis, we have considered solar PV and solar thermal as a potential technology for the generation of energy from the domestic rooftops. Wind technology is not being considered as the results shown in the literature are not very promising (section 2.10.3). The energy generation potential by utilizing solar energy has been studied by many researchers for small scale individual case studies and found huge potentials in Pakistan (section 2.10.1 & 2.10.2). We would be using solar PV to estimate the electrical energy, and solar thermal to provide energy to domestic hot water (DHW) and space heating needs. Currently, DHW and space heating is being done by using gas and biofuels as sources of energy.

Solar PV perspective: From the literature review we have seen that solar PV have huge potential to generate energy {(0.5-1.5 kWh/day/m^2_{PV} or 210 times (2900GW) of current production capacity (17GW) is claimed by solar PV)}, which is why we are going to explore the renewable energy generation from individual rooftop. Different methodologies adopted by other researchers are discussed in detail in section 3.2.3. this thesis is trying to find out solar PV generation potential by conducting field surveys to know the acceptable rooftop area available of different house sizes in Punjab, which is never done before. (details can be seen section 3.2.3). the simulations will use actual data of occupancy level, gross internal floor area, rooftop area and energy demand/m^2 of relevant household.

Solar thermal perspective: Solar thermal technology is widely accepted and being used globally as an alternative to domestic energy for not only heating but also for cooling, by providing heat for desiccant cooling. It is proved to be economical than conventional gas and electric domestic heating system, in terms of lifespan performance, and payback time is calculated between 0.7-3.5years in a different part of the world. The energy-saving potentials shown in literature make this technology a viable solution of domestic heating and details can be found in section 2.12.2.1.

Pakistan is also one of the beneficiaries of solar thermal water heating. Attempts made to calculate its financial and environmental benefits assured promising results (2.12.2.2) and found 50% more efficient than conventional electric and gas heaters. The green energy generation potential by using this technology based on the socially acceptable available rooftop area has not been done for different house sizes in Punjab. This research would try to find out this potential based on the actual roof area available.

4.4.1 Approach for objective 4 (estimation of energy generation potential)

The approach used for solar PV: to understand the potential role of domestic buildings, to help reduce the energy demand from the main grid and to produce their clean energy. We adopted the process given in Figure 4.2 below, which is an attempt to answer the questions, required to measure actual potential. These questions and the methods used to answer are explained below,

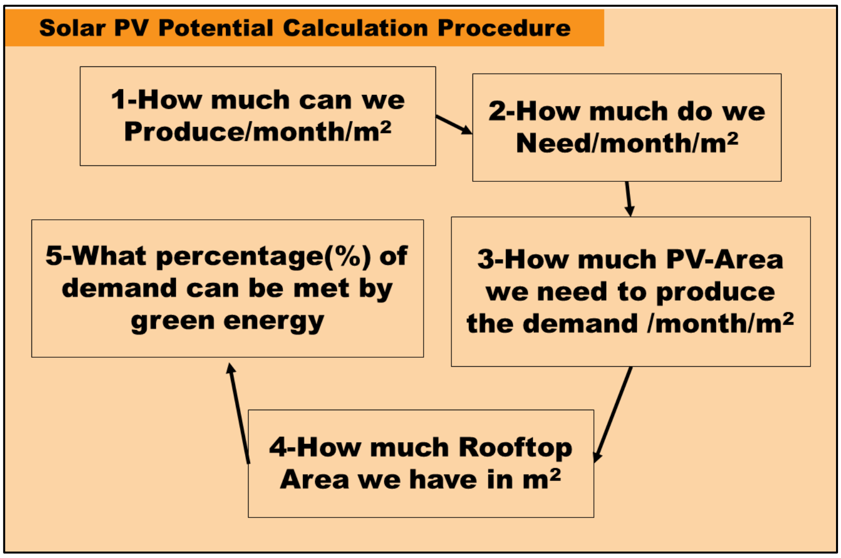


Figure 4.2 Steps of solar PV potential calculation procedure for all house sizes

Step1-How much can we produce/month/m^2?

To calculate the electrical energy generation potential from the domestic rooftop, we performed simulations. The actual climatic data of each division of Punjab was used in the simulation. We used three different software to calculate the solar PV potential, i.e. RETScreen, PV-GIS and PV-Watts are the software used for the simulations. In all three simulations, mono-crystalline Silicon PV panels were used, and different specifications used are given in Table 4.2. We used the local climatic data of every division and the angle of installation (Slope) used was the optimum angle for energy generation we found for every division[6]. For calculation purposes, PV of 1kW was used with 17% efficiency. The results are presented as kWh/month/m^2_{PV}[7], and the final useable energy produced from PV are discussed in chapter 5. The **average** results of three simulations performed for each site of every division are used to know the generation potential.

Table 4.2 Specifications used for solar PV

Photovoltaics	
Type	Mono-Crystalline Silicon
Power Capacity (kW)	1
Efficiency %	17
Solar collector area (m^2)	6.1
Miscellaneous losses %	14
Slope	32-40
Inverter	

[6] The cities climatic data used for each division was the city on which the divisions have been given their names, for example, city of Lahore was chosen to calculate the potential of 'Lahore division'.

[7] M^2_{PV} is the solar PV area required to produce green energy

Efficiency %	97
Capacity (kW)	1
Miscellaneous losses %	0

Step 2-How much electrical energy do we need/month/m^2

To estimate the amount of energy (kWh) we need per m^2 for different house sizes ranged in various divisions of Punjab, we asked our respondents in the physical questionnaire survey that how much energy they consume? We took the energy consumption values from the actual energy bills for monthly and annual consumptions. It is how we were able to calculate energy demand/m^2 of every house size in our sample survey along with their current demand per m^2. We divided the average monthly electrical energy consumption values with the total gross internal floor area (GIFA) of that household. We found the electrical energy demand/m^2 for every house size and all ten divisions of Punjab. By adopting this approach, we were able to link the actual electrical energy demand on the ground with the generation potential from the same household. This approach makes this research unique and novel because it relates to actual current demand on ground, incorporating local climatic conditions and needs of various house sizes into the calculation.

Step 3-How much **PV-Area** we need to produce the demand/month/m^2

To calculate the active Solar PV area, we need to meet the current demand; first, we multiplied the current demand of electrical energy/m^2 (we calculated in step 2), with the total GIFA of that household. It gave us aggregate monthly demand, and then we divided this monthly demand by the generation potential/m^2_{PV} (calculated in step 1). It is how we figured the active solar PV area required to meet the current electrical energy demand of that household. We did the same process to calculate the PV area required to meet per capita demand. The equation A below explains the calculation process as,

Total active Solar PV area required(m^2_{PV}) = Total electrical energy demand/m^2 X total area of household GIFA (m^2) **/**energy generation/m^2_{PV} of active Solar PV

Step 4-How much **Rooftop Area** we have in m^2

We needed to know, on how much of an area of household we must install solar PV on the domestic rooftops to meet its current electrical energy demand, or do we actually have this much of an area? The actual acceptable roof area available for renewable energy generation is collected by a physical domestic **questionnaire survey** of the whole Punjab of every house size ranges. Where the respondents were asked how much their roof area is, and how much of this area that we are willing to use for Solar energy generation. It was important for us to know because we are interested in using this actual available area in our calculations. This approach makes this research novel, as it is utilizing the actual available area on the ground in producing the '**Area Solar Model'** to calculate generation potentials.

Step 5-What percentage (%) of demand can be met by green energy

In the last step to calculate the generation potential from the domestic rooftop, we have taken in to account the findings of all previous four steps. It included calculating what we can generate/$m^{2,}$ what we need/m2, how much area we need to produce the current demand and how much actual area we have available to install solar PV. By utilizing the findings of all these questions, we will calculate the complete or percentage (%) of the current electrical energy demand of each house size in all ten divisions. We will highlight or compare the area we need to have to meet the current demand and actual area we have.

The approach used for solar thermal: We followed a potential measurement procedure, based on the number of steps, to calculate the energy generation possibilities by solar thermal technology installed on the domestic rooftop. Figure 4.3 shows the procedural steps we followed to calculate solar thermal potential, consisting of 5 steps, and these steps are repeated for every division and every house size in our data set.

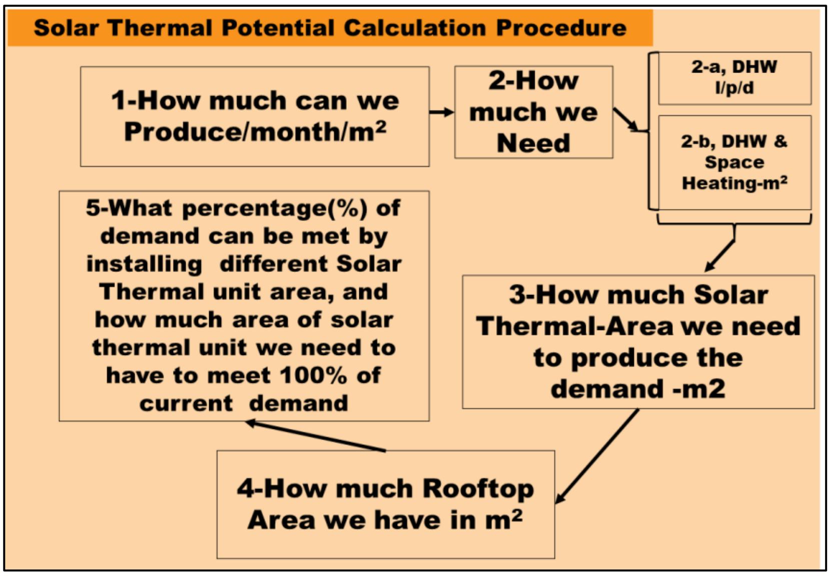


Figure 4.3 Steps of Solar thermal potential calculation procedure for all house sizes

Step1-How much can we **produce**/month/m^2?

To calculate the heating energy (kWh) generation potential from the domestic rooftop, we performed simulations. The actual climatic data of each division of Punjab was used in the simulation. We used two different software to calculate the solar thermal potential, i.e. RETScreen and Valentin are the software used for the simulations. In all simulations, evacuated and flat tube collectors were used, and different specifications/descriptions used in the simulations are given in Table 4.3. We used the local climatic data of every division and the angle of installation (Slope) used was the optimum angle for energy generation we found for every division[8]. For all calculations, we run simulations for (a) domestic hot water (DHW) requirements, (b) DHW and space heating needs (both were taken in one simulation). The results are presented as the active solar thermal area required for each incidence, and the amount of energy saved (kWh) for each house size, and every division of Punjab using two

[8] The cities climatic data used for each division was the city on which the divisions have been given their names, for example, city of Lahore was chosen to calculate the potential of 'Lahore division'.

different types of solar thermal, i.e. evacuated or flat tube collectors. The final useable energy produced from solar thermals is discussed in chapter 5. The winter period, between October-March, of six months, is taken in simulations.

Table 4.3 Specifications used for solar thermal

Solar Thermal	
Type (used in simulation)	Evacuated tube Collector
Conversion factor	66.8%
Solar collector Active area (m^2)	as per the number of collectors
Miscellaneous losses %	10%
Slope (installations)	32-40 degree (as per optimum angles of each division)
Storage Tank	
Capacity	1000-3000L (as per the size of collector used) the storage capacity is taken as 50L/M2 area of solar collector,
Miscellaneous losses %	miscellaneous losses of pipes and storage tank are taken as 7+7=14%
Losses	5.29kWh/day
Domestic hot water (DHW)	
Number of hot water(litres) required	the average use of daily water is taken as 90l/p and 47% of it, would be **42 l/p** is taken as hot water required per person
Occupancy of households	The average occupancy of every house size of every division is taken in simulations, from survey data
Hot water temperature required	60C (is taken as the required temperature in simulation)
Space Heating	
Area(m^2)	The complete area of every house size is taken in simulation for space heating
Space temperature maintained	21C

Step 2-How much heating energy(kWh) do we need/month

2-a: Domestic hot water (DHW), we have taken 90 litres water required per person/day (excluding toilet flushing) as a standard in our calculations (taken from literature). The hot water requirement is taken as 47% of daily water needed per person/day, so (90L*47%= 42L) 42 litres of hot water is considered as a standard requirement in all simulations having a temperature of 60C. The occupancy level of each house is taken from the physical survey data, and average values are used in simulations.

2-b: in other simulations, we have taken DHW and space heating combined requirements for every house size. The DHW requirements are adopted as discussed above, for space heating requirements we have taken the complete gross internal floor area (GIFA) of each house size in every division. The average occupancy level and GIFA, of each house size, is taken from the survey data obtained by questionnaires as discussed before. The space heating is maintained at 21C in all simulations.

Step 3-How much **Solar thermal-area** we need to produce the demand

We put the requirements of DHW and space heating for the simulations in the software. The two types of solar thermal were used, and each type of solar thermal have a different active solar area to generate heating energy. We kept on increasing the number of collectors of each type to see how much area of solar thermal collectors we would need to meet the current demand for each instance. It is explained in step five in detail.

Step 4-How much **Rooftop Area** we have in m^2

To know the actual rooftop area, we have from each household, we did the physical survey, and the details are given in step-4 of the solar PV procedure method, the same method was used for solar thermal as well.

Step 5-What percentage (%) of demand can be met by installing different Solar thermal unit area, and how much area of the solar thermal unit we need to have, to achieve 100% of current demand. We were interested to know how much of the roof area we will need if we want to generate all of the heating energy required from solar thermal in both cases either we need it only for DHW or both for DHW and space heating. So, we run the number of **simulations** and noted different values of active solar thermal area(m^2) if we want to meet specific percentages (%) of our heating energy from the sun. We also calculated the solar thermal area required if we must generate the total current demand of each house size of every division. The results are shown and analysed in chapter 5. By adopting this approach, we have linked the generation of heating energy with the actual requirements on the ground for each instance and makes this research unique and novel.

4.5 Summary of the research section

After adopting the research methodologies to answer research objective in chapter 3, this chapter explained in detail how the actual research was conducted and procedures used to get the results, and the results and analysis are presented in the next chapter.

At this stage of the thesis, we have discussed the aims set for the research, explored literature (stage 2), as per our goals and came up with our thesis objectives (stage 3). In the next stage, we looked in the literature (stage 4), what methods other researchers used, and adopted appropriate methods of this research (stage 5). In the next stage, we will present the results and would analyse in terms of what they mean for the thesis objectives, the different stages are summarized in Figure 4.4.

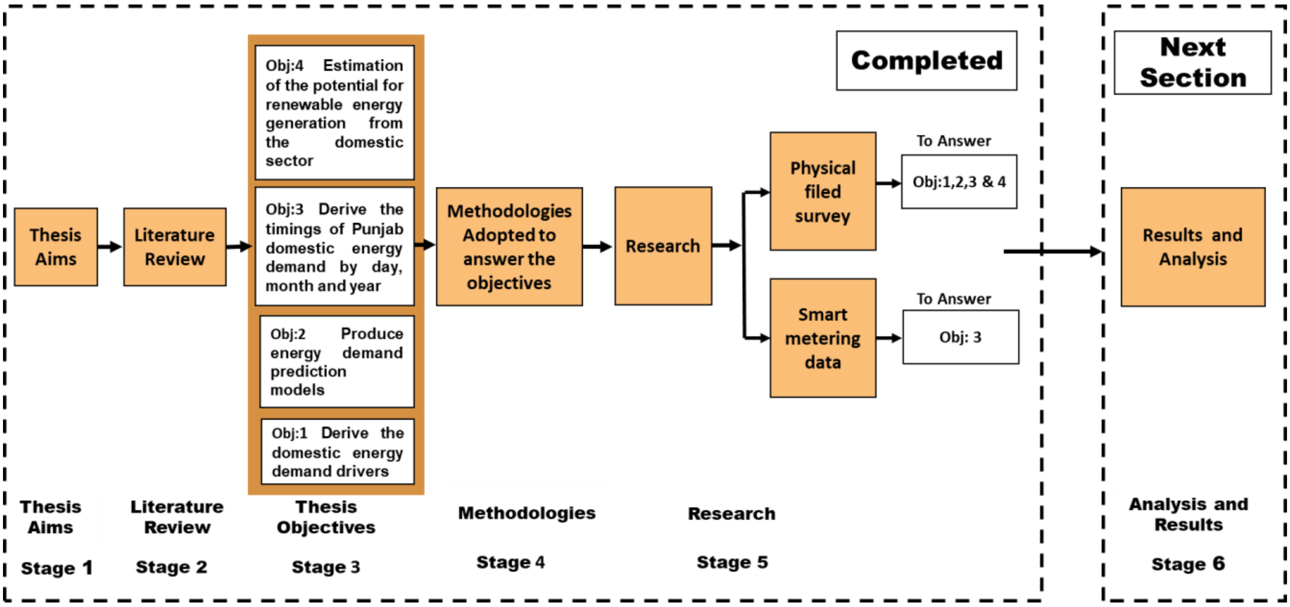


Figure 4.4 Research stages of the thesis 1-5, and description of next stage

Chapter 5

Results and Analysis

5 Results and Analysis

5.1 Introduction

This chapter analyses data obtained in terms of the thesis aims and notes any other notable findings and observations arising from the study. A significant amount of data has been collected from the survey. Therefore, there are many things that can be said. We have seen (in the previous chapter) that data is collected in two datasets, i.e. survey data and smart meter data. We achieved **CL=95%,** and **CI=1.45** for electricity and **CI=1.85** for gas, from different divisions of Punjab. Figure 5.1 shows a glimpse of the research conducted and describes the usage of data sets to answer the research objectives.

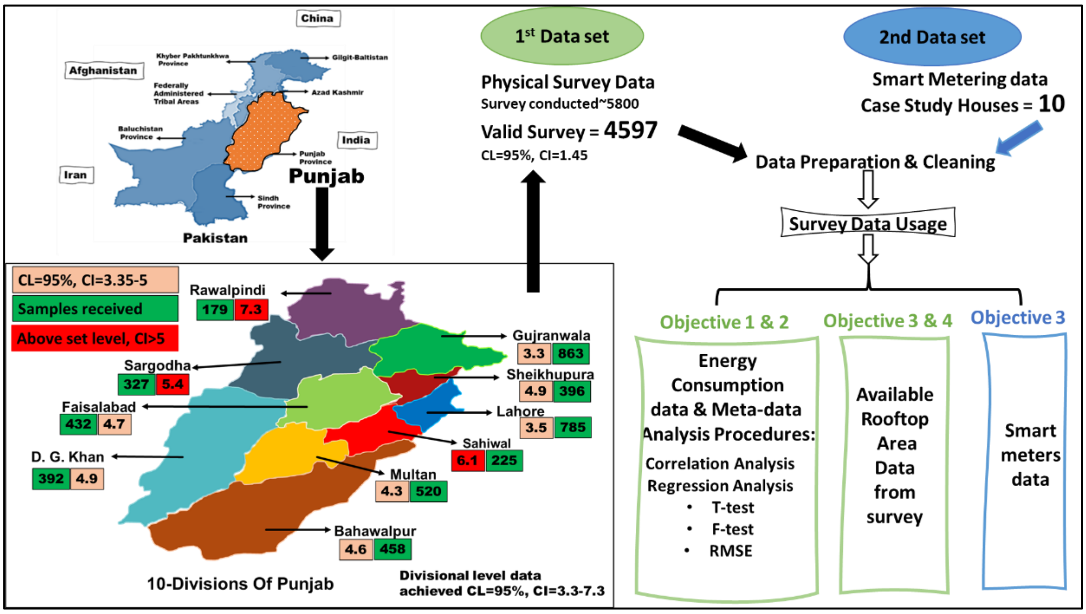


Figure 5.1 Research summary

To make the chapter easy to read, below is the flow chart of the result and analysis chapter, explaining how it is laid out. We will start to look at the answers for objectives 1 and 2, and both objectives are using similar variables, adopting different analysis procedures. At the end of these objectives, we will provide a summary or conclusion. We will follow the same method for objectives 3 and 4. First, we will try to answer or produce models for each objective; then we will conclude each objective in Figure 5.2. At the end of each objective, we will provide an overall conclusion and would try to relate it with the aims and motivations to conduct this research.

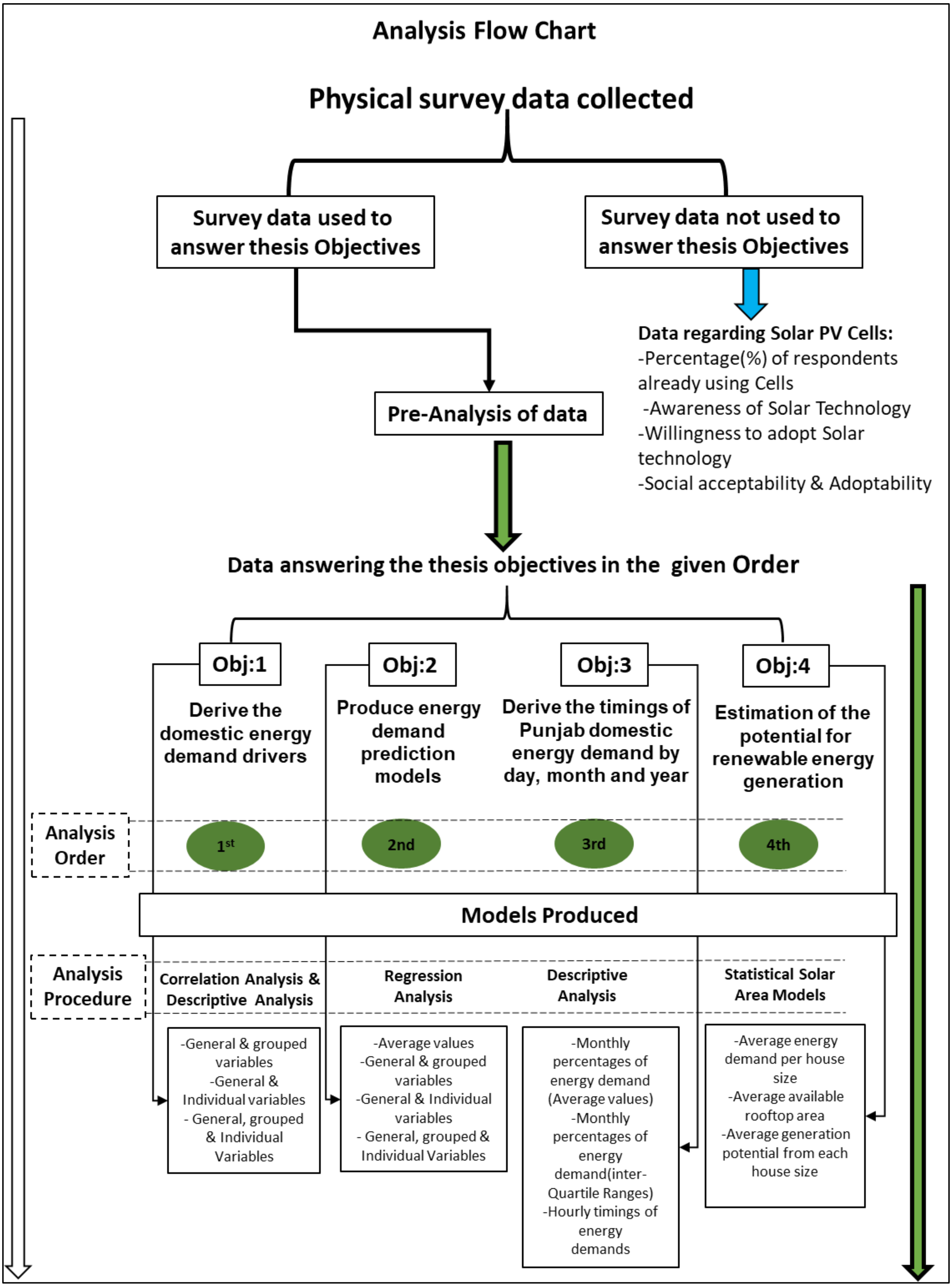


Figure 5.2 Analysis flow chart for chapter 5

5.2 Results and analysis of objective 1 & 2 (drivers & prediction models)

- Derive the domestic energy demand drivers
- Produce energy demand prediction models

The results and analysis to answer objective 1 & 2 is carried out at two levels,

1. Whole Punjab level
2. Divisional[9] level (all ten divisions of Punjab)

The survey data collected covered all 10 Divisions in Punjab (population 110M out of a total Pakistan population of 210M). Analysis of the survey data is done in two parts. In the first part, this analysis addresses the whole Punjab Province and demonstrates the application of the methodology and analysis approach taken. The divisional level data sets are then analysed in the second part. Where the impact on the Punjab level conclusions from considering the data at the ten individual divisional levels will be discussed for research objectives 1 & 2. We will then address if the results drawn for the whole of Punjab are affected when different ten divisional data are analysed. The building floor area data is presented in m^2 rather than the more commonly used Pakistan's floor area unit of the Marla (1 Marla = 20.9m^2).

The domestic sector of the Punjab province is studied through a survey methodology designed to yield statistically significant results. Figure 5.3 shows, the assessment is based on actual billed consumption data, household floor area, occupancy level, number of conditioned rooms and their area, appliances ownership, appliances ratings, and usage hours/day data, for the year 2017-18 obtained from individual household questionnaires collected via physical surveys. The questionnaire is provided in **Appendix B**. The data is analysed using correlation coefficients to understand demand drivers. The data is also divided into two sets for regression analysis to produce separate equations for each fuel type, i.e. electricity and gas. Six equations are derived for electricity, three each for per household and capita. Two are derived for gas fuel type one each for per household and per capita. These analyses were used to determine energy consumption data for the survey year and produce prediction models of consumption based on variable changes.

[9] Division- it is an administrative unit of Punjab Province, Punjab consists of 10 divisions

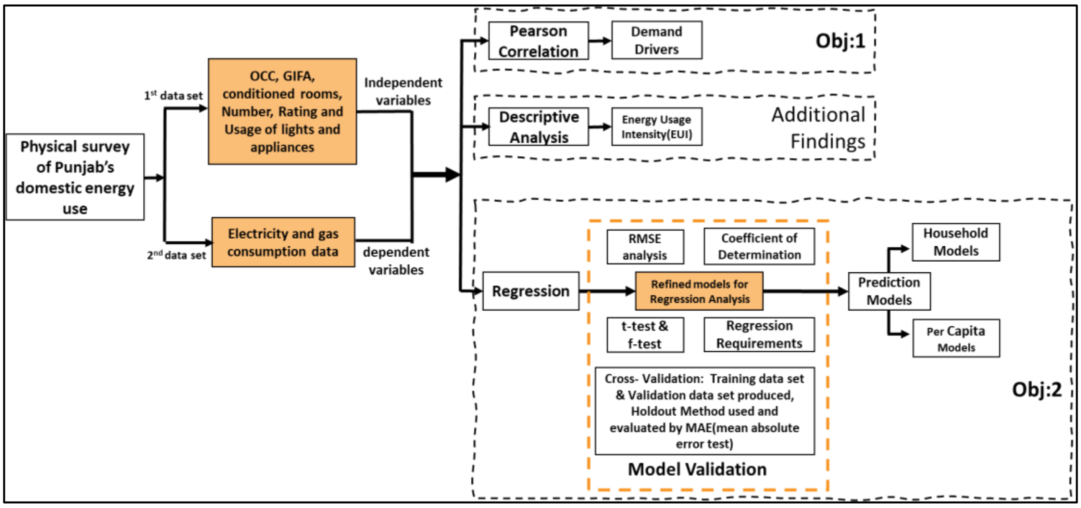


Figure 5.3 Method flowchart for objective 1 & 2

The methodology adopted to conduct the physical survey, data preparations, validation and analysis procedures adopted are discussed in detail in chapter 3, and the method we used to extract information and to develop models are shown in Figure 5.3. It must be noted that we have also calculated Energy Usage Intensity (EUI) at per household and per capita level, as additional findings, in our research which was not set as one of the objectives. We calculated EUI for the whole Punjab and at individual division levels. The results are presented for objective 1(demand drivers) first, then the results of EUI are shown in the end, the results of objective 2 (prediction models) are produced.

5.2.1 Variables groupings

The data collected from the survey is divided into three main variable categories (see detail in Figure 5.4 & Table 5.1) and explained below

(a) Indirect Variables – 4 (occupancy (OCC), gross internal floor area (GIFA), number of conditioned rooms (CON.RMS) and area of conditioned rooms (CON.RM.AR). These variables do not directly consume energy

(b) Direct variables-63 (the list is provided in the questionnaire Figure 5.4, 21 individual appliances and lights variables at three levels, i.e. number, rating and usage) Table 5.1. These variables directly consume energy.

(c) Grouped Variables – 9 (number of appliances, lights and the combined number of appliances +lights, Rating of the appliance, lights and combined rating of appliances + lights, usage of the appliance, lights and the combined number of appliances +lights). Groupings of direct variables to help simplify physical surveys.

Table 5.1 Survey variables and their confidence level and confidence interval achieved, for correlation and regression analysis

Survey Questions or Variables	**Acronym**	**Responses Received**	**Confidence level=95%, with Confidence intervals, CI**
Indirect Variables			
How many people are usually living in the house? (also include house worker(s)/servant(s) who live(s) in the same house?	OCC	4597	1.45
What is the total covered area of your house? (Gross internal floor area)	GIFA	4597	1.45
What is the total number of conditioned rooms (rooms which are heated and/or cooled) in your house?	CON.RM	4388	1.48
What is the total combined area of conditioned rooms?	CON.RM.AR	2515	1.95
How much electricity do you use per month(kWh) or per year?	kWh/year	4597	1.45
How much Gas do you use per month(kWh) or per year?	kWh/year	2901	1.8

Grouped Variables									
	Acronym			**Responses Received**			**Confidence level=95%, with Confidence intervals, CI**		
	#	**Rating (kW)**	**Use (kWh)**	**Number (Owned)**	**Rating (kW)**	**Use (kWh) /day**	**Number (Owned)**	**Rating (kW)**	**Use (kWh) /day**
Number of appliances, Rating (Appliances) & Usage (Appliances)	APP	APP (kW)	APP (kWh)	4479	4479	4287	1.46	1.46	1.50
Number of Lights, Rating (Lights) & Usage (Lights)	LTS	LTS (kW)	LTS (kWh)	4473	4491	4265	1.46	1.46	1.51
Number of appliances and lights, Rating (Appliances +Lights) & Usage (Appliance + Lights)	APP+ LTS	APP+LTS (kW),	APP+ LTS (kWh)	4519	4519	4348	1.46	1.46	1.48
Direct Variables									
# of Fluorescent tube lights, their wattage(W), and their average seasonal use per day(kWh)?	FTL,	FTL (kW)	FTL (kWh)	1921	1921	1784	2.24	2.24	2.32
# of Incandescent Bulbs, their wattage(W), and their average seasonal use per day(kWh)?	IB	IB (kW)	IB (kWh)	566	566	513	4.12	4.12	4.33
# of Compact Fluorescent bulbs, their wattage(W), and their average seasonal use per day(kWh)?	ES	ES (kW)	ES (kWh)	4071	4071	3853	1.54	1.54	1.58

# of LED & SMD, their wattage(W), and their average seasonal use per day(kWh)?	LED	LED (kW)	LED (kWh)	1202	1202	1069	2.83	2.83	2.99
# of Fan(s) (bracket, ceiling, Pedestal, etc.), their wattage(W), and their average seasonal use per day(kWh)?	FN	FN (kW)	FN (kWh)	4455	4455	4227	1.47	1.47	1.51
# of Air conditioner(s) (cooling only), their wattage(W), and their average seasonal use per day(kWh)?	ACONC	ACONC (kW)	ACONC (kWh)	1807	1807	1694	2.30	2.30	2.38
	Acronym			**Responses Received**			**Confidence level=95%, with Confidence intervals, CI**		
	#	**Rating (kW)**	**Use (kWh)**	**Number (Owned)**	**Rating (kW)**	**Use (kWh) /day**	**Number (Owned)**	**Rating (kW)**	**Use (kWh) /day**
# of Air conditioner(s) (heating only), their wattage(W), and their average seasonal use per day(kWh)?	ACONH	ACONH (kW)	ACONH (kWh)	65	65	55	12.2	12.2	13.3
# of Air conditioner(s) (both cooling & heating), their wattage(W), and their average seasonal use per day(kWh)?	ACONCH	ACONCH (kW)	ACONCH (kWh)	59	59	40	12.8	12.8	15.5
# of Direct electric heater (bar, fan heaters, etc.), their wattage(W), and their average seasonal use per day(kWh)?	DEH	DEH (kW)	DEH (kWh)	349	349	328	5.25	5.25	5.41
# of Fridge(s), their wattage(W), and their average seasonal use per day(kWh)?	FRG,	FRG (kW)	FRG (kWh)	3906	3906	3712	1.57	1.57	1.61
# of Freezer(s), their wattage(W), and their average seasonal use per day(kWh)?	FRZ	FRZ (kW)	FRZ (kWh)	408	408	358	4.85	4.85	5.21
# of Television(s), their wattage(W), and their average seasonal use per day(kWh)?	TV	TV (kW)	TV (kWh)	3756	3756	3547	1.60	1.60	1.65
# of Computer(s) & Laptop(s), their wattage(W), and their average seasonal use per day(kWh)?	CM.LP	CM.LP (kW)	CM.LP (kWh)	1396	1396	1212	2.62	2.62	2.81
# of Microwave(s), their wattage(W), and their average seasonal use per day(kWh)?	MW	MW (kW)	MW (kWh)	1153	1153	1007	2.88	2.88	3.10
# of games consoles/video games, etc., their wattage(W), and their average seasonal use per day(kWh)?	PS.VG	PS.VG (kW)	PS.VG (kWh)	85	85	70	10.63	10.63	11.72
# of Cooker extract fan, their wattage(W), and their average seasonal use per day(kWh)?	SEF	SEF (kW)	SEF (kWh)	302	302	240	5.63	5.63	6.33
# of Extract fan (kitchen, bathrooms, etc.), their wattage(W), and their average seasonal use per day(kWh)?	EF	EF (kW)	EF (kWh)	1317	1317	1268	2.70	2.70	2.75
# of Internet Modem/router/hub, etc., their wattage(W), and their average seasonal use per day(kWh)?	IM	IM (kW)	IM (kWh)	728	728	455	3.63	3.63	4.59
# of washing machines(s) their wattage(W), and their average seasonal use per day(kWh)?	WM	WM (kW)	WM (kWh)	3261	3261	2984	1.72	1.72	1.79

# of the vacuum cleaner(s), their wattage(W), and their average seasonal use per day(kWh)?	VC	VC (kW)	VC (kWh)	206	206	131	6.83	6.83	8.60
# of water cooler/Desert cooler(s) their wattage(W), and their average seasonal use per day(kWh)?	DC	DC (kW)	DC (kWh)	411	411	281	4.85	4.85	5.84

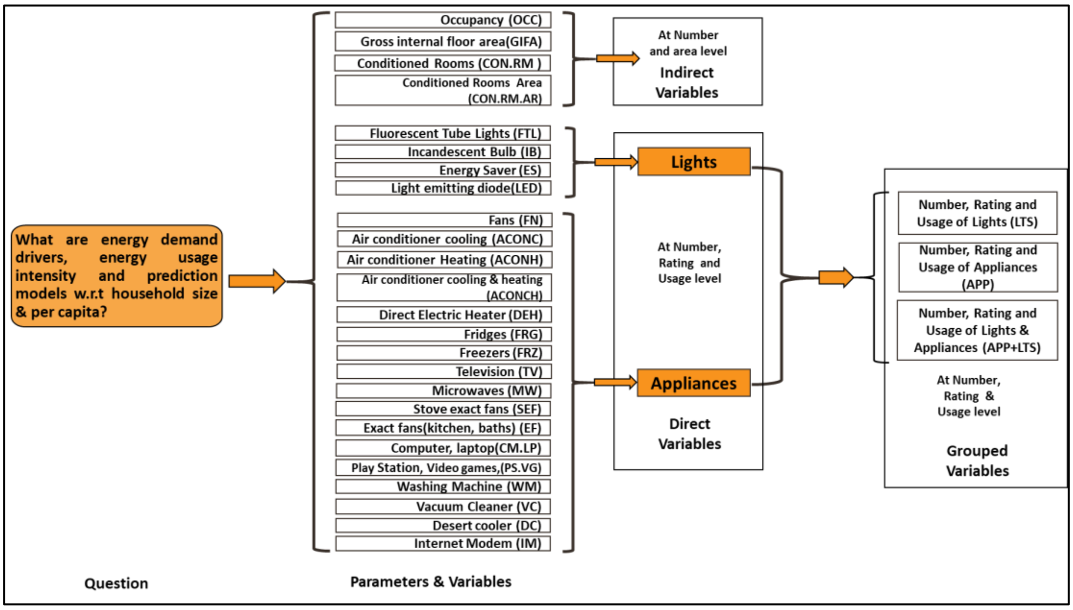


Figure 5.4 Domestic energy demand parameters and variables covered in the physical survey

Selection of prediction models for whole Punjab and all divisions

The models selected for the final analysis were those with the following characteristics:

- the lowest RMSE,
- the highest coefficient of determination R^2,
- satisfying predictive strengths (f-test) of models,
- individual variables with unique predictive values (t-test) at sig. p<0.001, and
- meeting the required regression assumptions (as presented in section)

5.2.2 Results and analysis of whole Punjab

The house sizes covered in the survey range from $20.9m^2$ to $418m^2$, which includes the dominant house sizes in Punjab. The average house size is $109m^2$, and the house size of $104.5m^2$ is the most surveyed house in the data set shown in Table 5.2. The average size available per capita is $17m^2$. The minimum and maximum values of m^2 per capita are $2.9m^2$ and $146.3m^2$, respectively (Table 5.2). These variations show that the data set covers the full range of Punjab society and provides further confidence in the general application of the findings.

Table 5.2. House area and per capita area of the sample houses

Values	House size (m^2)	Capita(m^2)
Mean	109	17
Median	104.5	14.9
Mode	104.5	20.9
Standard Dev	70.5	10.2
Minimum	20.9	2.9
25th percentile	62.7	11.9
75th percentile	125.4	20.9
Maximum	418	146.3

The results are presented in three parts. In the first part, the current Punjab energy demand drivers in the domestic sector are shown (5.2.2.1)(objective 1). In the second part, energy usage intensity (EUI) is presented using descriptive statistics (5.2.2.2)(additional findings), and in the third part, energy consumption prediction models are presented, utilizing simple & multiple regression procedures (5.2.2.3)(objective 2)

5.2.2.1 Domestic demand drivers (whole Punjab)

Pearson's correlations for the dependent variable, annual electricity consumption per household (kWh/year.), and the independent variables defined in Table 5.1 are shown in Table 5.3. A correlation > 0.3 is taken as a reasonable correlation to show that the variables have a relationship with the dependent variable. Table 5.3 shows the hierarchal correlations of annual electricity consumption for per household and capita with independent variables.

Per household(electricity): The results of modelling the **direct and indirect** variables per household show CON.RMS (r=0.604), CON.RM.AR (r=0.554), ACONC (kW) (r=0.553), ACONC (r=0.543) and ACONC (kWh) (r=0.504) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP+LTS (r=0.636), APP (kW)+LTS (kW) (r=0.629), APP (r=0.617), APP (kW) (r=0.616) and CON.RMS (r=0.604) have a good correlation with the dependent variable. (Figure 5.5 & Figure 5.6)

Per Capita(electricity): The results of modelling the **direct and indirect** variables per capita show ACONC (kW) (r=0.569), ACONC (r=0.558), CON.RMS (r=0.550), CON.RM.AR (r=0.538) and ACONC (kWh) (r=0.524) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP (kW) (r=0.655), APP (kW)+LTS (kW) (r=0.654), APP (r=0.637), APP+LTS (r=0.626) and APP(kWh)+LTS(kWh) (r=0.580) have good correlations with the dependent variable. (Figure 5.5 & Figure 5.6)

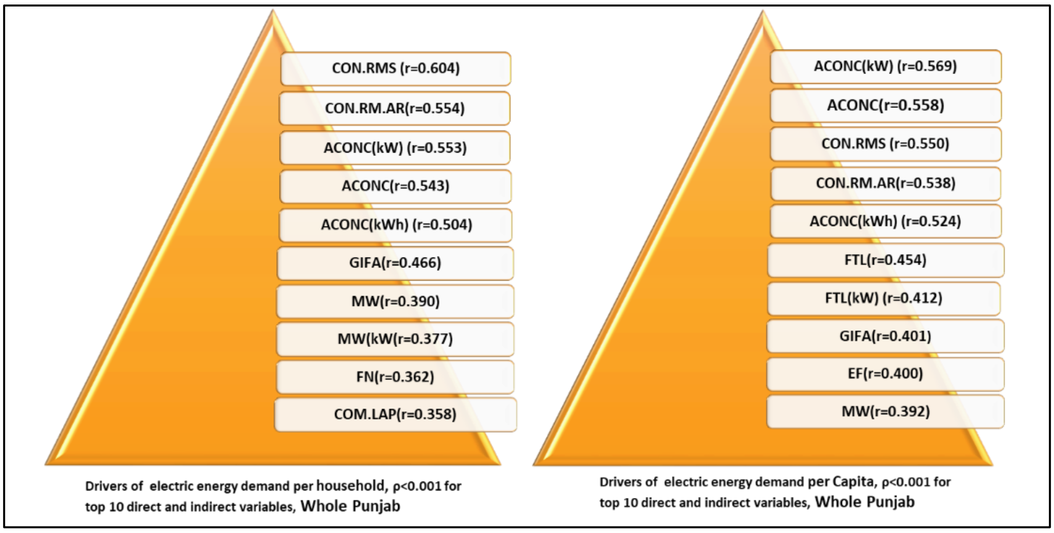


Figure 5.5 Hierarchical presentation of top 10 electricity demand drivers per household and per capita in Punjab, Pakistan for direct and indirect variables

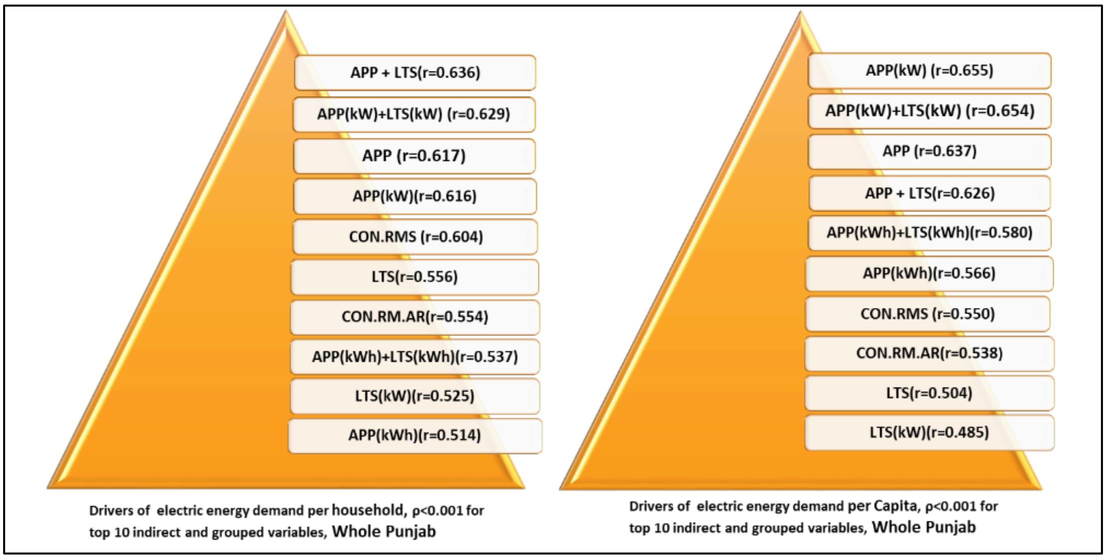


Figure 5.6 Hierarchical presentation of top 10 electricity demand drivers per household and per capita in Punjab, Pakistan for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Table 5.3[10], which shows the strongest correlation is with the total number of APP+LTS (r=0.636), for the per household model, and with an installed electrical capacity of the appliances APP (kW) (r=0.655), for the per capita model.

[10] **Note:** Correlations (r ≥ 0.30) are shown in Table 5.3 in the descending order for both models (i.e. per household and per capita).

Table 5.3 Hierarchal Pearson's correlations statistics of electric energy models for direct, indirect and grouped variables

Hierarchal Correlations of all variables				
Sr. No	Model Electric kWh/year per Household		Model Electric kWh/year per Capita	
	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)
1	APP+LTS	0.636	APP (kW)	0.655
2	APP (kW)+LTS (kW)	0.629	APP (kW)+LTS (kW)	0.654
3	APP	0.617	APP	0.637
4	APP (kW)	0.616	APP+LTS	0.626
5	CON.RMS	0.604	APP (kWh)+LTS (kWh)	0.580
6	LTS	0.556	ACONC (kW)	0.569
7	CON.RM.AR	0.554	ACONC	0.558
8	ACONC (kW)	0.553	APP (kWh)	0.566
9	ACONC	0.543	CON.RMS	0.550
10	APP (kWh)+LTS (kWh)	0.537	CON.RM.AR	0.538
11	LTS (kW)	0.525	ACONC (kWh)	0.524
12	APP (kWh)	0.514	LTS	0.504
13	ACONC (kWh)	0.504	LTS (kW)	0.485
14	GIFA	0.466	FTL	0.454
15	LTS (kWh)	0.437	FTL (kW)	0.412
16	MW	0.390	GIFA	0.401
17	MW (kW)	0.377	EF	0.400
18	FN	0.362	MW	0.392
19	COM.LAP	0.358	FTL (kWh)	0.388
20	FTL	0.350	LTS (kWh)	0.384
21	FTL (kW)	0.350	WM	0.370
22	MW (kWh)	0.343	MW (kW)	0.355
23	FTL (kWh)	0.333	FRG	0.350
24	OCC	0.332	TV	0.348
25	FRG	0.330	EF (kW)	0.344
26	TV	0.329	FRG (kWh)	0.346
27	FN (kWh)	0.325	FN	0.326
28	LED/SMD	0.318	FRG (kW)	0.325
29	ES	0.315	FN (kWh)	0.324
30	EF	0.311	MW (kWh)	0.319
31	COM.LAP (kW)	0.300	TV (kWh)	0.317
32	-	-	DEH	0.314
33	-	-	DEH (kW)	0.309

Per household and capita (gas): Acceptable gas correlations are only to the size of the house (GIFA), where r= 0.228 & 0.280 for the per household and capita models, respectively. The other variable, i.e. occupancy of the house does not show any reasonable correlation with the dependent variable, and it is close to zero.

5.2.2.2 Energy usage intensity (EUI) (additional findings)

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (Table 5.4):

- The average household electric and gas energy use is around 2401 kWh/annum and 5245 kWh/annum, respectively.
- Per capita, the average energy use is 391 kWh/capita/annum and 769.5 kWh/capita/annum for electricity and gas, respectively.
- The average energy use per m^2 per household is 26 kWh/m^2/annum and 55 kWh/m^2/annum for electricity and gas, respectively.
- The average energy use per m^2 per capita is 5kWh/m^2/capita/annum and 8.3 kWh/m^2/capita/annum for electricity and gas, respectively.
- The ranges of electric and gas demand are significant in both per household and per capita models.

Table 5.4 Energy usage intensity

Survey findings						
Utility	**N**	**Average**	**S.D.**	**Median**	**Min.**	**Max.**
kWh/household/a						
Electric	4597	2401	1568.1	2103	3.0	12762
Gas	2901	5245	4764	4188.4	40.6	31380.5
kWh/capita/a						
Electric	4597	391	248.1	339.5	0.65	2973
Gas	2901	769.5	743	594.3	5.8	8152.5
kWh/m^2.household/a						
Electric	4597	26	18.6	22	0.05	288.2
Gas	2901	55	61.4	34.2	0.32	642.5
kWh/m^2.capita/a						
Electric	4597	5	3.9	3.54	0.01	52.7
Gas	2901	8.3	10.4	5	0.05	203.5

The data collected also allows us to consider these figures every month. The average EUI for electric and gas use per household per month can be seen in Figure 5.7 and Figure 5.8. Over a year, the EUI/month ranges from 114kWh to 303kWh for electricity use. For gas use, the monthly range is from 269 kWh to 673 kWh. They reveal the importance of electrically driven cooling in the Summer and gas driven heating in the Winter on overall loads.

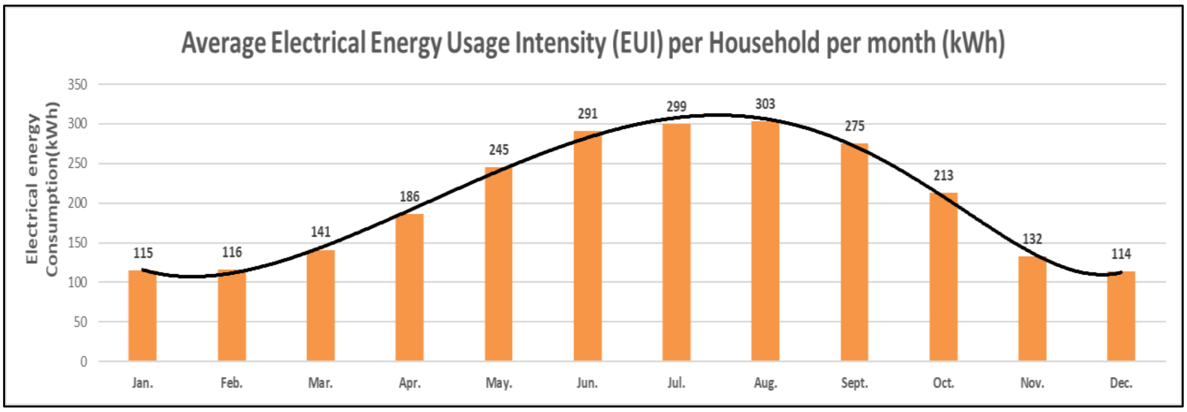


Figure 5.7 Average electrical energy intensity (EUI) per household per month

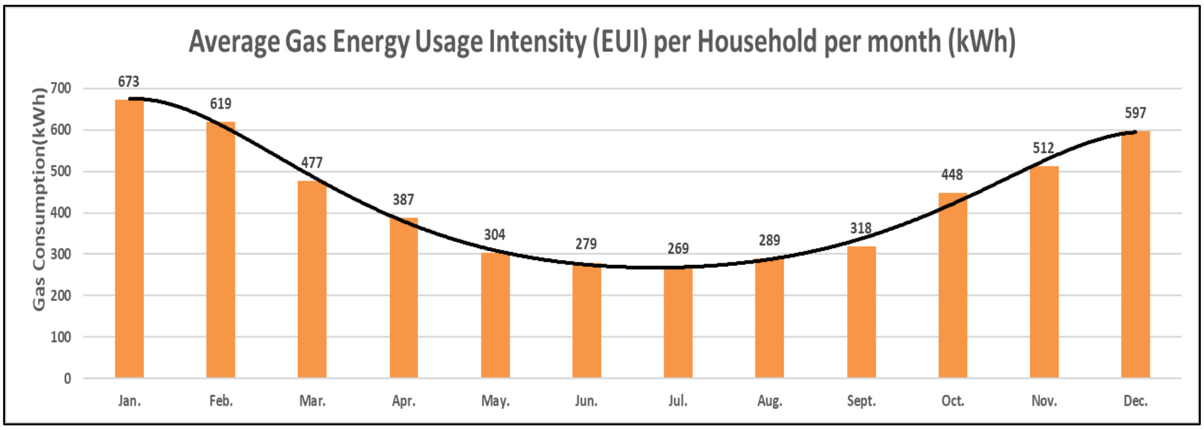


Figure 5.8 Average gas energy intensity (EUI) per household per month

5.2.2.3 Energy consumption prediction models (objective 2)

Eight energy consumption (kWh/year) prediction models are presented, six for electricity and two for gas usage.

Named as:

- Detailed models (direct + indirect variables)
- Grouped models (indirect + grouped variables)
- Combined models (detailed+ grouped models, OR direct, indirect and grouped variables)

For electricity and gas, all these models are produced at per household and capita levels. For gas, as we have only one predictive variable, i.e. GIFA, we have just named them as per household and per capita models. The three models were produced to enable their use with different data availability. There is not a significant difference between their accuracies, so all should give similar results.

5.2.2.3.1 Descriptive statistics for models' final predictive variables

Table 5.5 presents the means and standard deviations of the dependent (criterion) and independent (predictor) variables of the final models derived. The correlations of electrical models' variables with the dependent variable (electricity consumption kWh) are shown in Table 5.3 and gas GIFA is the only predictor variable in the data set for both gas models. The dependent variable (kWh/yr.) and independent variable (GIFA) are related by 0.228 & 0.280 (Pearson's correlation) for per household and per capita gas models, respectively. Only simple regression models can be produced for gas consumption predictions.

Table 5.5. Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			PER CAPITA		
Electricity use per household of Detailed model			Electricity use per capita of Detailed model		
Variable	Mean-unit	Std. Deviation	Variable	Mean-unit	Std. Deviation
kWh/yr.	2401 kWh	1568.1	kWh/yr. /capita	390.6 kWh	248.1
OCC	6.44	2.4	GIFA/capita	17.5	10.2
GIFA	109.3 m^2	70.5	FN/capita	0.59 m^2	0.35
FN	3.73	2.22	DEH/capita	0.015	0.06
FRG	0.92	0.47	FRG/capita	0.16	0.11
TV	1.1	0.73	MW/capita	0.043	0.08
ES	5.3	4.2	ACONC (kW) /capita	0.11	0.16
LED/SMD	1.3	3.1	TV (kWh) /capita	0.16	0.15
MW	0.26	0.47	CON.RM.AR/capita	0.99	1.39
FTL	1.3	1.99	FTL/capita	0.24	0.35
CON.RMS	1.6	1.1	-		
Electricity use per household of Grouped model			Electricity use per capita of Grouped model		
Variable	Mean	Std. Deviation	Variable	Mean	Std. Deviation
kWh/yr.	2401 kWh	1568.1	kWh/yr./capita	391 kWh	248.1
OCC	6.44	2.4	GIFA/capita	17.5 m^2	10.2
GIFA	109.3	70.5	APP (kW)+LTS (kW)/capita	0.36 kW	0.31
APP+LTS	17.3	9.76	CON.RM.AR/capita	0.99 m^2	1.4
CON.RMS	1.63	1.1	-		
Electricity use per household Combined model			Electricity use per capita Combined model		
Variable	Mean	Std. Deviation	Variable	Mean	Std. Deviation
kWh/yr.	2401 kWh	1568.1	kWh/yr. /capita	390.6 kWh	248.1
OCC	6.44	2.4	GIFA/capita	17.5 m^2	10.2
GIFA	109.3 m^2	70.5	FN/capita	0.6	0.36
FN	3.73	2.21	DEH/capita	0.02	0.06
FRG	0.92	0.47	FRG/capita	0.16	0.11
LED/SMD	1.26	3.06	TV (kWh) /capita	0.16 kWh	0.16
FTL	1.32	1.99	CON.RM.AR/capita	0.98 m^2	1.39
CON.RMS	1.63	1.03	FTL/capita	0.24	0.35
APP (kW)	1.96 kW	1.75	APP (kW) + LTS (kW)/Capita	0.36 kW	0.31
ES	5.31	4.15	-		
Gas use per household model			Gas use per capita model		
Variable	Mean	Std. Deviation	Variable	Mean	Std. Deviation
kWh/yr.	5245 kWh	4764	kWh/yr./capita	769.5 kWh	743
GIFA	121.57 m^2	77.1	GIFA /capita	17.45 m^2	11.63

5.2.2.3.2 Strength of models

Two methods of deciding which variables were included or removed from the models were adopted. These were the 'stepwise' and 'forward' methods. In both methods, variables with $p<0.05$ and independent variables with the smallest partial correlations, which have no significance, were removed until the best-fit models were obtained. The final method chosen was 'enter' Table 5.6.

The models selected for the final analysis were those with the following characteristics:

- the lowest RMSE,

- the highest coefficient of determination R^2,
- satisfying predictive strengths (f-test) of models,
- individual variables with unique predictive values (t-test) at sig. p<0.001, and
- meeting the required regression assumptions (as presented in section)

Table 5.6 Strength of the electricity and gas use per household and capita models

Models Summary				
R	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**
Electricity use per household of Detailed model				
0.723	0.523	0.522	1084.6	1.65
Electricity use per household of Grouped model				
0.719	0.517	0.517	1090.3	1.62
Electricity use per household of Combined model				
0.729	0.531	0.53	1075.1	1.65
Electricity use per Capita of Detailed model				
0.698	0.487	0.486	177.8	1.60
Electricity use per Capita of Grouped model				
0.727	0.528	0.527	170.6	1.66
Electricity use per Capita of Combined model				
0.729	0.532	0.531	169.9	1.66
Gas per household area model				
0.228	0.056	0.052	4054.9	0.78
Gas per capita model				
0.280	0.078	0.078	713.46	0.87

5.2.2.3.3 Analysis of model coefficients

The higher the beta value of the independent variables, the higher the strength it has to explain the dependent variable (Table 5.7).

Table 5.7 Predictive coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
Constant	-206.3							Constant	103.4						
OCC	56.8	0.09	6.7	0.000	0.099	0.64	1.6	GIFA/capita	2.13	0.09	7.5	.000	0.11	0.74	1.4
GIFA	1.62	0.07	5.5	0.000	0.081	0.59	1.7	FN/capita	136.9	0.2	18.1	.000	0.26	0.88	1.2
FN	77.33	0.11	7.8	0.000	0.12	0.53	1.9	DEH/capita	661.9	0.15	14.2	.000	0.21	0.88	1.1
FRG	191.1	0.06	4.9	0.000	0.072	0.77	1.3	FRG/capita	215.2	0.09	7.6	.000	0.11	0.72	1.4
TV	120.6	0.06	4.8	0.000	0.070	0.76	1.3	MW/capita	228.1	0.08	6.3	.000	0.09	0.75	1.3
ES	47.94	0.13	9.4	0.000	0.138	0.57	1.8	ACONC (kW)/capita	299.8	0.2	13.9	.000	0.20	0.51	1.9
LED/SMD	62.1	0.12	10.5	0.000	0.153	0.78	1.3	TV (kWh)/capita	121.2	0.08	6.5	.000	0.10	0.76	1.3
MW	219.44	0.07	5.5	0.000	0.080	0.73	1.4	CON.RM.AR/ capita	45.9	0.26	19.4	.000	0.28	0.58	1.7
FTL	117.62	0.15	12.4	0.000	0.180	0.71	1.4	FTL/capita	71.1	0.10	8.2	.000	0.12	0.68	1.5
CON.RMS	566.96	0.37	28.6	0.000	0.389	0.62	1.6	-							
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
Constant	-55.41							Constant	165.3						
OCC	53.27	0.08	6.8	0.000	0.099	0.74	1.4	GIFA/capita	2.48	0.102	8.5	0.000	0.13	0.77	1.3
GIFA	1.39	0.06	4.8	0.000	0.070	0.61	1.6	APP (kW)+LTS (kW)/capita	404.33	0.501	37.9	0.000	0.49	0.64	1.6
APP+LTS	61.73	0.39	28.8	0.000	0.391	0.59	1.7	CON.RM.AR/ capita	37.45	0.211	15.9	0.000	0.23	0.64	1.6
CON.RMS	548.68	0.36	28.2	0.000	0.383	0.64	1.6	-							
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
Constant	-89.28							Constant	101.8						
OCC	67.14	0.10	8.1	0.000	0.118	0.64	1.6	GIFA/capita	1.9	0.08	6.6	0.000	0.097	0.74	1.4

GIFA	1.45	0.07	4.9	0.000	0.073	0.59	1.7	FN/capita	112.1	0.16	14.6	0.000	0.210	0.84	1.2
FN	70.1	0.1	7.2	0.000	0.105	0.54	1.9	DEH/capita	415.8	0.096	8.3	0.000	0.121	0.75	1.3
FRG	135.1	0.04	3.5	0.000	0.051	0.77	1.3	FRG/capita	124.4	0.053	4.3	0.000	0.063	0.67	1.5
LED/SMD	58.51	0.11	9.9	0.000	0.146	0.78	1.3	TV (kWh)/capita	97.9	0.061	5.3	0.000	0.077	0.76	1.3
FTL	97.15	0.12	10.1	0.000	0.147	0.68	1.5	CON.RM.AR/ capita	45.7	0.257	19.8	0.000	0.280	0.61	1.7
CON.RMS	445	0.29	19.2	0.000	0.273	0.45	2.3	FTL/capita	62.32	0.089	7.2	0.000	0.105	0.67	1.5
APP (kW)	178.3	0.19	11.8	0.000	0.171	0.36	2.8	APP (kW)+LTS (kW)/capita	245.7	0.305	18.2	0.000	0.260	0.37	2.7
ES	44.84	0.19	8.9	0.000	0.130	0.57	1.8	-							
Gas use per household model								**Gas use per capita model**							
Constant	3532.2							Constant	458.1						
GIFA	14.1	.228	12.6	.000	.228	1.0	1.0	GIFA/CAPITA	17.85	0.280	15.68	0.000	0.280	1.0	1.0

5.2.2.3.4 Analyses of the annual electricity consumption prediction per household model

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each individual variables, and explained below in the following models:

Detailed model explained & equation:

Explained: Whether ten independent variables OCC, GIFA, FN, FRG, TV, ES, LED/SMD, MW, FTL and CON.RMS significantly predicted the annual electricity use (kWh/yr.) per household. The results showed that they explained 52.2% of the variance (R^2=0.522, F (10,4587) =502.6, p<0.001). It was further found that CON.RMS, FTL and ES were the most significant predictors of the ten variables (**β**=0.371, p<0.001), (**β**=0.149, p<0.001) and (**β**=0.127, p=0.001) respectively (Eq-1) (Table 5.7 & Table 5.6).

Equation: Where OCC, GIFA, FN, FRG, TV, MW, ES, LED/SMD, FTL and CON.RMS is known than the following equation is valid to an accuracy of **R^2=0.522**, RMSE=1084.6

$$\bar{Y} = -206.33 + 56.8*(OCC) + 1.62*(GIFA) + 77.33*(FN) + 191.1(FRG) + 120.6(TV) + 47.94(ES) + 62.1(LED/SMD) + 219.44(MW) + 117.62(FTL) + 566.96*(CON.RMS) \quad (1)$$

Grouped model explained & equation:

Explained: If independent variables OCC, GIFA, APP+LTS and CON.RMS significantly predicted the annual electricity use (kWh/yr.) **per household**. The results showed that they explained 51.7% of the variance (R^2=0.517, F (4,4593) =1229.8, p<0.001). It was further found that APP+LTS & CON.RMS was the most significant predictors of the four variables (**β**=0.384 & 0.359, p<0.001). GIFA (**β**=0.062, p<0.001) and OCC (**β**=0.081, p=0.001) were shown to only weakly predict annual energy use per household **(Eq-2)** (Table 5.7 & Table 5.6).

Equation: Where OCC, GIFA, APP+LTS and CON.RMS are known then the following equation is valid to an accuracy of **R^2= 0.517** and RMSE= 1090.3:

$$\bar{Y} = -55.41 + 53.27*(OCC) + 1.39*(GIFA) + 61.73*(APP+LTS) + 548.68*(CON.RMS) \quad (2)$$

Combined model explained & equation:

Explained: Whether independent variables OCC, GIFA, FN, FRG, LED/SMD, FTL, CON.RMS, APP (kW) and ES significantly predicted the annual electricity use (kWh/yr.) **per household**. The results showed that they explained 53.0% of the variance (R^2=0.530, F (9,4588) =576.9, p<0.001). It was found that CON.RMS, FTL and APP (kW) were the most significant predictors (**β**=0.292, p<0.001), (**β**=0.123, p<0.001) and (**β**=0.199, p=0.001) **(Eq-3)** (Table 5.7 & Table 5.6).

Equation: Where OCC, GIFA, FN, FRG, ES, LED/SMD, FTL, CON.RMS and APP (kW) are known than the following equation is valid to an accuracy of (**R^2=0.530**, RMSE=1075.3)

$$\bar{Y} = -89.28 + 67.14*(OCC) + 1.45*(GIFA) + 70.1*(FN) + 135.1*(FRG) + 44.84*(ES) + 58.51*(LED/SMD) + 97.15*(FTL) + 445*(CON.RMS) + 178.3*(APP_{(kW)}) \quad (3)$$

5.2.2.3.5 Analyses of the annual electricity consumption prediction per capita model

Detailed model explained & equation:

Explained: For the **per capita** model, the analysis showed that nine per capita predictors GIFA, FN, DEH, FRG, MW, ACONC (kW), TV (kWh), CON.RM.AR and FTL explained 52.7% of the variance (R^2=0.527, F(9,4588) =570.6, p<0.001). Of these, the most significant predictors were CON.RM.AR/capita (**β**=0.258, p<0.001), FN/capita (**β**=0.196, p<0.001), and ACONC (kW)/capita (**β**=0.196, p<0.001) **(Eq-4)** (Table 5.7 & Table 5.6).

Equation: Where GIFA/capita, FN/capita, DEH/capita, FRG/capita, TV/capita, MW/capita, ACONC (kW)/capita, FTL/capita and CON.RM.AR/capita is known than the following equation is valid to an accuracy of **R^2= 0.527**, RMSE= 170.6

$$\bar{Y} = 103.38 + 2.14*(GIFA/capita) + 136.9*(FN/capita) + 661.9*(DEH/capita) + 215.21*(FRG/capita) + 121.52*(TV_{(kW)/}\ capita) + 228.1*(MW/\ capita) + 299.8*(ACONC_{(kW)/}\ capita) + 71.1*(FTL) + 45.9*(CON.RM.AR/\ capita) \quad (4)$$

Grouped model explained & equation:

Explained: For the **per capita** model, the analysis showed that three predictors, GIFA/capita, APP (kW)+LTS (kW)/capita and CON.RM.AR/capita, explained 48.6% of the variance (R^2=0.486, F (3,4594) =1452.1, p<0.001). APP (kW)+LTS (kW)/capita significantly predicted annual electricity use (kWh/yr./capita) (**β**=0.501, p<0.001), as did CON.RM.AR/capita (**β**=0.211, p<0.001), and GIFA/capita (**β**=0.102, p<0.001) **(Eq-5)** (Table 5.7 & Table 5.6).

Equation: Where GIFA/capita, APP+LTS/capita and CON.RM.AR/capita are known then the following equation is valid to an accuracy of **R^2= 0.486**, RMSE= 177.8:

$$\bar{Y} = 165.33 + 2.48*(GIFA/Capita) + 404.3*(APP\ (kW)+LTS(kW)/Capita) + 37.45*(CON.RM.AR/Capita) \quad (5)$$

Combined model explained & equation:

Explained: For the **per capita** model, the analysis showed that eight per capita predictors GIFA, FN, DEH, FRG, TV (kWh), CON.RM.AR, FTL & APP (kW)+LTS (kW) explained 53.1% of the variance (R^2=0.531, F(8,4589) =651.5, p<0.001). Of these, the most significant predictors were APP (kW)+LTS (kW))/capita (**β**=0.305, p<0.001), CON.RM.AR/capita (**β**=0.257, p<0.001) and FN/capita (**β**=0.160, p<0.001), **(Eq-6)** (Table 5.7 & Table 5.6).

Equation: Where GIFA/capita, FN/capita, DEH/capita, FRG/capita, TV/capita, FTL/capita, CON.RM.AR/capita and APP (kW)+LTS (kW)/capita are known then the following equation is valid to an accuracy of **R^2= 0.531**, RMSE= 170

$\bar{Y}$= 101.77 + 1.9*(GIFA/capita) + 112*(FN/capita) + 415.82*(DEH/capita) + 124.37*(FRG/ Capita) + 97.87*(TV(kW)/ capita) + 62.32*(FTL) + 45.74*(CON.RM.AR/ capita) + 245.64*(APP (kW)+LTS(kW)/capita) (6)

In all three models for per household, we found that number of conditioned rooms and number of appliances & lights are the variables with higher predictive strengths. However, in per capita models, the area of conditioned rooms and the power rating of appliances & lights are better predictors of electrical energy consumption.

For both the 'per household' and 'per capita' models the greatest accuracy (highest R^2, and Least RMSE) is found in the combined model, though probably the most accessible model to use is the grouped model, which does not significantly reduce the accuracy. The model produced by individual variables is in between the two in terms of its use and accuracy. We would recommend the detailed and combined models when more accuracy is required and grouped model where ease of use is of concern. They are all similar in their accuracy, so the choice of which one to use will depend on the format of the information available.

5.2.2.3.6 Analyses of the annual gas consumption prediction per household & capita models

Gas per household model: A simple regression analysis tested whether the independent variable (GIFA) significantly predicted the annual gas use (kWh/yr.) **per household**. The result showed that the predictor explained 5.6% of the variance (R^2=0.056, F (1,2900) =159.1, p<0.001). GIFA therefore, very weakly predicts annual gas use (kWh/yr.) (**β**=0.228, p<0.001). **(Eq-7)** (Table 5.7 & Table 5.6).

Equation: The equation for the prediction of annual gas consumption per household in kWh is: (R^2= 0.056, RMSE= 4050.9)

$\bar{Y}$= 3532.13 + 14.1*(GIFA) (7)

Gas per Capita model: For the per capita model, the analysis showed that the predictor GIFA explained 7.8% of the variance (R^2=0.078, F (1,2800) =245.8, p<0.001). GIFA therefore weakly predicts annual gas use per person (kWh/yr./capita) (**β**=0.280, p<0.001) **(Eq-8)** (Table 5.7 & Table 5.6).

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: (R^2= 0.078, RMSE= 713.5)

$\bar{Y}$= 458.1 + 17.85*(GIFA/capita) (8)

Table 5.7 and Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

5.2.3 Discussion and conclusion of objective 1 & 2 for whole Punjab

Discussion: As well as deriving the above equations, which allow various energy consumption scenarios to be modelled, in absolute energy terms we are now also able to identify the energy impact each variable statistically has when present. The table below shows the ranges of annual electricity consumption per household that the models showed can be expected due to the presence of each instance of the following variables:

Table 5.8 Ranges of energy consumption (kWh) per instance

Variable	Annual Energy Consumption Range per instance (kWh)
Number of air-conditioned rooms (CON.RMS)	445 – 567
Per microwave (MW)	219
Per fridge (FRG)	135 – 191
Per TV (TV)	120
Per fluorescent tube (FTL)	97 - 117
Per ceiling fan (FN)	77 – 97
Per LED light/SMD (LED/SMD)	58 – 62
Per occupant (OCC)	53 – 67
Per Energy Saving CFL or halogen bulb (ES)	45 – 48
Per m^2 of gross internal floor area (GIFA)	1.4 – 1.6

The main implications for future energy policy are that they show the potential impact that a warming climate could have on domestic energy demand as the number of rooms needing cooling will increase, and fridges must work harder. With a current average electricity demand of 2401 kWh/a per household, every additional room cooled would increase a household's annual electrical energy demand by around 18 - 23%.

The models presented do not vary much in their accuracies. So, the choice of which one to use will be dictated by the format of data available and user choice. The models produced show that the numbers of appliances and lights, their installed power, and space conditioning for cooling are the main drivers of electrical energy demand in Punjab's domestic sector. Addressing these drivers are vital to reducing or reversing the growth in carbon emissions in Punjab domestic sector. A mitigation strategy would, therefore, be expected to involve increasing the energy efficiency of installed appliances and lights especially air conditioners for cooling and controlling the demand for cooling in conditioned rooms area (Table 5.3). Other controls available to address the demand drivers require either reduced floor areas per household, reduced numbers of occupants, or reduced ownership of appliances.

Removing inefficient appliances and lights from the market would bring Punjab (Pakistan) in line with more developed economies [352] [353]. However, current Punjab per capita and household energy demands are still very low relative to industrialised and advanced economies [354]), as shown in Figure 5.9. It appears that increased appliance energy efficiency standards will only help reduce demand growth, not prevent it.

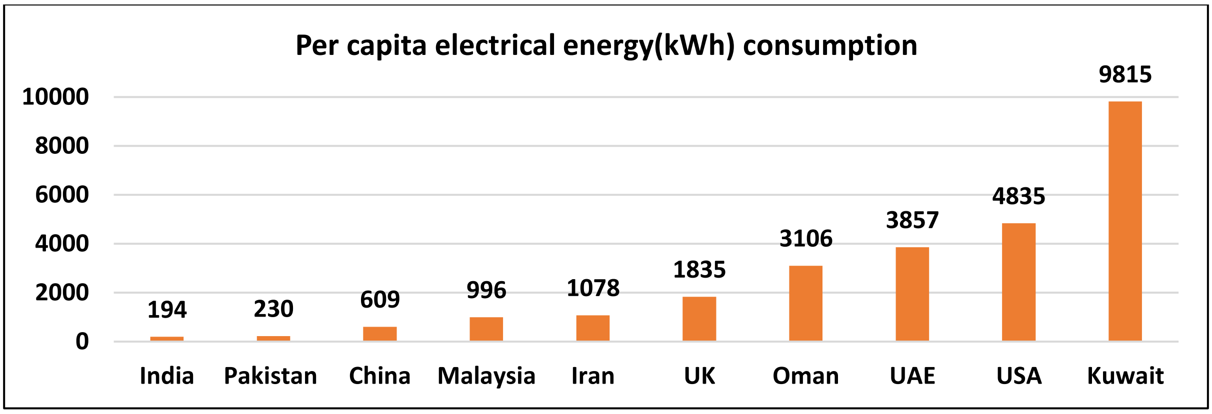


Figure 5.9 electrical energy consumption (kWh) per capita, source [354]

However, this is still an important policy to enact to maximise the positive impact of any growth in the Pakistan energy supply and to improve the current electricity crisis in the country where the supply authorities impose power-cuts for several hours each day.

The average demand models produced for per household and per capita can be used by policymakers to assess the impact of changes in the drivers on future energy demand as they evaluate future energy policy and power supply options. This thesis also identifies that the monthly EUI's for electricity and gas have predictable variations throughout the year per household. Electricity demand is highest in summer, whereas gas demand is highest in the winter. The summer peaking electricity demand is helpful as it coincides with peak renewable energy output from PV systems, which could help meet the demand over this period.

For gas demand, the gross internal floor area (GIFA) is the only predictive variable in both gas models (5.2.2.3.6) showing that the internal gains from occupancy, appliances, and lighting do not significantly impact heating demands. This suggests the houses are probably poorly designed from a thermal efficiency viewpoint.

Statistically, there is no significant relationship between the number of people and gas usage, despite its predominant use for space heating, cooking, and water heating. The reasons for this could be gas cost, system efficiencies and personal habits. These parameters require further research to understand how they influence gas use in regions where heating is not a major consumer of energy. Separating the use of gas for space/water heating and cooking would enable an understanding of the potential for renewable sources to offset some of this still significant demand. The domestic energy consumption prediction models can be used for the whole population if all these variables are known.

Conclusions: This study aimed to understand the domestic demand drivers and energy usage intensity (EUI) of the Punjab, Pakistan. Eight energy prediction models have been produced, based on information gathered in 2017-18 about 76 different variables and associated annual energy consumption data in 4597 Punjab households. Pearson coefficient analysis (r) was used to identify demand drivers, descriptive statistics like average values were used to understand EUI, and regression analysis was conducted to develop the prediction models. All these results are presented at two levels, i.e. per household and capita.

The results show that the annual demand for electricity use per household and capita can be significantly predicted from knowledge of the numbers and types of appliances and lights, their installed power ratings, the number of conditioned rooms, and their area (especially for cooling). Gross internal floor area and occupancy are not very significant factors in predicting electrical consumption. The gross internal floor area is the only demand driver variable available for gas demand in both models. Annual energy usage intensity (EUI) of gas is higher than electricity for both cases, i.e. per household and capita.

These findings suggest that increasing the efficiency of appliances (especially air conditioners for cooling) and lights would help in reducing the current electrical energy consumption of the domestic sector of Punjab and in achieving low carbon economy goals. It is suggested this efficiency improvement should happen as quickly as possible to both ease the current impact of daily electrical supply interruptions and to prepare the country for managed growth in increasing energy use. Comparison of the per capita electricity use in Punjab with the average electricity use per capita internationally suggests there is a vast potential for domestic electricity growth which will exacerbate existing power shortages in Pakistan. Identifying the variables of domestic energy demand will be of value to the energy supply and policy-making authorities when formulating policies to address supply capacity issues and carbon emissions. The findings are also of use to Engineers and Architects looking to design or renovate domestic properties to meet Zero Carbon or Positive Energy Housing standards.

We have seen and analysed the energy drivers, energy usage intensity (EUI), and developed prediction models for the future estimation of energy demand for the whole Punjab. In the next section, we will develop the similar models for each division of Punjab, and these models could be used to understand the demand drivers and prediction models for each individual division, which is a new contribution of knowledge, as no such models are available for the whole Punjab and any of its division. We will also conclude in the next section, are these drivers are similar or different from the one we found for the whole Punjab, and how the strengths and variables involved in the prediction models changes?

In the next section, the results and analysis of all ten divisions are done, similarly as it is done for the whole Punjab. Most of the tables and details are presented in Appendix -C, as it is not possible to present all these details of each division in the main body of the thesis.

5.2.4 Results & analysis for objective 1 & 2 of each division

- Demand drivers
- Prediction models

In the second part, to answer the research objectives 1& 2, we will discuss each division separately. It would be addressed with fewer details as most of the features like tables of descriptive statistics, model summaries, and Pearson's correlations are presented in the form of combined tables in Appendixes C, to avoid the repetition of similar information in the main body of the thesis. The individual demand drivers, average EUI, and prediction models of each division are presented in the main body of the argument, as we know that this is the first attempt in Punjab to look for the answers of these objectives, and it is imperative to put these findings in the thesis. The results at each divisional level are unique and novel and never appeared in any research before. Only the results of Lahore division are shown here, and results of all remaining divisions are provided in **Appendixes C** along with their names.

5.2.4.1 Lahore division

The house sizes covered in the survey range from 20.9m^2 to 418m^{2,} which covers the dominant house sizes in the Lahore division. The average house size is 115.1m^{2,} and the house size of 104.5m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 19.5m^2. The minimum and maximum values of m^2 per capita are 5.9m^2 and 104.5m^{2,} respectively (Appendix-C-1). These variations show that the data set covers the full range of Punjab society and provides further confidence in the general application of the findings.

5.2.4.1.1 Domestic demand drivers, Lahore division

Per household (electricity): The results of modelling the **direct and indirect** variables per household show CON.RMS (r=0.651), ACONC (kW) (r=0.62), and CON.RM.AR (r=0.598) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show CON.RMS (r=0.651), APP+LTS (r=0.635) and APP(kW)+LTS(kW) (r=0.623) have a good correlation with the dependent variable (Figure 5.10 & Figure 5.11).

Per capita (electricity): The results of modelling the **direct and indirect** variables per capita show ACONC (kW) (r=0.578), CON.RMS (r=0.564) and ACONC (r=0.562) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP(kW)+LTS(kW) (r=0.637), APP(kW) (r=0.627) and APP+LTS (r=0.581) have good correlations with the dependent variable (Figure 5.10 & Figure 5.11).

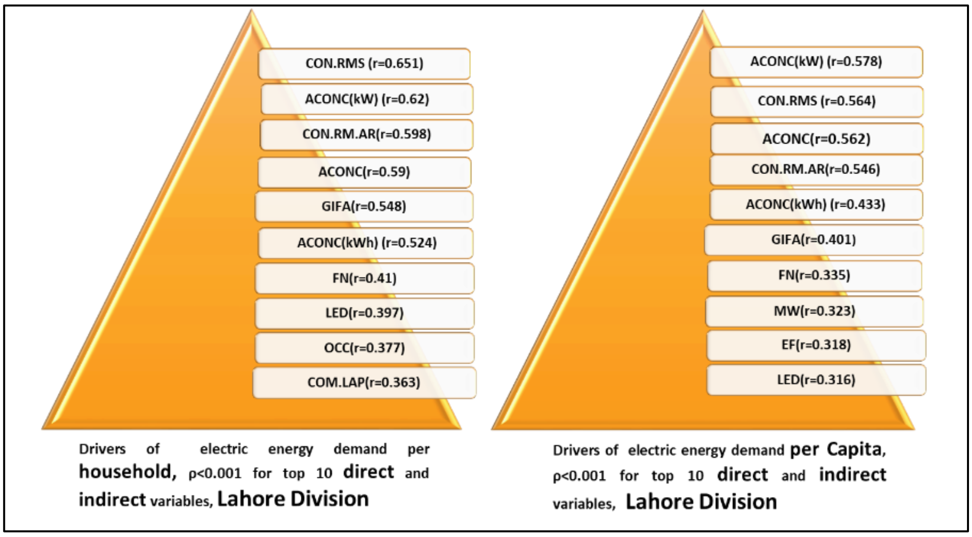


Figure 5.10 Hierarchical presentation of electricity demand drivers per household and per capita in Lahore division, Punjab for direct and indirect variables

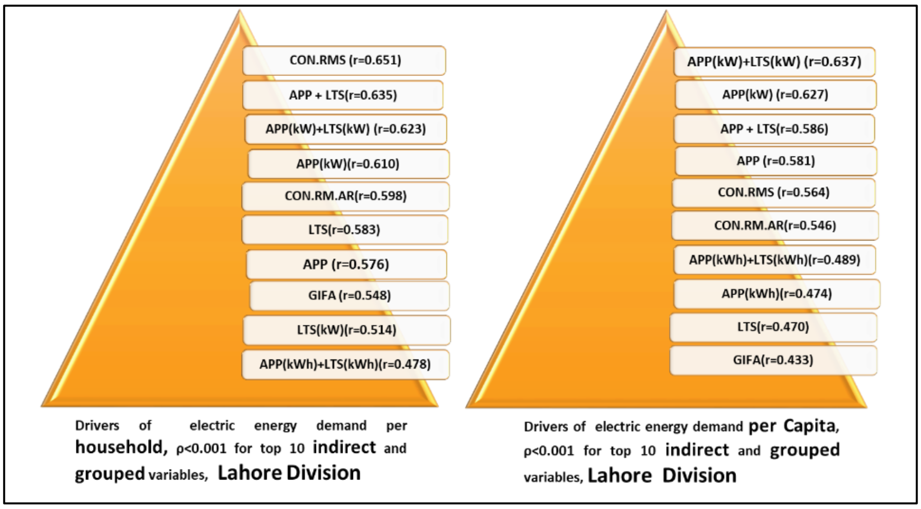


Figure 5.11 Hierarchical presentation of electricity demand drivers per household and per capita in Lahore division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables is presented in Appendix C-2-1, which shows the strongest correlation is with the total number of CON.RMS (r=0.651) for the per household model, and with an installed electrical capacity of the appliances and lights, APP (kW)+LTS (kW) (r=0.637) for the per capita model.

Per household and capita(gas): Acceptable gas correlations are only to the size of the house (GIFA), where r= 0.531 & 0.586 for the per household and capita models, respectively. The other variable, i.e. occupancy of the house does not show any reasonable correlation with the dependent variable; it is close to zero.

5.2.4.1.2 Energy usage intensity (EUI) Lahore division

Analysis of the average annual Energy usage intensity (EUI) reveals the following (appendix C-3-1):

- The average household electric and gas energy use is around 3036.4 kWh/annum and 4748 kWh/annum, respectively.
- Per capita, the average energy use is 527.8 kWh/capita/annum and 727.7 kWh/capita/annum for electricity and gas, respectively.
- The average energy use per m^2 per household is 31 kWh/m^2/annum and 33 kWh/m^2/annum for electricity and gas, respectively.
- The average energy use per m^2 per capita is 6.2 kWh/m^2/capita/annum and 5.3 kWh/m^2/capita/annum for electricity and gas, respectively.
- The ranges of electric and gas demand are large in both per household and per capita models.

5.2.4.1.3 Energy consumption prediction models of Lahore division

Descriptive Statistics of final predictive variables selected for the Lahore division are presented in Appendix C-Lahore-1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-1 and Appendix C-Lahore-2

5.2.4.1.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2=0.543**, RMSE=1227.4, strongest predictive variable =**CON.RM.AR** (**β**=0.270, p<0.001)

$$\bar{Y} = 567.5 + 112.2*(OCC) + 3.7*(GIFA) + 394.5*ACONC\ (kW) + 212.4*(TV) + 57.6(LED/SMD) + 40.8*(CON.RM.AR) \quad (1)$$

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known than the following equation is valid to an accuracy of **R^2= 0.530** and RMSE= 1244.1, strongest predictive variable = **CON.RMS** (**β**=0.394, p<0.001)

$$\bar{Y} = 317.5 + 36.9*(OCC) + 2.6*(GIFA) + 48.6*(APP+LTS) + 557.0*(CON.RMS) \quad (2)$$

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of (**R^2=0.545**, RMSE=1224.3), strongest predictive variable =**CON.RMS** (**β**=0.219, p<0.001)

$$\bar{Y} = 414.3 + 69.5*(OCC) + 3.5*(GIFA) + 76.9*(LED/SMD) + 190.1*(APP\ (kW)+LTS\ (kW) + 477.5*(CON.RMS) \quad (3)$$

5.2.4.1.4 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.470}$, RMSE= 213.7, strongest predictive variable =**ACONC (kW)/ capita** (**β**=0.281, p<0.001)

$$\bar{Y}= 219.8 + 3.2*(GIFA/capita) + 233.2*(EF/ capita) + 185.9*(MW/ capita) + 421.6*(ACONC (kW)/ capita) + 37.8*(LED/SMD) + 42.2*(CON.RM.AR/ capita) \quad (4)$$

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.497}$, RMSE= 208.1, strongest predictive variable = **APP (kW)+LTS (kW)/capita** (**β**=0.42, p<0.001)

$$\bar{Y}= 143.3 + 1.9*(GIFA/Capita) + 365.0*(APP (kW)+LTS(kW)/Capita) + 40.6*(CON.RM.AR/Capita) +30.9(LTS) \quad (5)$$

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.505}$, RMSE= 206.6, strongest predictive variable =**APP (kW)+LTS (kW)/Capita** (**β**=0.37, p<0.001)

$$\bar{Y}= 137.2 + 1.8*(GIFA/capita) + 142.7*(EF/ capita) + 35.6*(LTS) + 42.5*(CON.RM.AR/ capita) + 316.9*(APP (kW)+LTS (kW)/capita) \quad (6)$$

In all three models for per household, we found that number of conditioned rooms and area of conditioned rooms are the variables with higher predictive strengths. However, in per capita models, the number of air-conditioners for cooling and the power rating of appliances & lights are better predictors of electrical energy consumption.

For both the 'per household' and 'per capita' models the highest accuracy is found in the combined model, though probably the most comfortable model to use is the grouped model, which does not significantly reduce the accuracy. The model produced by individual variables is in between the two in terms of its use and accuracy. We would recommend the detailed and combined models when more precision is required and grouped model where ease of use is of concern. They are all similar in their accuracy, so the choice of which one to use will depend on the format of the information available.

5.2.4.1.5 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: (R^2= 0.280, RMSE= 5062.7), strongest predictive variable =GIFA (**β**=0.531, p<0.001)

$$\bar{Y}= -408.2 + 36.85*(GIFA) \quad (7)$$

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: (R^2= 0.341, RMSE= 768.5), strongest predictive variable =GIFA/capita (**β**=0.586, p<0.001)

$\bar{Y}$= -52.87 + 36.59*(GIFA/Capita) (8)

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

Details of all other divisions are provided in Appendixes-C- (divisional name)

5.3 Discussion and conclusion for objectives 1 & 2 of all divisions

The domestic energy usage data is analysed at the individual division level in this section. Where all ten divisions of Punjab are thoroughly studied using the survey data of each division, the CL and CI achieved by each division to answer the objective 1 and 2 are discussed in chapter 4 (Figure 4.1). To look for the electrical demand drivers in each division, we produced results at per household and per capita level, and are detailed out in Table 5.9 and Table 5.10.

Electrical demand drivers (per households): We found that number of CON.RMS is the strongest electrical energy demand driver for three divisions (Lahore, Rawalpindi and Bahawalpur). The power rating of appliances and lights is the most reliable driver for the other three divisions (Sheikhupura, Sargodha and Multan). However, the ownership of appliance and lights is found the key driver of electrical energy for Gujranwala and Sahiwal divisions, and the number of appliances owned, and the power rating of appliances are found main drivers for Faisalabad and Dera Ghazi Khan divisions respectively. The electrical energy demand in all divisions of Punjab is governed by the number and power ratings of appliances and light along with the number of conditioned rooms individual households possess. The practical measures taken to reduce the energy demand would include the decreasing number of appliances and lights owned and increasing their efficiencies (power rating). Reducing the number of conditioned rooms, may not be a doable measure in the divisions of Punjab, as the average occupancy of households is approximately 6(found in survey and literature review). However, the room's dimensions and construction details could be improved to reduce the energy consumption required to achieve comfortable conditions. We found that the usage of appliances and lights does not have much effect on energy demand. It may be because the people have limited or much control usage, which could be due to economic or affordability factor. It implies that there is a hidden potential of demand increase if the affordability would increase. (Table 5.9)

Electrical energy driver as **per capita** analysis indicates that the combined rating of appliances and lights is the primary driver of energy demand, as 4 out of 10 divisions have this variable as the strongest driver (Lahore, Sheikhupura, Sargodha and Sahiwal). The number (Gujranwala), a power rating (Multan) and usage (Dera Ghazi Khan and Rawalpindi) of appliances are also significant drivers. The number of conditioned rooms (Bahawalpur) and the number of air conditioners for cooling (Faisalabad) are key drivers for other divisions. The per capita analysis of all divisions suggests that the energy efficiency of appliances and lights would help in decreasing the consumption, especially the appliances owned. The number of conditioned rooms and air-conditioners installed are the other drivers, whose control may help in the reduction of electrical energy demand. (Table 5.9).

The electrical **energy usage intensity (EUI)** analysis of all ten divisions shows a vast range of average energy consumed both at per household and per capita level. The average usage goes from (1569-3036) kWh/annum and (233-563) kWh/annum for per household and per capita respectively. It implies that within Punjab, there is a huge potential for demand increase in those divisions which are consuming less amount of energy (Multan and Dera Ghazi Khan). The higher demand, almost double, in some divisions (Lahore and Bahawalpur), could be because of more economic affordability, different lifestyle and availability of energy. Further, we have already seen that the electrical energy demand per capita of whole Punjab (391kWh/a, see the conclusion of whole Punjab analysis) is far less than the average need of the advanced and developed countries. To achieve the aims of this research, the exploitation of renewable energy supply seems the only solution to the way forward.

Electrical energy prediction models (per households): we produced prediction models for each division, and the most influential models of each division are presented in Table 5.9. We found different model's strengths for different divisions ranging from weakest R^2=0.289 for Sargodha and strongest R^2= 0.867 for Faisalabad divisions. The second most potent model is for Sheikhupura (R^2=0.791) divisions, and the third more robust model is for Multan(R^2=0.662) division. We have observed that the models with higher R^2 values have lowest RMSE values. We have seen that the key predictable variables in the models are related to space conditioning in the form of CON.RM.AR, CON.RMS, ACONC (kWh) and FN or FN (kW) in 6 out of 10 divisions. It suggests that the measures for the mitigation strategies would include increasing the conditioning equipment's efficiencies like Air conditioners and fans and reducing the area of conditioned rooms would help to control the electrical energy demand. The power ratings of appliances and lights are the other predictive variables (Sargodha, Multan and Dera Ghazi Khan divisions) and increasing their efficiencies would be useful steps to realize the thesis aims. The combined models (CM) are the most robust models in different divisions of Punjab (7 out of 10 divisions).

Electrical energy prediction models (per capita): the prediction models of different divisions of Punjab per capita showed that the weakest model is for Sargodha (R^2=0.303) and the strongest model is of Multan (R^2=0.693). The second strongest model is of Faisalabad (R^2=0.683), and the third strongest model is of Sheikhupura (R^2=0.635). The power rating of appliances and light and their ownership is the most influential predictable variable in 8 out of 10 divisions. Other variables like the number of conditioned rooms and the number of air conditioners have predictive strength shown in two divisions. Overall, we can conclude that the efficiencies and number of appliances and lights owned would result in higher electrical energy demand.

Table 5.9 Summary of objective 1 & 2 of all ten divisions for electrical energy

Electrical Energy	Objective 1 (Demand Drivers)		Energy Usage Intensity (EUI)		Objective 2 Energy Prediction Models (Strongest Models presented)							
	Per Household	Per Capita	Per Household	Per Capita	Per Household Detail model=DM, Grouped Model,=GM, Combined Model=CM				Per Capita Detail model=DM, Grouped Model,=GM, Combined Model=CM			
Divisions	Strongest Driver (r)	Strongest Driver (r)	Average Value (kWh/a)	Average Value (kWh/a)	Strongest model	R^2	RMSE	Strongest Variable(β)	Strongest model	R^2	RMSE	Strongest Variable(β)
Punjab	APP+LTS (0.636)	APP (kW) (0.655)	2401	391	CM	0.530	1075.3	CON.RMS (0.292)	CM	0.531	170	APP(kW)+LTS(kW) (0.305)
Lahore	CON.RMS (0.651)	APP (kW)+LTS (kW) (0.637)	3036.4	527.8	CM	0.545	1224.3	CON.RMS (0.219)	CM	0.505	206.6	APP (kW)+LTS(kW) (0.37)
Sheikhupura	APP (kW)+LTS (kW)(0.840	APP (kW)+LTS (kW) (0.728)	2658.6	563	CM	0.791	744.7	CON.RM.AR (0.354)	DM	0.635	169.7	CON.RM.AR (0.349)
Gujranwala	APP+LTS (0.521)	APP (0.570)	2546	381.7	CM	0.424	1127.2	FN(KW) (0.280)	GM	0.458	174.7	APP (0.370)
Faisalabad	APP (0.888)	ACONC (kWh) (0.659)	2211.9	394.5	DM	0.867	514.5	ACONC(kWh) (0.285)	CM	0.683	95.23	ACONC (kWh)(0.238)
Sargodha	APP (kW)+LTS (kW)(0.475)	APP (kW)+LTS (kW) (0.418)	1758.2	248.8	CM	0.289	905.7	APP(Kw)+LTS(KW) (0.378)	GM	0.303	138.5	APP (kW)+LTS(kW) (0.319)
Rawalpindi	CON.RMS (0.519)	APP (kWh)+LTS (kWh) (0.457)	2317	387.4	GM	0.412	961.2	GIFA (0.344)	GM	0.352	160.4	APP (0.333)
Sahiwal	APP+LTS (0.643)	APP (kW)+LTS (kW) (0.578)	2588.1	410.5	DM	0.575	917.8	FN (0.242)	GM	0.411	149.9	APP(kWh)+LTS(kWh) (0.504)
Multan	APP (kW)+LTS (kW)(0.774)	APP (kW) (0.764)	1634.2	241.5	CM	0.662	657.8	APP(KW)+LTS(KW) (0.272)	CM	0.693	99.2	APP(KW)+LTS(KW) (0.220)
Bahawalpur	CON.RMS (0.746)	CON.RMS (0.723)	2961.3	415.4	CM	0.635	1051.7	CON.RMS (0.669)	CM	0.609	145.2	CON.RMS (0.636)
Dera Ghazi Khan	APP(kW)(0.675)	APP(kWh) (0.650)	1568.9	232.9	CM	0.549	774.1	APP(KW) (0.441)	CM	0.537	111.6	APP(kW) (0.411)

Gas demand drivers (per households): we have two variables to predict gas energy consumption in our data set, i.e. GIFA and occupancy (OCC). We found that the gross internal floor area (GIFA) is the strongest predictive variable in 6 out of 10 divisions and occupancy of the households is the predictive variable in 4 divisions. (see Table 5.10). The most robust gas energy predictive model we have is of the Sheikhupura division with r=0.756(GIFA), While the weakest model is for the Rawalpindi division (r=0.181, OCC). The second and third strongest gas models we have for Faisalabad (r=0.686, GIFA) and Sargodha (r=653, GIFA). Overall, we recommend gas models of Sheikhupura, Faisalabad and Sargodha for prediction as they have good predictive strength and GIFA is the most predictive variable. It implies that decreasing the size of households and occupancy would help to reduce gas consumption. Since we do not have a split of gas usages for cooking, water and space heating, further research is required to analyse the individual usage of gas for these activities so that we can clearly understand the significant gas drivers in the households.

Gas energy driver as **per capita** analysis indicates that the GIFA is the only predictable variable to understand the gas demand per capita. The strongest gas consumption model we have is for Sargodha (r=0.730) and the weakest we have for the Dera Ghazi Khan (r=0.0073) divisions. The prediction strengths of Sheikhupura, Faisalabad and Lahore are 0.658,0.633 and 0.586 respectively and show good correlations. The strongest models can be used to assess gas energy consumption. We found a different huge range of correlation strengths of gas prediction models in different divisions, even when GIFA, is the only predictive variable. It implies maybe in some divisions; there are other sources of domestic energy for cooking, hot water and space heating like biofuels along with gas connections. It also coincides with our earlier findings in the literature that the domestic sector consumes 89% of the total biofuel available in Pakistan. Households may have a proper gas connection, but people may prefer to use the indigenous freely available fuel like animal and wood wastes. When the lifestyle of these people would change, and when they will start using the more modern fuel like gas as a source of domestic energy, the demand for gas would increase manifold. It will further worsen the current gas shortage in Pakistan in Table 5.10.

Table 5.10 Summary of objective 1 & 2 of all ten divisions for gas energy

Gas Energy	Objective 1 (Demand Drivers)		Energy Usage Intensity (EUI)		Objective 2 Energy Prediction Models					
	Per Household	Per Capita	Per Household	Per Capita	Per Household			Per Capita		
Divisions	Strongest Driver (r)	Strongest Driver (r)	Average Value (kWh/a)	Average Value (kWh/a)	R^2	RMSE	Strongest Variable(β)	R^2	RMSE	Strongest Variable(β)
Punjab	GIFA (0.228)	GIFA (0.280)	5245	769.5	0.056	4050.9	GIFA (0.228)	0.078	713.5	GIFA (0.280)
Lahore	GIFA (0.531)	GIFA (0.586)	4748	727.7	0.280	5062.7	GIFA (0.531)	0.341	768.5	GIFA (0.586)
Sheikhupura	GIFA (0.756)	GIFA (0.658)	6474	1042.5	0.565	3983.6	GIFA(0.756)	0.423	611.2	GIFA (0.658)
Gujranwala	OCC (0.304)	GIFA (0.529)	8633	1236.9	0.136	2925.4	OCC (0.239)	0.279	566.9	GIFA (0.529)
Faisalabad	GIFA (0.686)	GIFA (0.633)	2211.9	763.4	0.468	4031.5	GIFA(0.686)	0.398	636.1	GIFA (0.633)
Sargodha	GIFA (0.653)	GIFA (0.730)	1681	239	0.425	1610.2	GIFA(0.653)	0.531	212.5	GIFA (0.730)
Rawalpindi	OCC (0.181)	GIFA (0.044)	3771	629.8	0.027	4405.6	OCC (0.125)	-0.006	708.1	GIFA (0.044)
Sahiwal	GIFA (0.289)	GIFA (0.451)	4964	806.1	0.077	4070.8	GIFA (0.289)	-0.198	611.4	GIFA (0.451)
Multan	OCC (0.239)	GIFA (0.163)	5382	726.7	0.056	4264.8	OCC (0.223)	-0.024	594.5	GIFA (0.163)
Bahawalpur	GIFA (0.422)	GIFA (0.400)	2527	362.8	0.176	3303.1	GIFA (0.422)	-0.158	535.6	GIFA (0.400)
Dera Ghazi Khan	OCC (0.292)	GIFA (0.073)	7125	1041.5	0.081	3429.9	GIFA(0.292)	0.001	522.1	GIFA (0.073)

The gas **energy usage intensity (EUI)** analysis of all ten divisions shows a considerable range of average energy consumed both at per household and per capita level. The average usage goes from (1681-8633) kWh/annum and (239-1237) kWh/annum for per household and per capita respectively. It implies that within Punjab, there is a huge potential for demand increase in those divisions which are consuming less amount of gas energy (Sargodha and Bahawalpur divisions). The higher demand, almost five times of lowest demand, in some divisions (Gujranwala and Sheikhupura) could be because of more economic affordability, different lifestyle, and availability of energy, or maybe due to more usage of indigenous fuel like biofuels. This huge variation in gas consumption implies that there is an inherent potential of its demand increase in Punjab. Mitigation of the current gas shortage, especially in winter, the exploitation of alternate sources of domestic fuel for cooking, water and space heating is needed for all these activities or some of these individual domestic needs Table 5.10

Gas energy prediction models (per households): We produced prediction models for each division, and the strongest models of each division are presented in Table 5.10. We found different model's strengths for different divisions ranging from weakest R^2=0.027 for Rawalpindi and strongest R^2= 0.565 for Sheikhupura divisions. The second most reliable model is for Faisalabad (R^2=0.468), and the third stronger model is for Sargodha (R^2=0.425) divisions. We have observed that the models with higher R^2 values have the lowest RMSE values. We have seen that the vital predictable variables in 7 out of 10 models (of divisions) are GIFA. It suggests that the measures for the mitigation strategies would include optimizing the gross internal floor area of households. The strongest model for the gas energy consumption out of all ten divisions of Punjab is of Sheikhupura division (R2=0.565). It still has 3983.6kWh/a of error in its prediction accuracy. We would suggest that further in-depth research is required to understand the domestic gas demand. The GIFA and occupancy are not the most suitable factors to determine the gas demand in Punjab Table 5.10.

Gas energy prediction models (per Capita): the prediction models of different divisions of Punjab per capita showed that the weakest model is for Sahiwal (R^2=-0.198) and the strongest model is of Sargodha (R^2=0.531). The second strongest model is of Sheikhupura (R^2=0.423), and the third most reliable model is Faisalabad (R^2=0.398). The gross internal floor area (GIFA) Isis the only predictable variable in all divisions. Overall, we can conclude that the gas per capita model for Sargodha can be used though it has 212.5 kWh/a an error of the estimate. Five divisions have shown no significant strength of their gas prediction models, even zero, and this suggests that for per capita gas prediction, we cannot rely upon GIFA for an estimate. We can conclude that residents of these divisions might have gas connections in their homes. Still, either the gas supply is limited, or they hardly use it and utilize other alternates, like biofuel or oil, but this needs to be further investigated in some other research Table 5.10.

Having produced the demand drivers and prediction models, the thesis then went on to explore what this might mean for the domestic sector to be able to meet its own demand in the country where we see that there is huge energy crisis currently going on. The author's interest in starting this PhD, as an architect, was to look at how we should be designing the buildings in Pakistan, in order for them to become low energy consumers or reaching zero carbon ambitions. The initial aims of the thesis were to understand the demand drivers and prediction models, whilst it is not the main aim of the thesis to look at the shallow overview of installing Solar PV or other technologies on the rooftops. So, in the next part of the thesis, we are looking at this simplistically, assuming that all the PV or solar thermals are orientated in the right direction, not overshadowed from any obstruction etc. just to give a feel for what potentially can be generated or what is available? Before looking at the green generation potentials, we also need to understand when this energy demand occurs. So, the next objective of the thesis is to clearly understand the timings of demands and is discussed in detail below.

5.4 Results and analysis for timings of energy demand (objective 3)

5.4.1 Introduction

We are interested to know when does the energy demand occur in different household sizes within a year, month and even in a day. We want to see if the demand timings coincide with the energy generation timings from the domestic rooftops. To understand, do we need to have a storage battery in our households if the demand and generation timings are not the same. We are further interested to see how much of this average demand occurs during the daytime and how big an energy storage system we need to have to meet the specific demands of each house size ranges in Punjab. We will understand this through a detailed analysis of the timings of the energy demand of each house size which are available in all households of our survey data. To answer this objective, we have two sets of data, i.e. survey data of the whole Punjab and smart meters case studies) data, as shown in .

The timing of domestic energy demand is analysed based on survey data of whole Punjab:

(a) Survey data

Data was obtained by a physical survey in Summer 2018 that achieved 4597 and 2901 samples for electrical and gas energy, respectively. The surveys covered house sizes having 21 to 418m^2 gross internal floor area (GIFA). The responses received of the annual electrical and gas consumption of all house sizes, and attaining a confidence level of 95% and the stated respective confidence interval (we achieved different confidence intervals for different house sizes) as shown in Table 5.11 below, for instance for the house size range of 21-42m^2 we received 697 responses of electrical energy consumption, which is our dependent variable (along with all independent variables responses to support this energy consumption) and could achieve the CL=95% and CI=3.7, we are providing here only CL and CI for house sizes, as the other variables details are provided in Table 5.1, and we are taking house size as the basic unit of our analysis to understand the timings of energy demand. It will also help us to reconcile the energy demand and generation potential of each house size with its demand timings (discussed in objective 4 later).

Table 5.11 Electricity and gas annual consumption responses received of house size ranges to answer objective 3 (demand timings)

Electricity consumption		
House Sizes (M^2)	**Responses Received**	**Confidence level (95%) achieved, with the confidence interval given below**
21-42	697	3.7
63	642	3.9
84	870	3.3
105	1086	2.9
125-146	636	3.9
167-209	410	4.9
230-418	261	6.0
21-418	**4597**	**1.45**
Gas consumption		

House Sizes (M^2)	Responses Received	Confidence level (95%) achieved, with the confidence interval given below
21-42	307	5.6
63	296	5.7
84	577	4.1
105	764	3.6
125-146	434	4.7
167-209	319	5.6
230-418	226	6.5
21-418	**2901**	**1.8**

We were looking for CL=95% CI=1-5 to achieve which is acceptable in academic research, for our electrical electric consumption data for different house sizes we were able to meet the above criteria except for house size 230-418m^2 which is slightly more, i.e. CI=6.0 Table 5.11. For our gas energy consumption, we could not achieve the above criteria in 4 out of 7 house sizes, but the CI achieved for these house sizes are (CI=5.6-6.5) not too high than above-set criteria, while all are reaching CL=95%.

(b) Smart meter data

The electricity data (only, not gas) was obtained from the smart meters of 10 case study houses from the smart meter's suppliers' company [355]. Metadata for these houses was obtained by conducting physical surveys of these houses by the Author. The house size range of smart meters houses is 83.6-133.8m^2 Table 5.12.

Table 5.12 Smart metering electric consumption (case studies) data

Electricity consumption	
House Sizes (M^2)	**Case Studies Samples**
83.6	7
117	2
133.8	1

In the next section, the data is analysed to understand the timing of energy demand in domestic housing in two steps, as mentioned above. Firstly, the monthly energy demands from the survey data are presented and discussed for both fuel types, i.e. electricity and gas. Secondly, daily, monthly, and annual electrical (only) energy consumption profiles based on 15-minutes smart meter data are presented from the case studies data. In both datasets, analysis results are presented at two levels, i.e. at per household and per capita.

5.4.2 Flow chart of analysis for timings of energy demand

To make it easy to comprehend, we have developed a flow chart shown in Figure 5.12, to determine the timings of energy demand across the year, month, and daily profiles. The two data sets we have to ascertain the timings are firstly used separately. Then the findings of the smart meters data set are cross-checked with the survey data set, just to show if the estimated energy demands are similar to what we predicted from the survey data set. The descriptive analysis, utilizing average percentages and average percentages of inter-quartile range values of each energy consumption are taken as a yardstick to measure the 'timings of demand', for yearly and monthly periods from survey data. Similarly, the smart meter data is utilized to estimate the timings of electrical energy demand (only) of case studies houses at yearly, monthly, and daily bases.

Further, after knowing the timings of electrical energy demand from booth data sets, we have estimated the timings of daily and monthly demands of case studies house sizes, for the survey data set of similar house sizes. This is a rough estimate of the daily demand profiles of similar house sizes in survey data sets and are presented only for cross-checks. We cannot recommend these findings for the population at large, as they are based on only 10 case study houses. Broadly, the results & analysis for objective 3 are presented in two ways (Figure 5.12)

- Survey data results & analysis to know the timing of energy (both electrical & gas) demand over the year
- Smart meters data results & analysis to know the timings of energy (only electrical) demand over the year, daily and hourly profiles

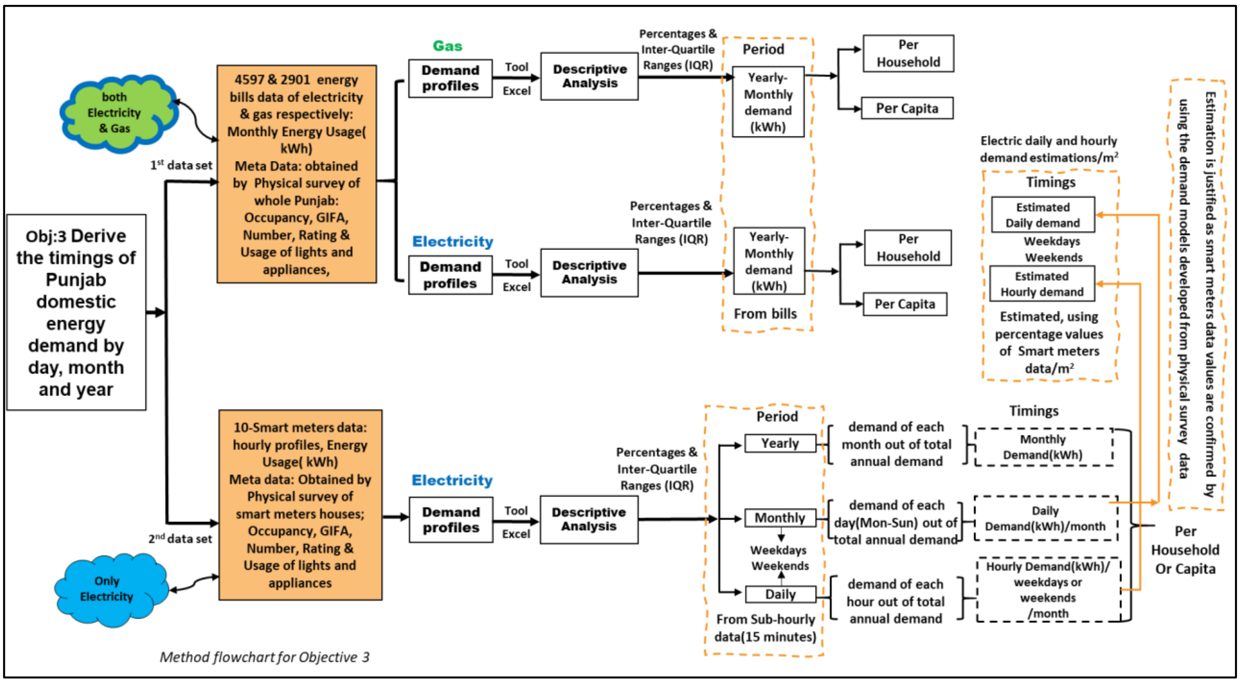


Figure 5.12 Flow chart of objective 3, timings of energy demand

5.4.3 Survey data results & analysis (timings of energy demand, objective 3)

We will analyse our survey data at two levels to fully understand the patterns or timings of energy demand across the year; these two levels of investigation are:

1. Timings of electrical energy demands per household and capita
2. Timings of gas energy demands per household and capita

In all these analyses, we would divide the year into four seasons (which is the weather characteristic of the whole Punjab). These seasons are described as

Summer: May – September

Spring: October-Mid November

Winter: Mid November-February

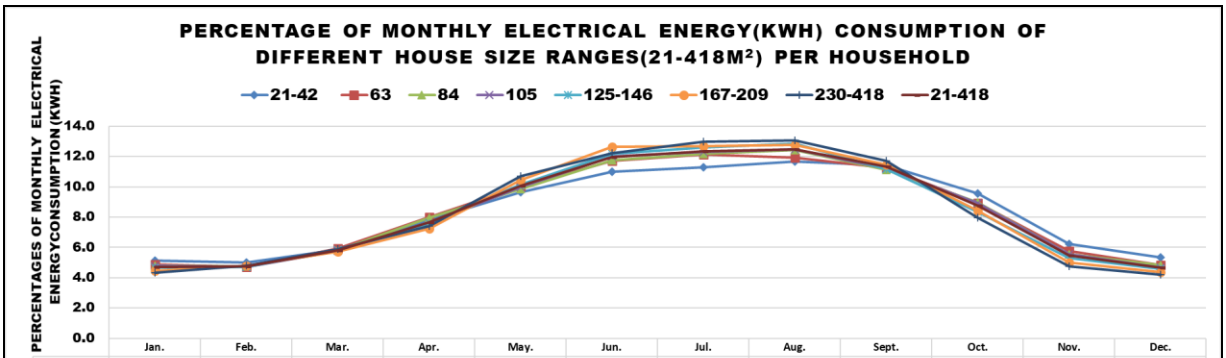
Autumn: March-April

5.4.3.1 Percentages & Inter-Quartile Ranges (IQR) of average annual electric energy demand timings per household and capita of different house sizes

Percentages of monthly electrical energy demand timings per household:

The timings of the electrical energy demand of all house sizes are shown in Figure 5.13. Where we could achieve a confidence level of 95% and range of confidence intervals are from 1.45 to 4.85 (Table 5.11) which is most acceptable in the academic research [356] (CI ≤ 5 is acceptable), except the house size range of 230-418m^2 where the confidence interval achieved is 6.0. The monthly percentages of average values of all house size ranges of electricity consumption are shown in Figure 5.13, which precisely identifies the four different demand timings over the year, which coincide mainly with the seasonal variations. Almost similar trends of demand timings are seen in all house sizes. The range of summer (May-Sept.) demand is 9.7-13% of total annual electric energy demand. In all house size ranges, the Autumn, winter and Spring, electrical energy consumption percentage ranges are 8.0-9.5%, 4.2-6.2% & 5.7-8%, respectively Figure 5.13. So, we can see that the timings of the highest electric demand occur during summer and lowest during winter. In all house sizes, the highest demand per household occurs during August (11.7-13%), and minimum in February (4.7-5.0%) Figure 5.13. We also observed that the summer period is stretched till the end of September, which initially was considered till the end of August, with this it makes summer the most extended season (almost five months) w.r.t to electric energy consumption or cooling demand.

As per all households analysis, the average difference in percentage consumption of seasonal demand between summer (11.35 %) and winter (5.2%) is 2.18 X higher in summer than winter demand. The average demands for Autumn (October, 8.75%) and Spring (March-April,6.85%) are 0.77 and 0.61 X lesser than average summer demand (11.35 %) Figure 5.13. So, the lowest demand for electricity per household occurs during winter months, which is further confirmed when we look at the box plot (figure 5.14) (which tells us the division of our data, i.e. 25%ile, median and 75%ile) of the timing of electrical energy demand.



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	5.1	5.0	5.8	7.8	9.7	11.0	11.3	11.7	11.4	9.5	6.2	5.4
63	4.9	4.7	5.9	8.0	10.0	11.7	12.1	11.9	11.2	8.9	5.7	4.8
84	4.8	4.7	5.8	7.9	9.9	11.7	12.2	12.4	11.1	9.0	5.5	4.8
105	4.8	4.7	5.8	7.6	10.0	12.0	12.3	12.5	11.2	8.9	5.5	4.7
125-146	4.7	4.7	5.8	7.6	10.2	12.2	12.6	12.9	11.2	8.3	5.3	4.6
167-209	4.5	4.8	5.7	7.3	10.4	12.6	12.7	12.8	11.4	8.4	5.0	4.4
230-418	4.3	4.8	5.9	7.4	10.7	12.2	13.0	13.0	11.7	8.0	4.8	4.2
21-418	4.7	4.8	5.8	7.7	10.1	12.0	12.3	12.5	11.3	8.7	5.4	4.7

Figure 5.13 Percentage of monthly electricity consumption of different house size ranges(21-418m^2) per household

Inter-Quartile Ranges (IQR) of monthly electrical energy demand timings per household:

At all percentile levels of all house sizes of our data set, the electrical energy consumption goes higher in summer, and the minimum is winter Figure 5.14. Further, ***Inter-Quartile Ranges (IQR)***[11]***,*** analysis shows that spread of percentage ranges are lower in winter months and higher in summer months, at 25%ile, median and 75%ile levels. It means there is more variation in average electricity energy consumption in summer, whereas, during winter all house sizes consume a similar percentage of annual energy. The average of percentage values of 75%ile, median and 25%ile of summer (75%ile=11.5%, median=12%, 25%ile=11%) are 2.3, 2.40 and 2.20 X higher than average values of winter (75%ile=5%, median=5%, 25%ile=5%) months Figure 5.14 & Table 5.13. We also noted as we move from smaller house size to larger house size, the percentage of electricity consumption increases during summer. It means larger houses use a higher percentage of their annual electric energy during summer Table 5.13, further the percentage consumption ranges are wider in summer and narrow in winter in all house sizes.

These increased percentages of annual electrical energy consumption per household in summer months show that there is a higher tendency of energy demand, some of the consumers are using more energy than others which could be because of (a) larger family size and associated activities (b) affordability (c) accessibility of energy (as there are often power cuts of different durations in different areas of Punjab) (d) having larger house size (e) having more cooling devices like fans and air conditioners.

[11] The interquartile ranges Q3, Q2 & Q1 is shown in Figure 5.14 by utilizing box plot, in box plot the bottom line of box plot shows 25%ile, middle line shows median and top line shows 75%ile values of the data set

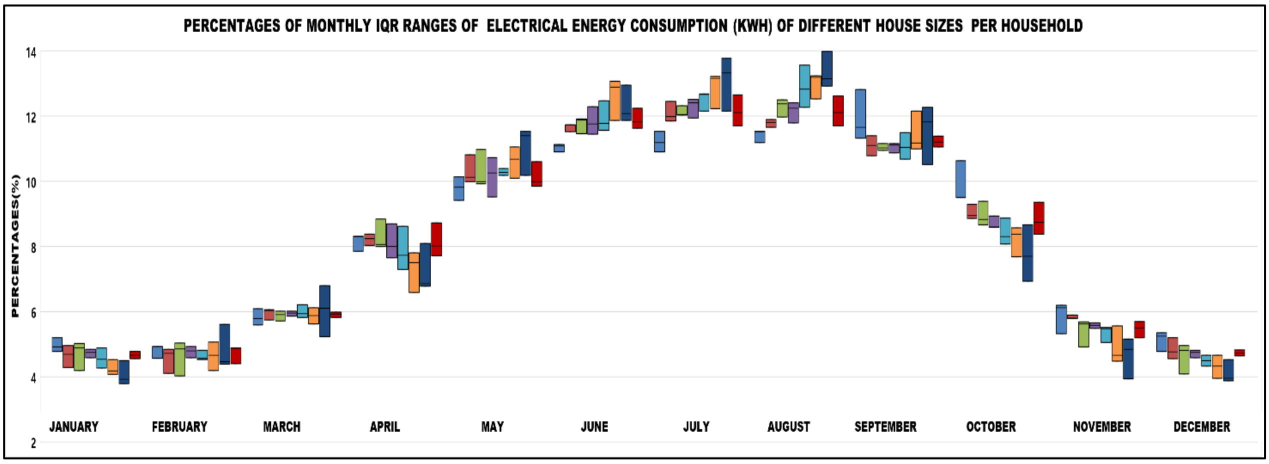


Figure 5.14 Percentages of monthly IQR (Inter-Quartile Ranges) of electrical energy consumption(kWh) of different house size ranges(21-418m^2) per household

If we can relate these percentage values of electrical energy demands with the generation potential of green energy from the available rooftops of different houses by solar PV, this would help in achieving thesis aims. The smaller houses with the lesser electrical energy demand during summer or winter may be able to meet their demand by producing their energy. We need to see what percentage of these houses electrical energy demand can be achieved by generation from their rooftops. The increase in electrical energy demand during summer is mainly due to the increased cooling load when most of the ceiling fans and air conditioners are turned on. It implies that to reduce the carbon emission and to achieve low carbon domestic buildings, this increased summer load needs to be shifted to low carbon sources of energy generation like Photo-Voltaic, which seems to be an important source as most of the cities of Punjab have peak solar radiations available during the summertime.

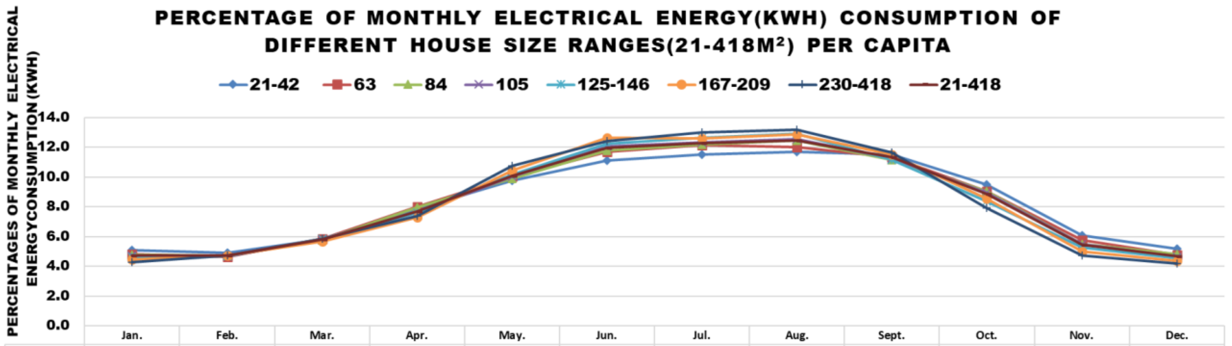
Table 5.13 Percentages of monthly IQR's of electrical energy consumption per household

House size	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
25%ile												
21-42	5	5	6	8	9	11	11	12	13	11	5	5
63	4	4	6	8	11	12	12	12	11	9	6	5
84	**4**	**4**	**6**	**9**	**11**	**12**	**12**	**13**	**11**	**9**	**5**	**4**
105	5	5	6	9	11	11	12	12	11	9	6	5
125-146	**5**	**5**	**6**	**9**	**10**	**12**	**12**	**12**	**11**	**9**	**5**	**4**
167-209	5	5	6	8	10	12	12	13	11	9	6	5
230-418	4	6	7	8	10	12	12	13	11	8	5	5
21-418	**5**	**4**	**6**	**9**	**11**	**12**	**12**	**12**	**11**	**9**	**5**	**5**
Median												
21-42	5	5	6	8	10	11	11	11	11	9	6	5
63	**5**	**5**	**6**	**8**	**10**	**12**	**12**	**12**	**11**	**9**	**6**	**5**

84	5	5	6	8	10	12	12	12	11	9	6	5
105	**5**	**5**	**6**	**8**	**10**	**12**	**12**	**12**	**11**	**9**	**6**	**5**
125-146	5	5	6	8	10	12	13	13	11	8	6	5
167-209	**4**	**5**	**6**	**8**	**11**	**13**	**13**	**13**	**11**	**8**	**5**	**4**
230-418	4	4	6	7	12	13	14	14	12	7	4	4
21-418	**5**	**5**	**6**	**8**	**10**	**12**	**12**	**12**	**11**	**9**	**6**	**5**
75%ile												
21-42	5	5	6	8	10	11	12	12	12	10	6	5
63	**5**	**5**	**6**	**8**	**10**	**12**	**12**	**12**	**11**	**9**	**6**	**5**
84	5	5	6	8	10	11	12	12	11	9	6	5
105	**5**	**5**	**6**	**8**	**10**	**12**	**13**	**12**	**11**	**9**	**5**	**5**
125-146	4	5	6	7	10	12	13	14	11	8	5	4
167-209	**4**	**4**	**6**	**7**	**11**	**13**	**13**	**13**	**12**	**8**	**4**	**4**
230-418	4	4	5	7	11	12	13	13	12	9	5	4
21-418	**5**	**5**	**6**	**8**	**10**	**12**	**13**	**13**	**11**	**8**	**5**	**5**

Percentages of monthly electrical energy demand timings per capita:

We found similar trends, as of per household, of timings of electric energy consumption in all house sizes per capita. When we look at the monthly percentage values of average electrical energy consumption across the year per Capita, we see that it is higher in summer months 9.8-13.1% (May-Sept.) and lower 4.2-6.1% in winter months (November-February) Figure 5.15. In all house sizes, the highest demand per capita occurs during August (11.7-13.1%), and minimum in February (4.7-4.9%) Figure 5.15. The average of summer demand (11.45%/capita) is 2.23 X higher than the average winter demand (5.15% /capita). The average demands for Autumn (October, 8.7%) and Spring (March-April,6.85%) are 0.76 and 0.60 X lesser than average summer demand (11.45 %). We will see in the next section of the thesis how much of this percentage demand during summer and winter can be met by the solar PV, which seems to be a reasonable low carbon measure to achieve our thesis aims.



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	5.1	4.9	5.8	7.9	9.8	11.1	11.5	11.7	11.5	9.5	6.1	5.2
63	4.8	4.6	5.8	8.0	10.0	11.7	12.1	12.0	11.3	9.0	5.7	4.8
84	4.8	4.7	5.8	8.0	9.9	11.8	12.2	12.5	11.2	9.0	5.5	4.8
105	4.7	4.7	5.7	7.6	10.0	12.0	12.3	12.5	11.2	8.9	5.5	4.6
125-146	4.7	4.7	5.8	7.6	10.1	12.2	12.6	12.9	11.1	8.4	5.3	4.6
167-209	4.4	4.7	5.7	7.3	10.4	12.6	12.6	12.9	11.5	8.5	5.0	4.4
230-418	4.3	4.7	5.9	7.4	10.7	12.4	13.0	13.1	11.6	7.9	4.7	4.2
21-418	4.7	4.7	5.8	7.7	10.1	11.9	12.3	12.5	11.3	8.8	5.5	4.7

Figure 5.15 Percentage of monthly electricity consumption of different house size ranges(21-418m^2) per capita

Inter-Quartile Ranges (IQR) of monthly electrical energy demand timings per capita:

The IQR values per Capita tells that the timings of peak electrical energy demand percentage, of all house size, are highest in summer (May-August or stretched to September), moderate in Autumn (September-October) and Spring (March-April), and lowest in winter (November-February) across all house sizes (21-418m^2) Figure 5.16. (the interquartile ranges Q3, Q2 & Q1 are shown Figure 5.16 & Table 5.14 by utilizing box plot). Further, we found that as we move from a smaller house to a larger house, the IQR of the percentages of annual electric energy consumption per capita during summer also increases for all house sizes. It means residents of larger houses utilize a higher percentage of their annual energy consumption during summer Figure 5.16 & Table 5.14. The average values of monthly percentages of 75%ile, median and 25%ile of summer months (May-Sept., 75%ile=12%/capita, median=12 %/capita, 25%ile=12%/capita) are 2.40, 2.40 and 2.40 X higher than winter months (November-February, 75%ile=5 %/capita, median=5%/capita, 25%ile=5%/capita) Figure 5.16 & Table 5.14. We will see for each season, what percentage of this average demand can be produced from the domestic buildings themselves per capita, and to what extent our aim to achieve low carbon domestic sector, could be met.

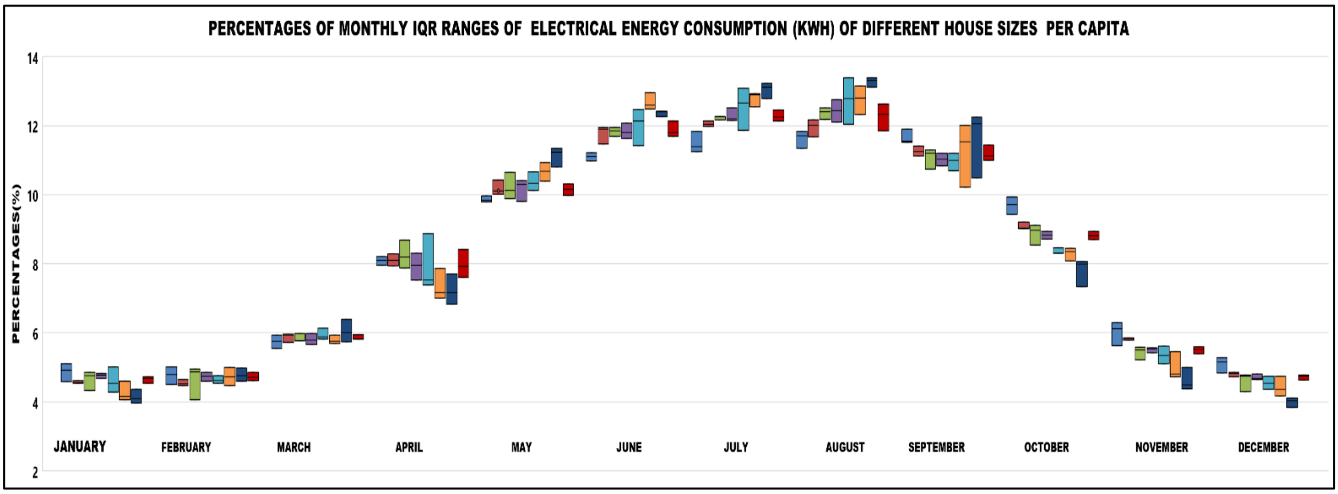


Figure 5.16 Percentages of monthly IQR (Inter-Quartile Ranges) of electrical energy consumption(kWh) of different house size ranges(21-418m^2) per capita

Further, knowing the values, ranges, and timings of electrical energy demand per capita would help us to understand, how much and how high the demand would be throughout the year and how it varies during different seasons. Further, looking at the occupancy level of each house size when compared with the percentage of demand ranges and generation potential from the respective rooftop would help us to understand how much of the total demand can be generated by the domestic buildings by themselves.

Table 5.14 Percentages of monthly IQR's of electrical energy consumption per capita

House size	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
25%ile												
21-42	5	5	6	8	10	11	12	12	12	10	6	5
63	5	5	6	8	10	11	12	12	11	9	6	5
84	4	4	6	9	11	12	12	12	11	9	5	4
105	5	5	6	8	10	12	12	12	11	9	5	5
125-146	5	5	6	9	11	11	12	12	11	8	6	5
167-209	5	5	6	8	10	12	13	12	10	8	5	5
230-418	4	5	6	8	11	12	13	13	10	8	5	4
21-418	5	5	6	8	10	12	12	12	11	9	6	5
Median												
21-42	5	5	6	8	10	11	11	12	12	10	6	5
63	5	4	6	8	10	12	12	12	11	9	6	5
84	5	5	6	8	10	12	12	13	11	9	6	5
105	5	5	6	8	10	12	12	12	11	9	6	5
125-146	5	5	6	8	10	12	13	13	11	8	5	5
167-209	4	5	6	7	11	13	13	13	12	8	5	4

230-418	4	5	6	7	11	12	13	13	12	7	4	4
21-418	5	5	6	8	10	12	12	12	11	9	6	5
75%ile												
21-42	5	5	6	8	10	11	11	11	12	9	6	5
63	5	5	6	8	10	12	12	12	11	9	6	5
84	5	5	6	8	10	12	12	12	11	9	6	5
105	5	5	6	8	10	12	13	13	11	9	6	5
125-146	4	5	6	7	10	12	13	13	11	8	5	4
167-209	4	4	6	7	11	13	13	13	12	8	5	4
230-418	4	5	6	7	11	12	13	13	12	8	4	4
21-418	5	5	6	8	10	12	12	13	11	9	5	5

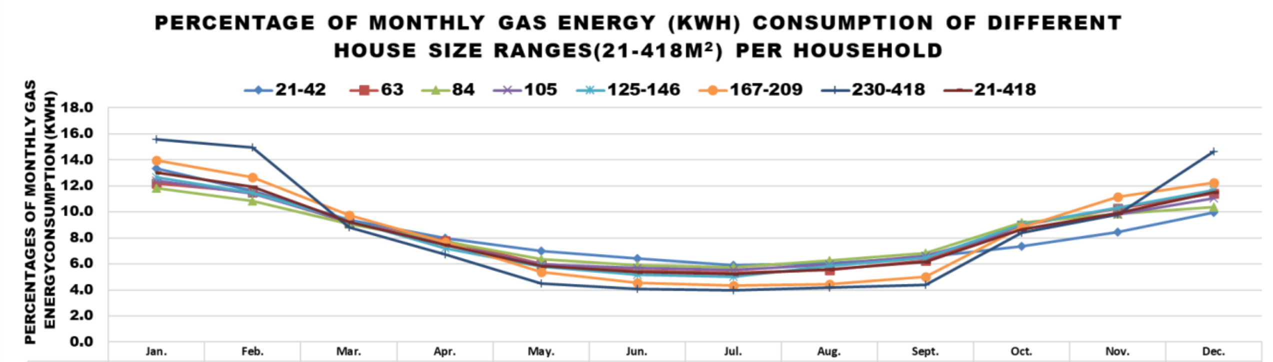
The results are shown in Figure 5.16 and Table 5.14 help us in estimating the percentage of electrical energy demand that can be met by energy generation from the domestic rooftops. Like how much percentage of average demand and the ranges of demand (per capita/m^2) could be produced when comparing the available rooftop area (per capita/m^2) of different houses with the occupancy level of the same house and looking at the generation potential from the same house. This generation potential may vary throughout the year as per solar irradiance variability, and we found that the demand also changes throughout the year. We will analyse during each season what percentage of electrical energy demand will be met by solar PV.

5.4.3.2 Percentages & Inter-Quartile Ranges (IQR) of average gas energy demand timings per household and capita of different house sizes

Percentages of monthly gas energy demand per household:

The timings of the gas energy demand of all house sizes are shown in Figure 5.17, where we achieved a confidence level of 95%. The ranges of confidence intervals which are widely accepted in the academic research [356] (CI ≤ 5 is acceptable) are from 1.8 to 4.7 (Table 5.11)(achieved by house sizes of 84, 105 & 125-146m^2), except the house size ranges from 21-63m^2 & 167-418m^2 where the confidence intervals achieved are 5.6-5.7 & 5.6-6.5 respectively Table 5.11. The monthly percentages of average values of all house size ranges of gas consumption are shown in Figure 5.17, which precisely identifies the four different demand timings over the year, which coincide largely with the seasonal variations. However, we observed in terms of monthly percentage of gas consumption, that the timings of relative higher use are stretched at both ends of the winter season, i.e. it starts increasing from October and stays high till march, especially in the house size ranges from 21-209m^2. The largest houses, i.e. from 230-418m^2, more precisely follow the change in percentage demand as per seasonal variations Figure 5.17. We found almost similar trends of demand timings in all house sizes. The measure of central tendency, like monthly percentages of average gas consumption (%) of winter months 8.5-15.6% (November-February) shows higher gas energy consumption (%) than summer months 4-7% (May-Sept.) in all house size ranges. The percentage consumption of autumn and spring seasons is 7.4-9.2 & 6.7-9.4, respectively. In all house sizes the highest gas consumption demand per household occurs in January (Avg.=13.75%) and lowest in July (Avg.=4.95%) Figure 5.17.

As per all households analysis, the average difference in percentages of seasonal gas consumption between winter (12.05 %) and summer (5.5%) is 2.20 X higher in winter than summer of all house sizes. The average percentage consumption of Autumn (October, 8.3%) and Spring (March-April,8.05%) are 0.69 and 0.67 X lesser than average winter demand (12.05 %) of all house sizes Figure 5.17. So, the lowest demand for gas per household occurs during summer months Figure 5.17, which is further confirmed when we look at the box plot (Figure 5.18) (which tells us the division of our data, i.e. 25%ile, median and 75%ile) of the timing of gas energy demand.



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	13.3	11.6	9.4	8.0	7.0	6.4	5.9	6.1	6.5	7.4	8.5	10.0
63	12.2	11.5	9.2	7.8	6.0	5.5	5.3	5.6	6.2	9.0	10.3	11.4
84	11.9	10.9	9.1	7.7	6.3	5.9	5.7	6.3	6.8	9.2	9.8	10.4
105	12.4	11.4	9.3	7.5	6.0	5.7	5.6	6.0	6.7	8.7	9.8	11.1
125-146	12.7	11.5	9.3	7.2	5.8	5.2	5.0	5.8	6.5	9.0	10.3	11.7
167-209	13.9	12.7	9.7	7.7	5.4	4.6	4.3	4.5	5.0	8.8	11.2	12.3
230-418	15.6	15.0	8.8	6.7	4.5	4.1	4.0	4.2	4.4	8.4	9.8	14.7
21-418	13.0	12.0	9.2	7.5	5.9	5.4	5.2	5.6	6.2	8.7	9.9	11.5

Figure 5.17 Percentage of monthly gas consumption of different house size ranges (21-418m^2) per household

The results of gas energy, per household, indicate its demand approximately reduces to half in summer than that of winter. The increased winter demand for gas is due to its high usage for hot water and space heating, which is not required in the summer months. Since gas is cheaply available in Pakistan and the primary source of domestic fuel for cooking (throughout the year), space heating (in winter), and water heating (in winter), people use it as per their affordability and availability. In the recent past, the gas supply was limited during winter, and there were times of gas-cut in Punjab. It is vital to shift its demand to other sources of energy. Following our thesis aims, the possibility of having solar thermal for water and space heating could be exploited. We will see in the next section how much of this space and water heating demand can be taken up by the generation of green energy from the rooftops of the same buildings. It will be estimated by utilizing solar thermal technology based on the actual available areas of respective house sizes (Area solar Model, discussed in the next session).

Inter-Quartile Ranges (IQR) of monthly gas energy demand timings per household:

The percentages of IQR values per household of all house sizes (21-418 m^2), tells that the timings of monthly percentages of gas energy demand are highest is Winter (November-February), moderate in Autumn (October) and Spring (March-April), and lowest in summer (May-Sept.) Figure 5.18. (the interquartile ranges Q3, Q2 & Q1 are shown in Figure 5.18 by utilizing a box plot, & Table 5.15).

The average values of monthly percentages of 75%ile, median and 25%ile of winter months (November-February ,75%ile=12%, median=12 %, 25%ile=15.5%) are 2.18, 2.18 and 6.2 X higher than summer months (May-Sept, 75%ile=5.5 %, median=5.5%, 25%ile=2.5%) of all house sizes. Figure 5.18 & Table 5.15. The average values of monthly percentages of 75%ile, median and 25%ile of winter months (November-February ,75%ile=12%, median=12 %, 25%ile=15.5%) are (1.5, 1.15 and 1.24 & 1.5, 1.10 and 2.07) X higher than autumn (Oct., 75%ile=8 %, median=10.5%, 25%ile=12.5%) & spring (March-April, 75%ile=8 %, median=10%, 25%ile=7.5%) months of all house sizes, respectively. Figure 5.18 & Table 5.15.

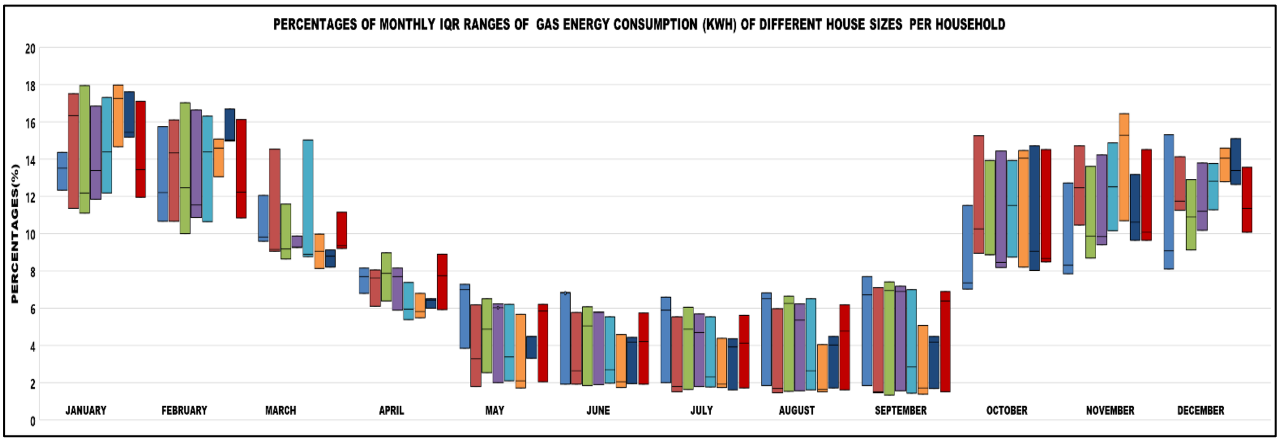


Figure 5.18 Percentages of monthly IQR (Inter-Quartile Ranges) of gas energy consumption (kWh) of different house size ranges (21-418m^2) per household

We observed (a) there are more extensive ranges (IQR's) in the monthly percentages of gas consumption almost throughout the year, except during spring season (March-April) where fewer variations are found, in all house size ranges. These large IQR's of different house sizes, and within the same house size, would mean that we must look for various possibilities of gas energy supply or other alternatives. It shows that one solution for one house size may not fit all houses of the same size, and for different house sizes. (b) We also found that the Interquartile ranges (IQR) of winter months are higher than in the summer months. (c) It is further found that as we move from smaller houses to larger houses over the year, the IQR's have similar trends. (d) we found that the houses of the smallest size (21-42m$^{2)}$ start utilizing a higher percentage of their gas energy at the start of October.

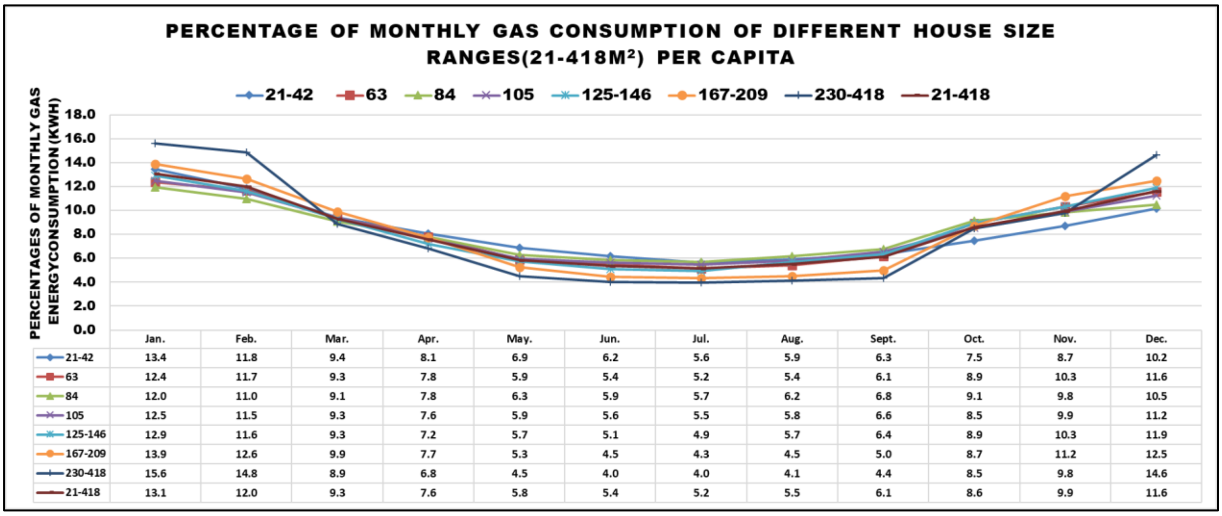
Table 5.15 Percentages of monthly IQR's of gas energy consumption per household

House size	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
25%ile												
21-42	14	16	12	7	4	2	2	2	2	12	13	15
63	18	14	9	6	2	2	2	2	1	15	15	14
84	18	17	9	6	3	2	2	2	1	14	14	13
105	17	17	9	6	2	2	2	2	2	14	14	14
125-146	17	16	9	6	2	2	2	2	1	14	15	14
167-209	18	15	9	6	2	2	2	2	1	14	15	15
230-418	18	17	9	6	3	2	2	2	2	15	13	13
21-418	17	16	9	6	2	2	2	2	2	15	15	14
Median												
21-42	12	11	10	8	7	7	7	7	8	7	8	8
63	16	16	15	8	3	3	2	1	2	10	12	12
84	12	12	12	9	5	5	5	6	7	9	9	9
105	13	12	10	8	6	6	5	5	7	8	10	10
125-146	14	14	15	5	3	3	2	3	3	12	13	13
167-209	17	15	8	5	2	2	2	2	2	14	16	14
230-418	15	15	9	7	5	4	4	4	4	9	11	13
21-418	13	12	11	9	6	4	4	5	6	9	10	10
75%ile												
21-42	14	12	10	8	7	7	6	7	7	7	8	9
63	11	11	9	8	6	6	6	6	7	9	10	11
84	11	10	9	8	7	6	6	7	7	9	10	11
105	12	11	9	8	6	6	6	6	7	8	9	11
125-146	12	11	9	7	6	6	6	7	7	9	10	11
167-209	15	13	10	7	6	5	4	4	5	8	11	13
230-418	15	15	8	6	5	4	4	5	5	8	10	15
21-418	12	11	9	8	6	6	6	6	7	8	10	11

Percentages of monthly gas energy demand timings per capita:

The monthly percentages of average values of all house size ranges of gas consumption per capita are shown in Figure 5.19, which clearly identifies the four different demand timings over the year, which coincide mainly with the seasonal variations. However, we observed in terms of monthly percentage of gas consumption that the timings of relative higher use are stretched at both ends of the winter season. It starts increasing from October and stays high till March, especially in the house size ranges from 21-209m^2, the largest houses, i.e. from 230-418m^2 more precisely follow the change in percentage demand as per seasonal variations per capita Figure 5.19. We found almost similar trends of demand timings per capita by the residents of all house sizes ranges. The measure of central tendency, like monthly percentages of average gas consumption (%) per capita of winter months 8.7-15.6% (November-February) shows higher gas energy consumption (%) than summer months 4-6.9% (May-Sept.) per capita by the residents of all house sizes ranges. The consumption percentages per capita of autumn and spring seasons are 7.5-9.1% & 6.8-9.9% respectively. In all house sizes the highest gas consumption demand per capita occurs in January (Avg.=14.35%) and lowest in July (Avg.=4.85%) Figure 5.19

As per capita analysis, the average difference in percentages of seasonal gas consumption per capita between winter (12.15 %/capita) and summer (5.45%/capita) is 2.23 X higher in winter than summer per capita by the residents of all house sizes ranges. The average percentage consumption of Autumn (October, 8.3%/capita) and Spring (March-April,8.35%/capita) are 0.69 and 0.68 X lesser than average winter demand (12.15 %/capita) per capita by the residents of all house sizes ranges Figure 5.19. So, the lowest demand for gas per capita occurs during summer months Figure 5.19, which is further confirmed when we look at the box plot (Figure 5.20) (which tells us the division of our data, i.e. 25%ile, median and 75%ile) of the timing of gas energy demand.



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	13.4	11.8	9.4	8.1	6.9	6.2	5.6	5.9	6.3	7.5	8.7	10.2
63	12.4	11.7	9.3	7.8	5.9	5.4	5.2	5.4	6.1	8.9	10.3	11.6
84	12.0	11.0	9.1	7.8	6.3	5.9	5.7	6.2	6.8	9.1	9.8	10.5
105	12.5	11.5	9.3	7.6	5.9	5.6	5.5	5.8	6.6	8.5	9.9	11.2
125-146	12.9	11.6	9.3	7.2	5.7	5.1	4.9	5.7	6.4	8.9	10.3	11.9
167-209	13.9	12.6	9.9	7.7	5.3	4.5	4.3	4.5	5.0	8.7	11.2	12.5
230-418	15.6	14.8	8.9	6.8	4.5	4.0	4.0	4.1	4.4	8.5	9.8	14.6
21-418	13.1	12.0	9.3	7.6	5.8	5.4	5.2	5.5	6.1	8.6	9.9	11.6

Figure 5.19 Percentage of monthly gas consumption of different house size ranges (21-418m²) per capita

The understanding of gas demand per capita will help us to know what the gas demand range is, per capita, across Punjab? How much of this demand could possibly be met by alternate green sources?

Inter-Quartile Ranges (IQR) of monthly gas energy demand timings per capita:

The monthly percentages values (IQR) per capita of all house sizes (21-418 m^2) suggest that the timings of gas energy demand are highest in Winter (November-February), moderate in Autumn(October) and Spring(March-April), and lowest in summer (May-Sept.) Figure 5.20.(the interquartile ranges Q3, Q2 & Q1 are shown in Figure 5.20 by utilizing box plot, Table 5.16). We observed (a) there are larger ranges (IQR's) in the monthly percentages of gas consumption per capita almost throughout the year, except during spring season (March-April) where fewer variations are found per capita by the residents of all house size ranges. The average values of monthly percentages (per capita) of 75%ile, median and 25%ile of winter months {(November-February ,75%ile=11.5%, median=13 %, 25%ile=15.5%)/capita} are 2.1, 2.9 and 5.2 X higher than summer months {(May-Sept, 75%ile=5.5 %, median=4.5%, 25%ile=3%)/capita} of all house sizes Figure 5.20 & Table 5.16. The average values of monthly percentages of 75%ile, median and 25%ile of winter months {(November-February ,75%ile=11.5%, median=13 %, 25%ile=15.5%)/capita} are 1.45, 1.3 and 1.07 & 1.3, 1.37 and 1.82 per capita X higher than autumn{(Oct., 75%ile=8 %, median=10%, 25%ile=14%)/capita} & spring {(March-April, 75%ile=8.5%, median=9.5%, 25%ile=8.5%)/capita} months of all house sizes, respectively Figure 5.20 & Table 5.16.

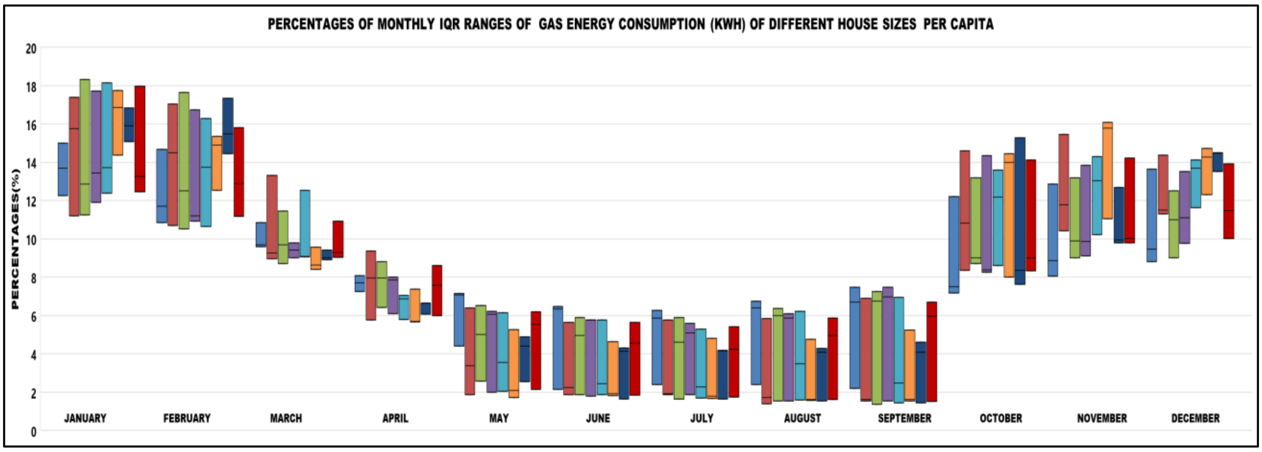


Figure 5.20 Percentages of monthly IQR (Inter-Quartile Ranges) of gas energy consumption (kWh) of different house size ranges (21-418m^2) per capita

These large IQR's of varying house sizes, and within the same house size, would mean that we must look for various possibilities of gas energy supply per capita or other alternatives. It suggests that one solution (per capita) for one house size may not fit for (per capita) all houses of the same size, and other house sizes. (b) We also found that the Interquartile ranges (IQR) of winter months are higher than in the summer months. (c) It is further found that as we move from smaller houses to the larger house of per capita consumption values over the year, the IQR's have similar trends. (d) we found that the residents of smallest house sizes (21-42m^2) start utilizing a higher percentage of their gas energy at the start of October and use it till the end of march Figure 5.20 & Table 5.16

Table 5.16 Percentages of monthly IQR's of gas energy consumption per capita

House size(m^2)	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
25%ile												
21-42	15	15	11	7	4	2	2	2	2	12	13	14
63	17	15	9	6	2	2	2	2	2	15	15	14
84	18	18	10	6	3	2	2	2	1	13	13	13
105	18	17	9	6	2	2	2	2	2	14	14	14
125-146	18	16	9	6	2	2	2	2	1	14	14	14
167-209	18	15	8	6	2	2	2	2	2	14	16	15
230-418	17	17	9	6	3	2	2	2	1	15	13	14
21-418	18	16	9	6	2	2	2	2	2	14	14	14
Median												
21-42	12	11	10	8	7	6	6	7	7	8	9	9
63	16	17	13	9	3	2	2	1	2	11	12	11
84	13	13	11	9	5	5	5	6	7	9	9	9
105	13	11	10	8	6	6	5	6	7	8	9	10
125-146	14	14	13	7	4	2	2	3	2	12	13	14
167-209	17	15	9	6	2	2	2	2	2	14	16	14
230-418	16	15	9	7	4	4	4	4	4	8	10	14
21-418	13	13	11	9	6	5	4	5	6	9	10	10
75%ile												
21-42	14	12	10	8	7	6	6	6	7	7	8	9
63	11	11	9	8	6	6	6	6	7	8	10	12
84	11	11	9	8	7	6	6	6	7	9	10	11
105	12	11	9	8	6	6	6	6	7	8	10	11
125-146	12	11	9	7	6	6	5	6	7	9	10	12
167-209	14	13	10	7	5	5	5	5	5	8	11	12
230-418	15	14	9	7	5	4	4	4	5	8	10	14
21-418	12	11	9	8	6	6	5	6	7	8	10	11

5.4.4 Summary of 'timings of energy demand' of survey data

All house sizes in households precisely showed four different demand timings within the year, which coincide with the seasonal variations. We found that the electrical energy demand of each season is different. The summer season (May-Sept.) is of the highest energy demand consuming 9-13% of total energy in different summer months. Winter months consumed 4-6% energy(mid-Nov.-Feb.). August is the month with the highest percentage demand (11-13%), and February has the lowest electrical energy demand (4-5%) in different house sizes. The summer demand is 2.18, 0.77, and 0.61 times different than winter, autumn, and spring demands. We found that the households with larger sizes in the sample, consume a higher percentage of their energy during summer. The percentage ranges of average demands are wider in summer and narrow in winter of all house sizes. It implies some consumers are using higher energy due to family size, affordability, accessibility, larger houses and different lifestyles. Overall, from per household analysis, we can say that smaller houses with lesser energy demand may be able to meet their current energy demand by their energy generation Figure 5.13 and Figure 5.14. Electrical per capita analysis, we found similar timings of electrical energy demands, i.e. highest in summer 9-13% and lowest in winter 4-6% in different house sizes. The average summer demand is 2.23, 0.76 and 0.60 times different than winter, autumn and spring demand, respectively Figure 5.15. we need to see how much of these per household and capita demands during different times of the year can be met by the alternate green source of energy like solar PV, (would be discussed in detail in next section). We need to know if a complete or partial storage capacities are required for different house size requirements.

Gas per household timings of demand suggests that there are precisely four different demand timings which coincide with the seasonal variations in all house sizes. Overall, winter demand is highest 8-15.6%, and summer demands are the lowest 4-7% in all house sizes during different months of these seasons. January is the month of highest demand (13.8%), and July has the lowest demand (5%) of total annual gas consumption of all house sizes Figure 5.17. The winter demand is 2.20, 0.69 and 0.67 times different than summer, autumn and spring months. Figure 5.17 & Figure 5.18. The increased winter demand for gas is due to water and space heating; therefore, the possibility of having solar thermal for water and space heating could be exploited. The large IQR's of different house sizes, and within the same house size, would mean that we must look for various possibilities of gas energy supply or other alternatives. One solution for one house size may not fit all houses of the same size and for different house sizes.

For per capita gas analysis, we see similar trends as per household, like more gas demand in winter and less in summer. The average percentage of winter gas demands is 2.23, 0.69 and 0.68 times different than summer, autumn and spring demands, respectively (per capita) Figure 5.19 & Figure 5.20. The IQR ranges of different months are wider except in spring, which suggests different mitigation strategies for various house sizes. Comparatively, the IQR's of winter months are more extensive than summer months. The increased gas usage by the occupiers of smaller house sizes starts earlier than larger houses, i.e. in October.

5.4.5 Smart meters data results & analysis for timings of energy demand

We will analyse our smart meter data at three levels: Annually (showing monthly values), monthly (showing daily values) and daily (showing hourly values), (in three steps) as shown in Figure 5.12. We will do this to fully understand the patterns or timings of electrical energy demand across the year. We will investigate the smart meter data for per household or capita; the average house size and occupancy in our data are 125-146m^2 and six, respectively. It is imperative to know that as we have only one value for an average range of house size and occupancy, so the results of percentage demand of electrical energy can either be presented as per household or per capita, though the values of household demand are 6 times higher than as per capita demand (as occupancy=6)

5.4.5.1 Percentages of average annual electrical energy demand timings per household and capita of 10 case study houses

Step:1 **Annual analysis (monthly values),** The percentages of the annual electrical energy demand of 10 case studies houses (size ranges from 125-146m^2) are shown in Figure 5.21

Step 2: Out of the total energy consumed in the year 2017-18, collected from smart meters, the results distinctly identify the four different demand timings over the year, which coincide mainly with the seasonal variations, quite similar trend as we saw in annual survey data analysis. The range of summer (May-Sept.) demand is 10.3-14.8% of the total annual electric energy demand. In our case studies houses, the autumn, winter and spring electrical energy consumption (%) ranges are 6.1%(Oct.), 3.3-4.4%(Nov.-Feb.) & 5.8-8%(Mar.-April) respectively Figure 5.21. So, we can say that the summer is the time of highest electricity demand and winter being the lowest. The results show that the highest demand per household or capita occurs during August (14.8%), and minimum in January (3.3%) Figure 5.21. We also observed that the summer period is stretched till the end of September, which initially was considered till the end of August, with this it makes summer the most extended season (almost five months) w.r.t to electric energy consumption or for cooling demand.

As per the annual analysis, the average difference in percentage consumption of seasonal electrical energy between summer (12.94 %) and winter (3.85 %) is 3.46 times, higher summer than winter demand. The average demands for autumn (October, 6.1%) and spring (March-April, 6.9%) are 0.47 and 0.53 X (lesser than) average summer demand (12.94 %) Figure 5.21. we have seen almost similar trends in the analysis of our survey data set for the annual electrical energy consumption, which is now being confirmed by our smart meters data. By now, we fully understand that the electrical energy demand changes across the different seasons and the months of highest demand in each season. In the next part, we will see how this demand changes over the different days of each month or does it stay the same in that particular month. Are there certain days of each month (of the week) which require more electricity? It would help us to more accurately size our solar PV to meet the demand of that month if the other parameters, like roof area and solar irradiance, are available.

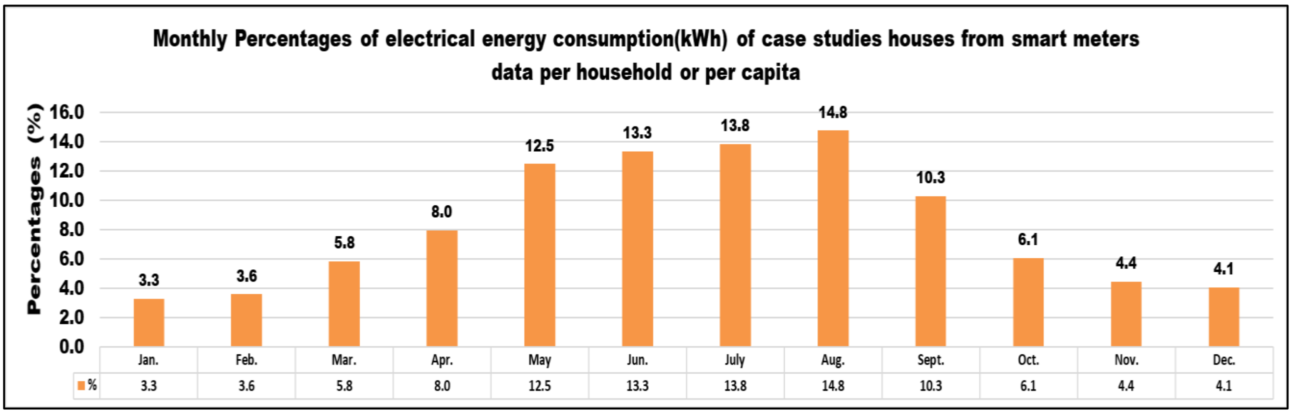


Figure 5.21 Percentage of monthly electricity consumption of 10 case studies, house size ranges (125-146m^2) per household or capita

***Step 2:* Monthly analysis (daily values):** We looked at the monthly percentages of electrical energy demands of each month, now we want to see at the days of each month. We are interested to know which days consume a higher percentage of electrical energy (Mon-Sun) out of the total energy being consumed in the same month. Further, we will understand the weekdays (Mon-Fri.) and weekend days (Sat-Sun) demand percentages of each month out of total energy being consumed in the same month**.** We are trying to split the timings of energy demand, to understand the peak demand of a specific day of the month, average weekdays and average weekend days demands. It will help us to size our solar PV, whether we are interested in designing it (PV) for peak day demand or the average weekdays or weekend days demands of each month Figure 5.22 & Figure 5.23 and Table 5.17. and discussed in detail in **Appendix-C-Timings-1**

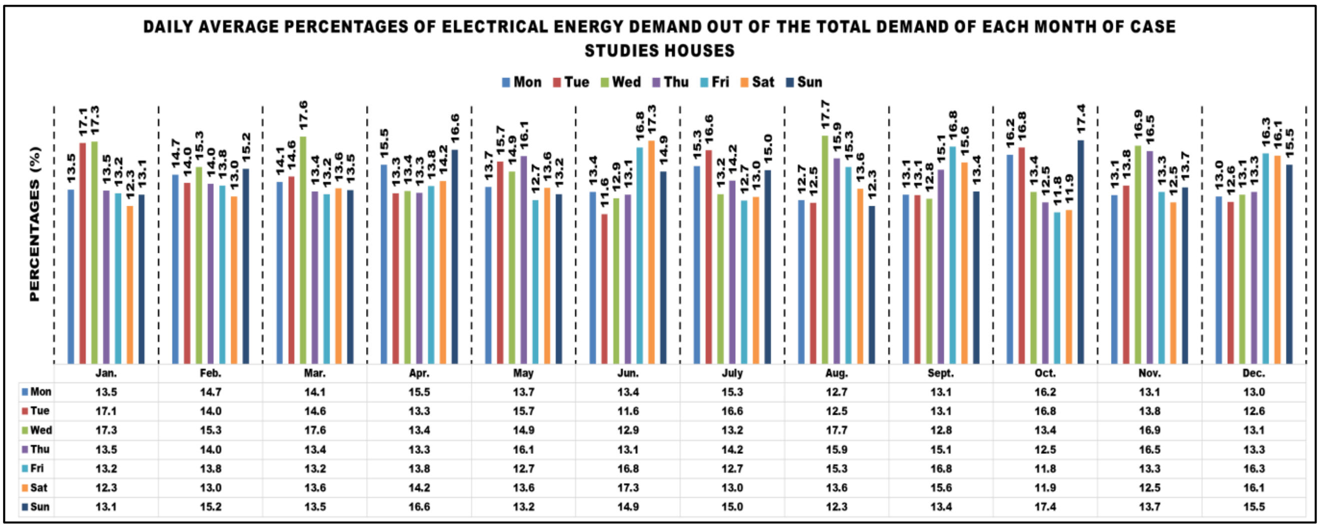


Figure 5.22 Daily average percentages of electrical energy demand out of the total need of each month of case studies houses (Mon-Sun)

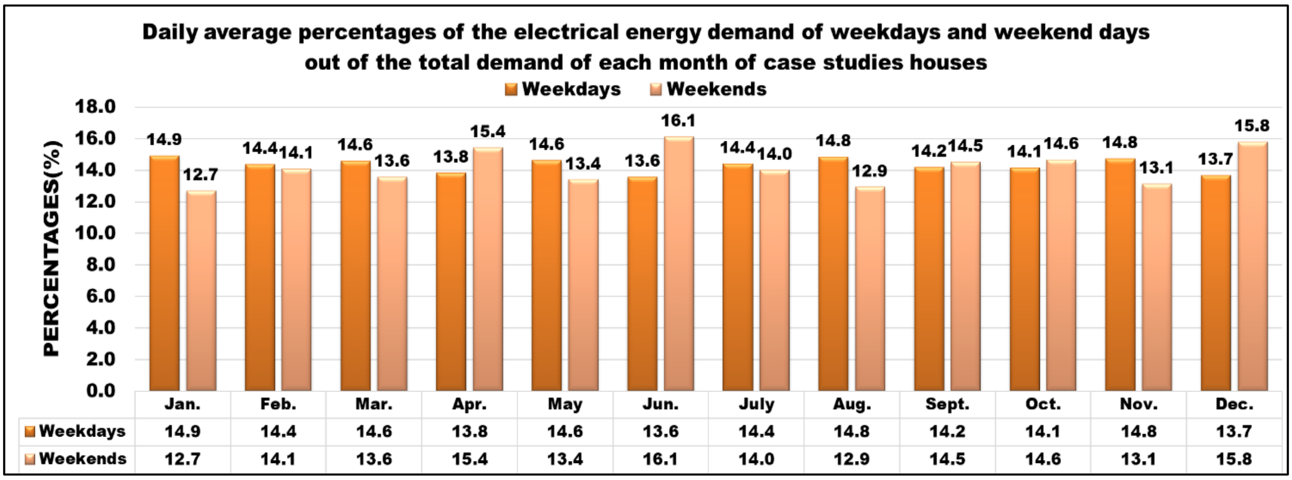


Figure 5.23 Daily average percentages of the electrical energy demand of weekdays and weekend days out of the total demand of each month of case studies houses

We found that Wednesdays are the days of peak demand of 5 months out of 12, Fridays and Sundays are other days of peak demand for two months each of electricity consumption throughout the year. We can use these percentage values of the days of the highest consumption to design our solar PV for the peak demand of each month. We further found that April, June, September, October and December are the months with higher average weekend days demand and January, February, March, May, July, August and November, are the months of higher average weekdays demand. We can use the average values of these months if we are interested in mitigating the energy supply system with renewable resources Table 5.17.

Table 5.17 Percentages of peak days and average weekdays & weekends electrical energy consumption demands of each month

Peak days of each month				Averages of weekdays and weekends		
Months	**Peak Days**	**Percentage (%)**	**Difference (%) from other days(higher)**	**Weekdays**	**Weekends**	**Difference (%)**
January	**Wednesdays**	17.3	25	14.9	12.7	15
February	**Wednesdays**	15.3	10	14.4	14.1	3
March	**Wednesdays**	17.6	28	14.6	13.6	7
April	**Sundays**	16.6	20	13.8	15.4	12
May	**Thursdays**	16.1	16	14.6	13.4	9
June	**Saturdays**	17.3	10	13.6	16.1	19
July	**Tuesdays**	16.6	21	14.4	14.0	3
August	**Wednesdays**	17.7	29	14.8	12.9	15
September	**Fridays**	16.8	21	14.2	14.5	2
October	**Sundays**	17.4	26	14.1	14.6	4
November	**Wednesdays**	16.9	22	14.8	13.1	13
December	**Fridays**	16.3	26	13.7	15.8	15

In the next part, we will see when this demand of electrical energy occurs within a day of each month. We will look into it by analysing three levels, i.e. (a) the hourly demand of electricity consumptions of peak day of each month and (b) the hourly demand of average weekdays and weekend's consumption values of each month (c) the average hourly seasonal demand of weekdays and weekend days

Step 3: Daily analysis (hourly values), Figure 5.24 shows the percentages of **hourly** (Mon-Sun) demands of peak days of each month & Figure 5.25 shows the averages of weekdays & weekends demands of electrical energy consumption out of the total energy consumption of each day (Mon-Sun). (a) we will see the daily demand hourly profiles of peak day of each **month.** (b) we will analyse the average daily demand hourly profiles of weekdays and weekends of each month. (c) we will present our analysis for the **seasonal** average daily demand hourly profiles for weekdays and weekends day. (d) we will show the percentages of **daytime** and **night-time** monthly (weekdays & weekends) and seasonal (weekdays & weekends) demands. It will enable us to design our solar PV if we wish to design it for **'Peak'** or **'Average' or 'Seasonal Average'** daily demand hourly profiles of each month. By knowing the percentages of daytime and night-time daily demands, we would show how big should be our storage capacity to meet night-time demand from solar energy. Targeting, to design the solar PV for the peak hourly demand of peak day of each month, would cater to the average daily-hourly demand as well. The average needs of other days of the week are less than the demand for peak day (though we will also be discussing the demands of the average of each day). Further, for a better understanding of the timing of electrical energy demand, we have grouped different months into seasons, and, explained and analysed as such. It is up to the user to use the timings of electrical energy demand as per requirement. It must be noted that the day length is shown in Figure 5.24 & Figure 5.25 presents the daylight timings precisely, excluding astronautical, nautical and civil twilight (which are included in the night time length, represented on the graphs [357]), further, in Figure 5.24, the percentages of average demand of each hour of specific peak days of each month are shown, for instance, for January, Wednesdays are the days of peak demand. Hence, the hourly time graph shows the average values of each hour of all Wednesdays of January. In Figure 5.25 the percentages of average demands of each hour of weekdays and weekends are shown, for instance, for weekdays at noon. The values are shown on the graph are the average percentage values of each day of the week (Mon-Fri) at noon, not weekends and vice versa. In the next section, we will present our analysis by showing the months of each season together to understand the seasonal demands better.

Peak day and average daily demand hourly profiles of each month (daily analysis a & b) is explained in Appendix-C-Timings-2

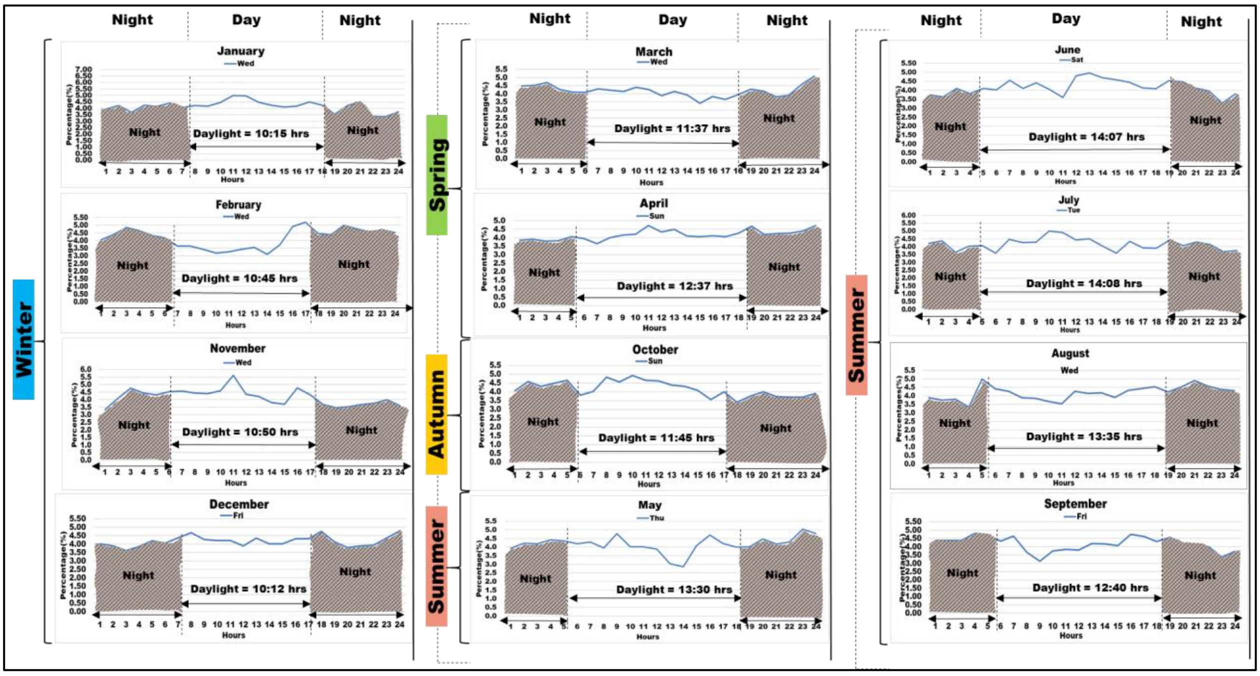


Figure 5.24 Percentages electrical energy hourly demand profiles of peak days of each month

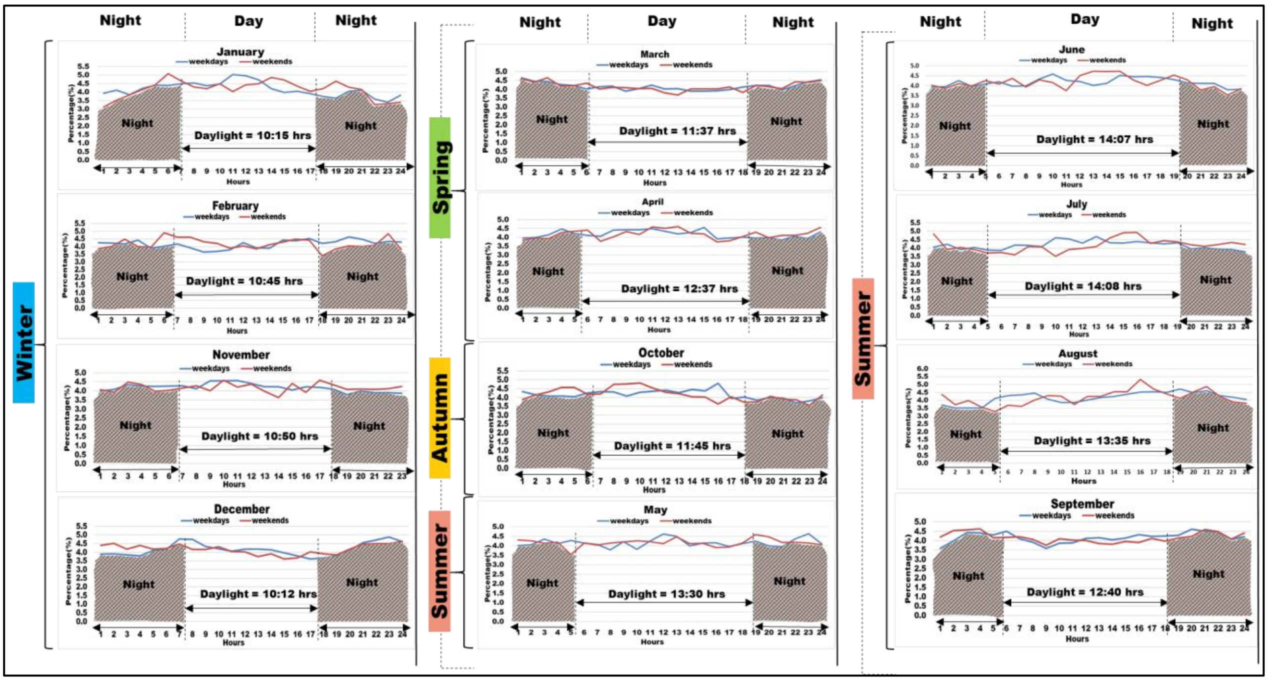


Figure 5.25 Percentages of electrical energy average hourly demands of each month (weekdays & weekends)

seasonal average daily demand hourly profiles for weekdays and weekends day (Daily analysis C)

we have analysed daily hourly profiles of weekdays and weekends of all four seasons out of the total monthly (Figure 5.26) and annual (Figure 5.27) demands of the case study houses. We found that summer weekends consume less energy than summer weekdays. The autumn and spring seasons demand follow similar profiles throughout the day. Winter demand percentages of weekdays are a little higher during night and midday (12:00hrs), and identical to weekends for the rest of the day. It indicates that overall, throughout the year the weekdays' demands are more than weekends and the same during autumn and spring season. We need to look for alternate energy generation solutions for almost all days of the year Figure 5.26 & Figure 5.27.

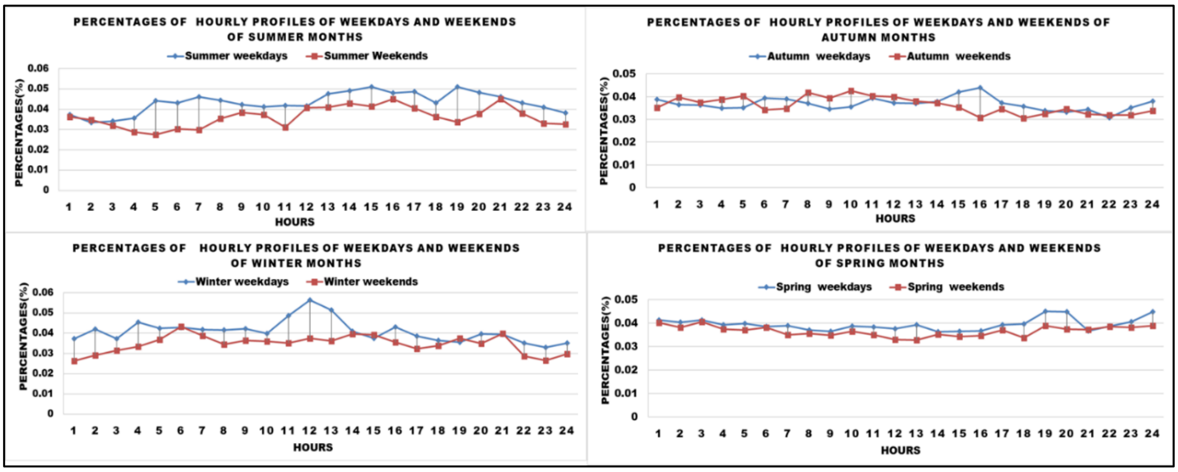


Figure 5.26 Percentages of hourly profiles of weekdays and weekends of all seasons out of total monthly demands

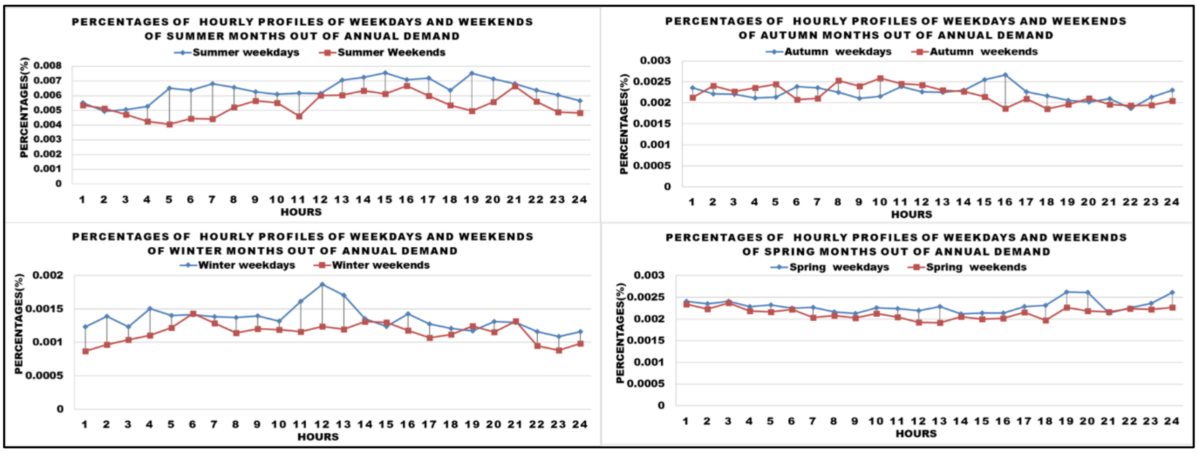


Figure 5.27 Percentages of hourly profiles of weekdays and weekends of all seasons out of total annual demands

Percentages of daytime and night-time monthly (weekdays & weekends) and seasonal (weekdays & weekends) demands

We have seen the aggregate electrical energy demand for each season and each month of the year. Summer daytime demands are 20% more than summer nights. Whereas winter night-time demands are approximately 13% more than daytime demands. The autumn daytime demands are 10% more than night-time demands, while Spring night-time demands are roughly 5% more than daytime needs. It shows that most of the summer demands occur during the daytime when there is enough solar energy available to mitigate. The higher winter night demands suggest having more storage capacities for a more significant number of hours, as night hours are more than day hours. For Autumn and Spring season the requirements are roughly equal, so we need to provide storage for 50% of the demands. The individual months of each season follow similar patterns as of seasonal demands Figure 5.28.

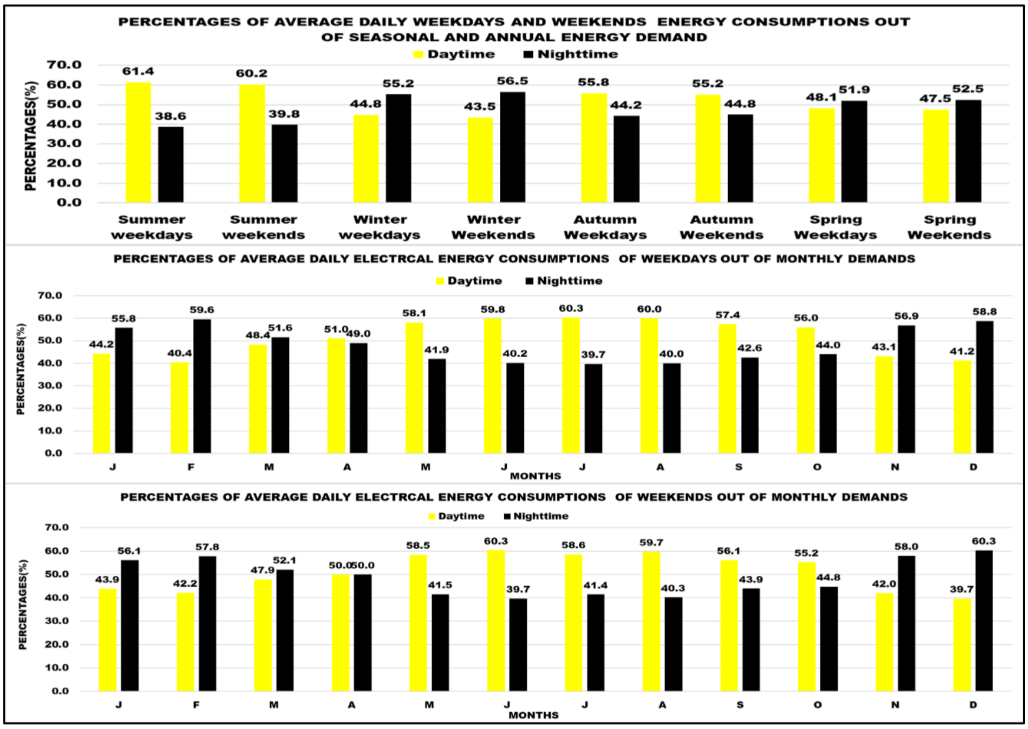


Figure 5.28 Percentages of daytime and night-time electrical energy demands out of total monthly and annual demands

5.4.6 Summary of objective 3 (demand timings)

Over the year the percentages of annual electrical energy demands are the highest during the summer season (10-12.5%) and lowest during the winter season (4.7- 5.4%). The autumn and spring demands are moderate (5.8-8.7%). We see that most of the annual demands are during the summer months which counts for 58.2% (survey data) of the total yearly demand and most of this, around 60% (smart metering data), occurs during the day. The summer days are longer and have more sunshine hours to produce green energy from solar PV. If we produce all our summer electrical energy during the day, we will be meeting 34.9% of our annual energy demand from the summer daylight only, without having the storage capabilities (like batteries).

Further, winter demands are 19.6% (survey data) of annual demands, and on average 42% (smart metering data) of this demand occur during the winter daytime, which means by producing this winter demand we can meet 8.2% of annual demand Figure 5.29. The combined autumn and spring electrical energy demand is 22.2% (survey data), and their combined daytime demand is, on average, 52% (smart metering data). If we produce this energy demand by Solar PV, we will be meeting 11.5% of annual demand. So, over the year, by producing our daytime demands, we will be able to achieve 54.62% of our electrical yearly energy demand without having any storage capability. It suggests that we need to have a storage capability of 45.4% of annual electrical energy demand if we want to meet all of our yearly demand by solar PV.

We have analysed these results utilizing the data collected from two sources, i.e. survey & smart metering data. We have strong confidence in the results of the survey data. Still, the smart metering data, which is used to know the daily daytime and night-time percentage of electrical energy consumption, has only ten samples to support these findings. Now we will see if the yearly percentages of the energy demand of smart meters data show similar energy percentages as we saw in survey data analysis. The smart meters summer months' electrical energy consumption is 49.9% (58.2% in our survey data), which is slightly more than survey data results, only 8.3% Figure 5.29. Further, the winter demand is 15.4% (19.6% in survey data), which is 4.2% different than survey data results. The combined autumn and spring consumption percentages are 19.9% (22.2% in survey data) which is 2.3% less as compared to survey data. So overall we can say the day the survey data and smart meter data results are closely related, i.e. 8.3% error, therefore, the daily percentages of energy consumptions of smart meter data can be taken as representative of survey data. Further, we have also cross-checked the total annual electrical energy consumed by the smart meter case studies houses with the energy prediction models produced from survey data (objective 2). We found that in 7 out of 10 case studies houses the electrical consumption values are within 6% error, similar to the actual values we have from energy bills. It increases our confidence, that we can relate the smart meters daily (daytime and night-time) percentages of energy consumption with our larger sample of survey data (but we are showing the results with the said errors of estimations).

From the electrical energy consumption results, we observed that percentage ranges of summer months (of different house sizes) are higher than in other seasons. It indicates that the summer demands fluctuate 10-13% for different house sizes, so when we are designing a renewable system for summer demands, we should take into account these ranges of demands. The peak day demand analysis of each month shows that the demands are around 10-29% (per daily demand) more than the other days of each month over the year.

The weekdays and weekend days demands are 2-19% (per daily demand) more than either for weekdays or weekends during different months of the year Table 5.17 & Figure 5.29.

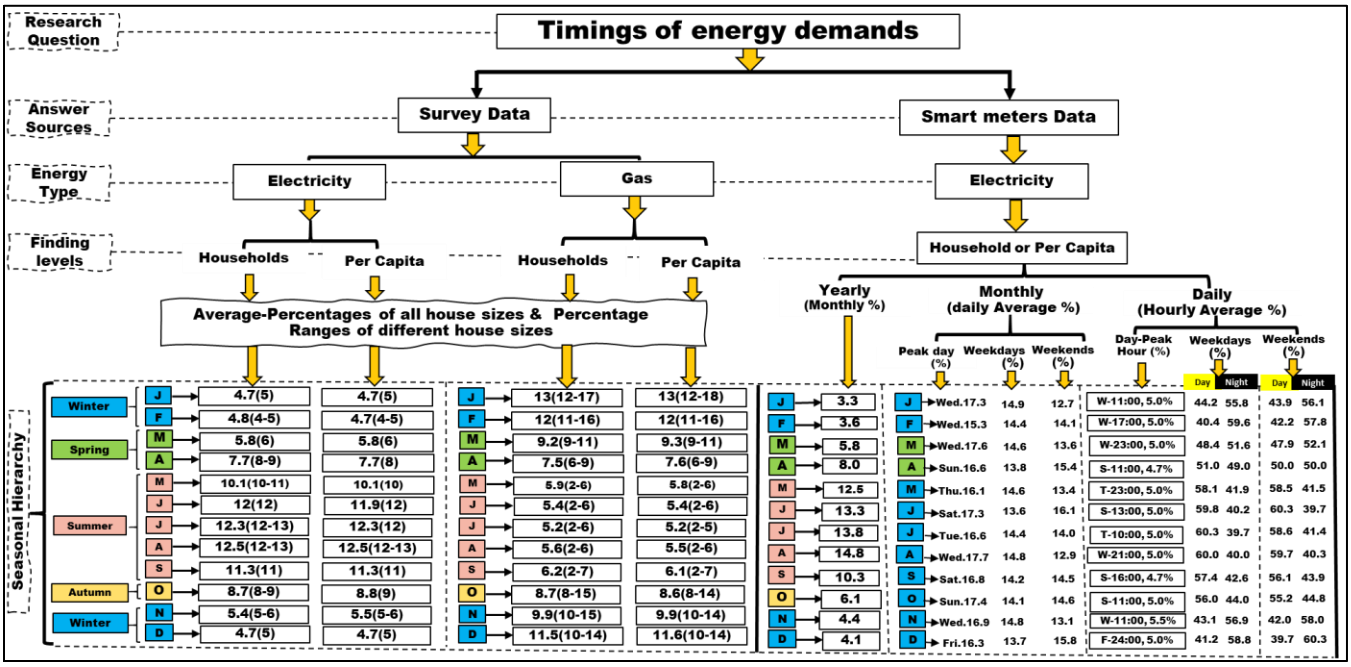


Figure 5.29 summary of timings of energy demands over the year

The daily daytime and night-time demands analysis suggest that most of the summer demands occur during the daytime when there is enough solar energy available to mitigate. The higher winter night demands recommend having more storage capacities for a higher number of hours, as night hours are more than day hours. For Autumn and Spring seasons the requirements are roughly equal, so we need to provide storage for 50% of the demands.

The gas energy demand is highest in winter than the rest of the year. The combined winter months' demands are 46.4%, the summer, autumn and spring demands are 28.3%, 16.7% and 8.7% respectively. We do not have separate data to show the division of this demand on a daily and hourly basis, and further, our data does not support the individual causes of this demand, although we know the gas energy demand occurs mainly due to cooking, water and space heating. The mitigation measures to meet these energy demands by solar thermals would help to reduce the gas demands Figure 5.29.

We found the electrical energy demand during the daytime (54.62%) and night-time (45.4%) throughout the year. We need to have big storage capacity to meet the night time energy demand and so larger solar PV are required and to cater to the gas demands we need to see the potentials of solar thermals. In the next section, we will see (a) how much on average we can produce during each month per m^2, considering the sunshine hours and solar irradiance (b) how much on average we need to produce during each month per m^2 per house size or household, considering average occupancy of each house size (c) how much area in m^2 we need to have on average (rooftop) of each house size available for the generation of green energy from solar PV & solar thermal. (d) how much we would be able to achieve out of total electrical and gas energy demands during each month.

5.5 Analysis and results of objective 4 (estimation of generation potential)

We have discussed the energy demand drivers, demand intensity, demand forecasts, and timings of this demand in the domestic sector of Punjab for all divisions and all available house sizes. Now we need to know how much of this demand can be met with renewable energy generation from the rooftops of the respective domestic buildings. This way, we will be able to determine the role that these domestic buildings can play if we want to shift from predominantly non-renewable resources of energy to renewable ones like Solar PV and Solar thermal.

We have seen in chapter 4, what method we have followed, and the steps taken, to calculate the energy generation potential from domestic rooftops. Briefly, we will combine the energy demand of each house size with the possible potential of clean energy generation from the same house, utilising the actual data consisting of their available roof areas, demands and occupancy levels.

5.5.1 Method flow chart of objective 4 (estimation of generation potential)

As discussed in chapter 4, we have adopted five steps method to calculate the clean energy generation from solar PV and solar thermal. Briefly, we will calculate how much energy we can generate, generally, from the per m^2 area in different divisions of Punjab, due to their geographical location (step 1). Then from the survey data, we will see how much we need for each house size per m^2, utilizing the survey data (energy consumption data, step 2). After this, we will calculate how much active generation areas(rooftop) we need to have to meet the required energy demand (step 3) and how much areas(rooftop) we have (survey data, step 4). Later, we will analyse what percentage of the demand is met by different house sizes. We will follow a similar process for both solar PV and Solar thermal technologies, whereas Solar PV will be analysed to see the electrical energy generation. Whereas, solar thermal would be analysed for DHW and DHW & space heating, separately. The whole process of analysis is shown in Figure 5.30, where each method adopted to gain the data, software used, procedures followed, and steps taken to answer the objective 4 are presented and discussed in detail in chapter 4.

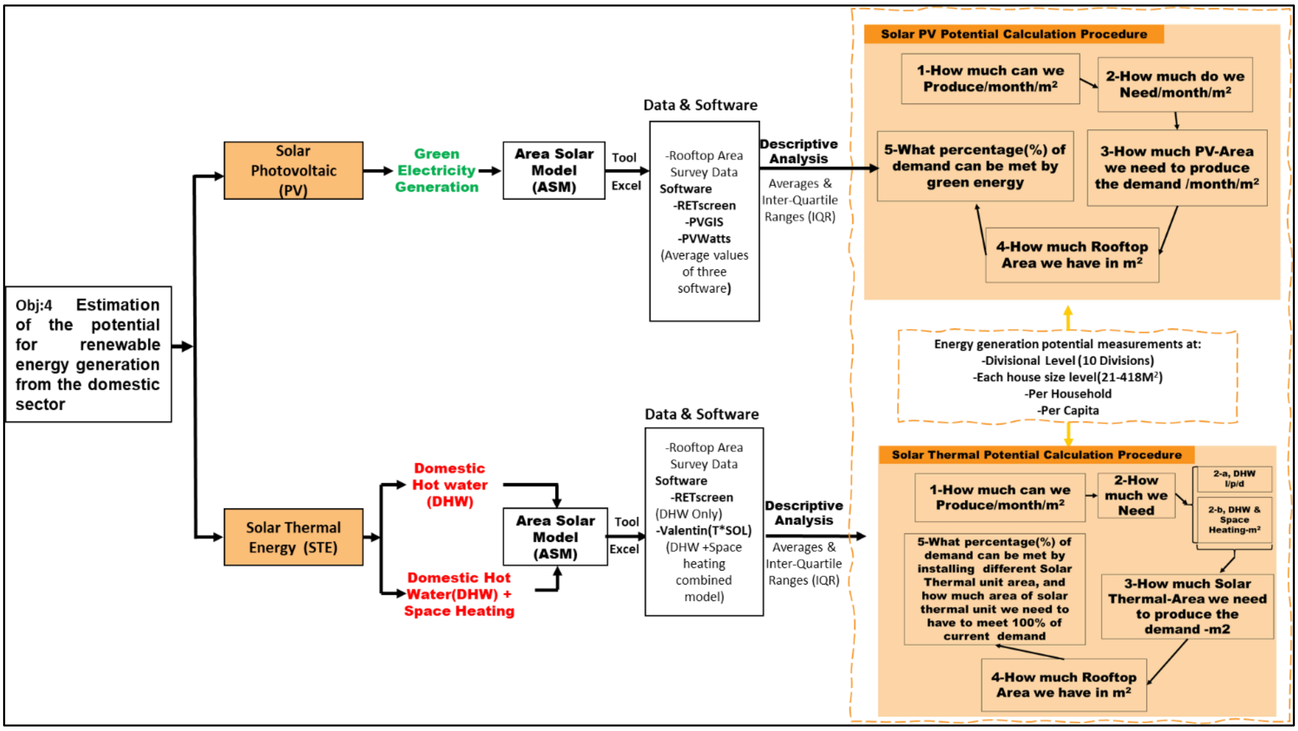


Figure 5.30 Flowchart for objective 4 (generation potential)

5.5.2 Results and analysis of energy generation calculation from solar PV

The results are presented, and analysis is carried out by following the five steps measurement procedure as discussed and shown in Figure 4.2. The results based on the average values are presented in the next section, while the results based on inter-quartile ranges (IQR) are provided in Appendixes D. The results are discussed for all ten divisions of Punjab, to estimate accurate contextual potentials related to each house size demands.

5.5.2.1 The energy produced per m^2

Step-1 Average annual energy produced per m^2 (solar PV) (kWh)

The electrical energy generation potential procedure starts with the estimation of energy(kWh) produced by per m^2 of the active area of solar PV. The details of solar PV and values used for estimates are provided in chapter 4. Table 5.18 below shows the monthly and daily useable (AC energy) electrical energy produced(kWh) after considering all losses involved. Table 5.18 shows the values of electrical energy that can be generated every month of the year and from all ten divisions of Punjab. Looking at the monthly energy units(kWh) produced, we see that for the Lahore division, the difference between the maximum (22.6 kWh March) and minimum (17.1Jan.) is 5.5 units(kWh). It is due to longer sunshine hours and clear skies. We found that the monthly difference of energy produced is around 4-5.5 units(kWh) in most of the divisions, except in Rawalpindi division where this difference is 7.2 units (kWh). It indicates that the monthly energy produced does not have huge variations (4-5.5 units) throughout the year. Therefore, we will be using the average values of energy produced per division in our calculations Table 5.18. While keeping all constant in the calculation, we found that annual energy produced from the Rawalpindi division is minimum (232.8 kWh) and from Bahawalpur division, it is maximum (257.0 kWh) from one m^2 active area of solar PV Table 5.18. The average energy produced annually/month ranges from 19.4-21.4 kWh in all divisions.

Table 5.18 Monthly electric energy (kWh) produced per m^2 from solar PV of all ten divisions

Divisions	kWh Potential	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Annual Total	Monthly Range	Difference (maximum-minimum)
Lahore	Output (kWh)/month/m^2	17.1	17.5	22.6	21.9	22.4	20.1	18.6	19.4	20.2	21.4	18.8	17.6	19.8	237.5	17.1-22.4	5.5
	Output(kWh)/day/m^2	0.55	0.60	0.73	0.73	0.72	0.67	0.60	0.63	0.67	0.69	0.63	0.57	0.65	7.79	0.55-0.72	0.18
Sheikhupura	Output (kWh)/month/m^2	16.9	17.5	22.1	21.9	22.3	20.1	19.5	20.0	20.5	21.1	18.6	17.7	19.8	238.1	16.9-22.3	5.4
	Output(kWh)/day/m^2	0.55	0.60	0.71	0.73	0.72	0.67	0.63	0.64	0.68	0.68	0.62	0.57	0.65	7.81	0.55-0.72	0.17
Gujranwala	Output (kWh)/month/m^2	17.9	18.0	22.7	22.9	23.4	21.3	19.7	20.3	21.3	23.1	20.3	18.7	20.8	249.5	17.9-23.4	5.5
	Output(kWh)/day/m^2	0.58	0.62	0.73	0.76	0.76	0.71	0.63	0.65	0.71	0.75	0.68	0.60	0.68	8.18	0.58-0.76	0.18
Faisalabad	Output (kWh)/month/m^2	18.3	18.2	22.6	22.3	22.8	20.6	19.5	20.2	20.8	21.8	19.3	18.9	20.5	245.5	18.2-22.8	4.6
	Output(kWh)/day/m^2	0.59	0.63	0.73	0.74	0.73	0.69	0.63	0.65	0.69	0.70	0.64	0.61	0.67	8.05	0.63-0.73	0.10
Sargodha	Output (kWh)/month/m^2	18.4	17.7	22.3	22.5	23.2	21.3	19.6	20.2	20.8	21.8	19.1	18.8	20.5	245.8	17.7-23.2	5.5
	Output(kWh)/day/m^2	0.59	0.61	0.72	0.75	0.75	0.71	0.63	0.65	0.69	0.70	0.64	0.61	0.67	8.06	0.61-0.75	0.14
Rawalpindi	Output (kWh)/month/m^2	15.9	15.3	19.8	20.6	22.1	21.0	19.8	19.7	20.4	22.5	18.8	17.0	19.4	232.8	15.3-22.5	7.2
	Output(kWh)/day/m^2	0.51	0.53	0.64	0.69	0.71	0.70	0.64	0.64	0.68	0.72	0.63	0.55	0.64	7.63	0.53-0.72	0.19
Sahiwal	Output (kWh)/month/m^2	18.1	19.3	22.7	22.3	22.3	20.7	20.1	20.8	20.9	21.9	19.6	18.9	20.6	247.7	18.1-22.3	4.2
	Output(kWh)/day/m^2	0.58	0.66	0.73	0.74	0.72	0.69	0.65	0.67	0.70	0.71	0.65	0.61	0.68	8.12	0.58-0.74	0.16
Multan	Output (kWh)/month/m^2	18.6	18.6	23.1	22.8	22.3	20.8	20.8	21.9	22.0	22.0	20.0	19.1	21.0	251.8	18.6-23.1	4.5
	Output(kWh)/day/m^2	0.60	0.64	0.74	0.76	0.72	0.69	0.67	0.71	0.73	0.71	0.67	0.62	0.69	8.26	0.64-.74	0.10
Bahawalpur	Output (kWh)/month/m^2	20.3	20.1	23.5	22.6	22.5	21.0	20.7	21.6	21.8	22.4	20.5	20.1	21.4	257.0	20.1-22.6	2.5
	Output(kWh)/day/m^2	0.66	0.69	0.76	0.75	0.73	0.70	0.67	0.70	0.73	0.72	0.68	0.65	0.70	8.43	0.69-0.75	0.06
D.G.Khan	Output (kWh)/month/m^2	20.3	19.3	22.9	21.9	22.0	20.3	20.0	21.1	21.4	22.7	20.2	20.0	21.0	252.2	19.3-22.9	3.6
	Output(kWh)/day/m^2	0.66	0.67	0.74	0.73	0.71	0.68	0.64	0.68	0.71	0.73	0.67	0.64	0.69	8.27	0.67-0.74	0.07

5.5.2.2 The energy required per m^2

Step-2 Average annual energy required per m^2 (kWh)

In this step, we looked at the energy per m^2 required each month by per household and per capita, for different house sizes and in all ten divisions of Punjab Table 5.19 & Table 5.20. We found that in all divisions per m^2 electrical energy required is highest in summer, moderate in spring and autumn and lowest in winter. The summer demands are double those of winter demands. Further, we found that the average annual demands per m^2 of small houses are higher than large houses, as we move from smaller houses to larger houses the demand/m^2 decreases in all divisions. It implies that the smaller houses would require a higher percentage of solar PV covered area than larger houses. The monthly, average and total energy required per households and capita in all divisions of Punjab are shown in Table 5.19 & Table 5.20 respectively. We will be using the average values of electrical energy demands of all house sizes in the next step for our estimation. The IQR's of energy demand values of all house sizes are provided in **Appendices D** (with divisional names) for all divisions, for any necessary calculations if required.

Table 5.19 Monthly electric energy (kWh/m²) required for all house sizes by division, per household

Divisions	House Sizes	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Annual Total
Lahore	**21-42m²**	2.0	1.9	2.2	3.3	4.0	5.0	5.0	4.6	5.1	4.2	2.7	2.1	**3.5**	42.3
	63m²	1.9	1.7	2.0	2.8	3.4	4.2	4.8	4.5	4.5	3.5	2.3	1.8	**3.1**	37.4
	84m²	1.5	1.5	1.6	2.4	2.9	3.7	4.0	3.6	3.6	2.7	1.9	1.4	**2.6**	30.9
	105m²	1.4	1.4	1.7	2.3	3.2	4.0	4.0	3.9	3.6	2.8	1.7	1.4	**2.6**	31.3
	125-146m²	1.2	1.2	1.5	2.0	2.8	3.7	3.8	3.9	3.2	2.3	1.4	1.2	**2.3**	28.2
	167-209m²	0.9	1.0	1.2	1.5	2.3	2.9	2.8	2.8	2.5	1.9	1.1	0.9	**1.8**	21.6
	230-418m²	0.7	0.8	0.9	1.3	1.7	2.2	2.3	2.2	1.9	1.4	0.8	0.7	**1.4**	17.0
Sheikhupura	**21-42m²**	2.0	2.1	2.4	2.9	3.9	4.4	4.2	4.5	4.1	2.9	1.9	1.9	**3.1**	37.2
	63m²	1.7	1.7	2.3	3.0	4.0	4.6	4.2	4.4	4.0	3.1	1.9	1.8	**3.1**	36.7
	84m²	1.6	1.5	2.1	2.6	3.4	4.1	4.0	4.4	3.7	3.0	1.7	1.8	**2.8**	33.8
	105m²	1.5	1.6	2.0	2.5	3.4	4.2	4.1	4.5	3.6	3.0	1.7	1.7	**2.8**	33.8
	125-146m²	1.2	1.2	1.5	1.8	2.9	3.8	3.5	3.9	2.6	2.1	1.1	1.3	**2.2**	26.9
	167-209m²	1.2	1.2	1.5	2.0	2.7	3.3	3.1	3.2	2.7	2.0	1.3	1.4	**2.1**	25.6
	230-418m²	0.9	0.9	1.3	1.7	2.3	2.8	2.6	3.0	2.4	2.0	1.1	1.0	**1.8**	21.9
Gujranwala	**21-42m²**	2.7	2.6	2.9	3.9	4.8	5.5	5.7	6.2	6.0	5.1	3.3	3.0	**4.3**	51.8
	63m²	1.5	1.5	1.7	2.3	2.9	3.6	3.9	3.7	3.1	2.6	1.7	1.5	**2.5**	30.1
	84m²	1.5	1.4	1.6	2.0	2.7	3.4	3.6	3.6	3.0	2.4	1.6	1.5	**2.4**	28.4
	105m²	1.4	1.3	1.5	1.9	2.5	3.2	3.3	3.3	2.9	2.3	1.6	1.3	**2.2**	26.6
	125-146m²	1.3	1.2	1.3	1.7	2.4	3.2	3.4	3.4	2.9	2.1	1.4	1.3	**2.1**	25.8
	167-209m²	1.0	1.0	1.2	1.5	2.1	3.1	3.2	3.0	2.7	2.0	1.3	1.1	**1.9**	23.2
	230-418m²	0.3	0.4	0.5	0.7	0.7	0.8	0.8	0.9	0.7	0.6	0.4	0.4	**0.6**	7.3
Faisalabad	**21-42m²**	1.1	1.0	1.2	1.9	2.4	2.6	2.6	2.8	2.8	2.2	1.3	1.0	**1.9**	22.8
	63m²	0.6	0.7	0.9	1.5	2.0	2.2	2.2	2.2	2.4	1.9	1.0	0.7	**1.5**	18.2
	84m²	0.9	1.0	1.1	1.6	2.1	2.5	2.5	2.6	2.6	2.0	1.2	0.9	**1.7**	21.0
	105m²	0.8	0.9	1.1	1.5	2.0	2.3	2.4	2.5	2.5	1.8	1.0	0.8	**1.6**	19.7
	125-146m²	0.7	0.9	1.2	1.5	2.2	2.7	2.8	2.9	2.9	1.9	1.0	0.8	**1.8**	21.5
	167-209m²	0.7	0.8	1.1	1.3	2.2	2.3	2.4	2.4	2.3	1.6	0.8	0.7	**1.6**	18.7
	230-418m²	0.4	0.5	0.7	0.8	1.5	1.4	1.6	1.7	1.5	0.9	0.5	0.4	**1.0**	11.8
Sargodha	**21-42m²**	1.2	1.3	2.0	2.4	2.8	2.2	2.7	2.8	2.9	3.1	1.5	1.0	**2.2**	26.0
	63m²	1.2	1.0	1.6	2.1	2.4	2.5	2.8	2.7	3.1	2.2	1.4	1.1	**2.0**	23.9
	84m²	0.9	0.8	1.3	1.8	2.0	2.4	2.5	2.4	2.1	2.0	0.9	0.8	**1.7**	20.0
	105m²	0.7	0.7	1.0	1.5	1.8	1.9	2.0	2.1	1.8	1.6	0.9	0.7	**1.4**	16.7
	125-146m²	0.8	0.8	1.1	1.5	1.7	1.8	1.9	2.0	1.8	1.7	1.0	0.8	**1.4**	16.7
	167-209m²	0.7	0.7	0.8	1.0	1.5	1.7	1.8	1.8	1.5	1.2	0.9	0.7	**1.2**	14.3
	230-418m²	0.4	0.4	0.6	0.8	1.1	1.2	1.5	1.5	0.9	0.9	0.6	0.4	**0.9**	10.5
Rawalpindi	**21-42m²**	3.0	2.9	3.5	4.1	5.5	5.8	5.9	6.0	5.6	4.9	3.5	3.0	**4.5**	53.8
	63m²	1.7	1.7	1.7	2.1	2.7	3.3	3.4	3.2	2.6	2.6	1.9	1.5	**2.4**	28.3
	84m²	1.2	1.3	1.3	2.1	2.2	3.1	2.9	3.0	2.9	2.5	1.8	1.2	**2.1**	25.6
	105m²	1.0	1.0	1.2	1.5	1.6	2.4	2.5	2.4	2.5	1.9	1.3	1.0	**1.7**	20.4
	125-146m²	1.1	1.1	1.4	1.5	2.0	2.2	2.3	2.3	2.0	1.5	1.1	1.1	**1.6**	19.7
	167-209m²	0.8	0.9	1.0	1.1	1.8	1.9	2.0	2.0	1.7	1.2	0.9	0.8	**1.4**	16.3
	230-418m²	0.5	0.6	0.7	0.8	1.3	1.5	1.6	1.5	1.4	0.8	0.5	0.5	**1.0**	11.8
Sahiwal	**21-42m²**	1.5	1.7	2.0	2.7	3.4	3.4	3.7	3.8	3.1	3.0	2.0	1.7	**2.7**	32.0
	63m²	1.6	1.7	2.4	3.0	3.5	4.0	3.8	3.5	3.2	2.7	2.0	1.8	**2.8**	33.1
	84m²	1.3	1.4	1.6	2.0	2.2	2.7	2.8	2.7	2.4	1.9	1.4	1.2	**2.0**	23.8
	105m²	1.2	1.1	1.4	1.9	2.6	3.0	3.0	3.0	2.5	1.9	1.4	1.1	**2.0**	24.0
	125-146m²	1.4	1.3	1.7	2.1	2.8	3.1	3.1	3.2	2.8	1.9	1.6	1.3	**2.2**	26.4
	167-209m²	1.1	1.2	1.5	1.6	2.1	2.7	2.7	2.7	2.5	1.9	1.2	1.1	**1.9**	22.3
	230-418m²	0.6	0.6	0.7	0.9	1.4	1.5	1.5	1.4	1.3	0.9	0.7	0.7	**1.0**	12.2
Multan	**21-42m²**	1.0	1.3	1.2	2.0	2.2	2.1	2.9	2.4	2.7	1.8	1.3	1.2	**1.8**	22.1
	63m²	1.2	1.2	1.4	2.1	2.3	2.4	2.4	2.4	2.7	2.2	1.4	1.2	**1.9**	22.8
	84m²	0.6	0.6	0.8	1.3	1.4	1.4	1.4	1.5	1.6	1.2	0.7	0.7	**1.1**	13.1
	105m²	0.8	0.8	1.0	1.5	1.6	1.7	1.7	1.7	1.9	1.4	0.9	0.8	**1.3**	15.7
	125-146m²	0.7	0.7	0.9	1.2	1.4	1.5	1.5	1.5	1.5	1.1	0.8	0.7	**1.1**	13.3
	167-209m²	0.7	0.7	0.9	1.1	1.4	1.5	1.6	1.6	1.5	1.0	0.7	0.6	**1.1**	13.3
	230-418m²	0.4	0.5	0.6	0.7	1.1	1.2	1.2	1.3	1.1	0.8	0.5	0.4	**0.8**	9.8
Bahawalpur	**21-42m²**	2.3	2.4	2.8	3.6	4.9	5.8	6.5	6.5	5.9	4.0	2.8	2.4	**4.1**	49.7
	63m²	1.5	1.7	1.9	2.7	3.1	3.8	3.9	4.2	3.8	2.8	1.9	1.6	**2.7**	32.9
	84m²	1.3	1.4	1.6	1.9	2.5	2.9	3.1	3.3	3.2	2.6	1.6	1.2	**2.2**	26.5
	105m²	1.2	1.3	1.4	1.8	2.5	2.9	3.1	3.1	2.8	2.2	1.4	1.2	**2.1**	24.8
	125-146m²	1.1	1.2	1.4	1.8	2.4	2.9	3.1	3.0	2.7	2.0	1.3	1.1	**2.0**	24.1
	167-209m²	0.7	0.8	0.9	1.2	1.6	2.0	2.1	2.1	1.9	1.4	0.9	0.7	**1.4**	16.5
	230-418m²	0.6	0.7	0.8	1.0	1.3	1.5	1.6	1.6	1.6	1.0	0.7	0.5	**1.1**	13.0
D.G.Khan	**21-42m²**	0.9	1.1	2.0	2.3	2.7	2.7	3.6	3.1	2.6	2.5	1.2	0.7	**2.1**	25.5
	63m²	1.0	0.9	1.3	1.9	2.2	2.0	2.6	2.6	2.4	2.1	1.0	0.9	**1.7**	20.7
	84m²	1.0	0.9	1.3	1.8	2.2	2.1	2.2	2.7	2.2	1.8	0.9	0.9	**1.7**	20.0
	105m²	0.6	0.5	0.8	1.2	1.5	1.7	1.8	2.0	1.4	1.4	0.6	0.6	**1.2**	14.2
	125-146m²	0.6	0.6	0.9	1.2	1.5	1.5	1.6	1.8	1.4	1.2	0.6	0.6	**1.1**	13.6
	167-209m²	0.7	0.7	0.8	1.1	1.7	2.0	1.8	1.8	1.9	1.1	0.8	0.7	**1.2**	14.9
	230-418m²	0.6	0.7	0.9	1.0	2.4	2.4	2.3	2.3	1.9	1.4	0.7	0.7	**1.4**	17.2

Table 5.20 Monthly electric energy (kWh/m²) required for all house sizes by division, per capita

Divisions	House Sizes	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Annual Total
Lahore	21-42m²	0.59	0.53	0.62	0.94	1.12	1.42	1.44	1.32	1.44	1.20	0.77	0.61	**1.00**	12.0
	63m²	0.41	0.36	0.41	0.59	0.73	0.89	1.02	0.96	0.99	0.76	0.50	0.38	**0.67**	8.0
	84m²	0.27	0.26	0.28	0.43	0.54	0.68	0.73	0.67	0.65	0.50	0.34	0.26	**0.47**	5.6
	105m²	0.23	0.23	0.27	0.37	0.52	0.65	0.66	0.64	0.59	0.46	0.29	0.23	**0.43**	5.2
	125-146m²	0.16	0.17	0.20	0.27	0.37	0.51	0.53	0.53	0.44	0.32	0.19	0.16	**0.32**	3.9
	167-209m²	0.14	0.15	0.17	0.23	0.35	0.43	0.42	0.42	0.38	0.30	0.16	0.13	**0.27**	3.3
	230-418m²	0.11	0.12	0.13	0.18	0.25	0.33	0.33	0.33	0.28	0.20	0.12	0.10	**0.21**	2.5
Sheikhupura	21-42m²	0.66	0.67	0.79	0.96	1.23	1.41	1.35	1.44	1.33	0.93	0.61	0.62	**1.00**	12.0
	63m²	0.43	0.43	0.56	0.72	0.97	1.12	1.02	1.07	0.97	0.78	0.47	0.45	**0.75**	9.0
	84m²	0.36	0.34	0.47	0.58	0.76	0.91	0.87	0.97	0.84	0.67	0.39	0.40	**0.63**	7.6
	105m²	0.29	0.30	0.40	0.48	0.65	0.81	0.79	0.87	0.69	0.56	0.32	0.32	**0.54**	6.5
	125-146m²	0.20	0.21	0.25	0.30	0.50	0.65	0.60	0.66	0.43	0.37	0.19	0.21	**0.38**	4.6
	167-209m²	0.20	0.19	0.25	0.32	0.44	0.53	0.50	0.53	0.43	0.32	0.20	0.22	**0.34**	4.1
	230-418m²	0.13	0.13	0.19	0.24	0.33	0.41	0.37	0.43	0.34	0.29	0.17	0.15	**0.26**	3.2
Gujranwala	21-42m²	0.43	0.42	0.49	0.66	0.80	0.91	0.95	1.02	0.97	0.83	0.53	0.47	**0.71**	8.5
	63m²	0.29	0.28	0.33	0.45	0.56	0.69	0.74	0.72	0.61	0.52	0.32	0.29	**0.48**	5.8
	84m²	0.24	0.23	0.25	0.31	0.43	0.54	0.55	0.57	0.47	0.37	0.25	0.23	**0.37**	4.4
	105m²	0.20	0.19	0.22	0.27	0.36	0.46	0.48	0.47	0.42	0.33	0.22	0.19	**0.32**	3.8
	125-146m²	0.17	0.16	0.15	0.21	0.30	0.39	0.41	0.41	0.36	0.26	0.18	0.16	**0.26**	3.2
	167-209m²	0.12	0.12	0.14	0.19	0.25	0.35	0.36	0.35	0.31	0.24	0.15	0.13	**0.23**	2.7
	230-418m²	0.03	0.04	0.05	0.07	0.06	0.07	0.07	0.08	0.06	0.06	0.04	0.04	**0.06**	0.7
Faisalabad	21-42m²	0.39	0.36	0.41	0.67	0.86	0.93	0.95	1.00	1.03	0.80	0.47	0.35	**0.68**	8.2
	63m²	0.17	0.18	0.25	0.42	0.57	0.64	0.63	0.64	0.69	0.55	0.30	0.20	**0.44**	5.2
	84m²	0.18	0.20	0.23	0.35	0.46	0.55	0.56	0.58	0.58	0.45	0.25	0.18	**0.38**	4.6
	105m²	0.15	0.16	0.20	0.28	0.38	0.44	0.46	0.47	0.47	0.35	0.19	0.16	**0.31**	3.7
	125-146m²	0.12	0.14	0.18	0.22	0.33	0.41	0.42	0.44	0.44	0.30	0.16	0.12	**0.27**	3.3
	167-209m²	0.10	0.11	0.15	0.19	0.31	0.33	0.33	0.34	0.33	0.23	0.12	0.10	**0.22**	2.6
	230-418m²	0.05	0.06	0.08	0.09	0.18	0.17	0.19	0.20	0.18	0.11	0.06	0.05	**0.12**	1.4
Sargodha	21-42m²	0.24	0.24	0.37	0.46	0.54	0.41	0.52	0.54	0.55	0.62	0.28	0.18	**0.41**	5.0
	63m²	0.21	0.17	0.27	0.35	0.42	0.42	0.47	0.46	0.51	0.36	0.24	0.19	**0.34**	4.1
	84m²	0.13	0.13	0.19	0.27	0.31	0.36	0.39	0.37	0.32	0.30	0.15	0.12	**0.25**	3.0
	105m²	0.10	0.09	0.13	0.19	0.23	0.24	0.26	0.26	0.23	0.21	0.12	0.09	**0.18**	2.1
	125-146m²	0.09	0.09	0.13	0.18	0.20	0.22	0.22	0.23	0.22	0.20	0.12	0.09	**0.16**	2.0
	167-209m²	0.10	0.10	0.11	0.13	0.19	0.21	0.24	0.24	0.20	0.15	0.12	0.09	**0.16**	1.9
	230-418m²	0.05	0.06	0.08	0.10	0.13	0.15	0.17	0.16	0.11	0.11	0.07	0.06	**0.10**	1.2
Rawalpindi	21-42m²	0.58	0.57	0.68	0.79	1.06	1.10	1.14	1.17	1.10	0.95	0.68	0.59	**0.87**	10.4
	63m²	0.32	0.32	0.33	0.42	0.57	0.70	0.71	0.67	0.55	0.53	0.39	0.30	**0.49**	5.8
	84m²	0.21	0.22	0.22	0.36	0.39	0.53	0.51	0.52	0.50	0.43	0.31	0.21	**0.37**	4.4
	105m²	0.16	0.16	0.19	0.24	0.26	0.38	0.39	0.39	0.40	0.30	0.21	0.16	**0.27**	3.2
	125-146m²	0.15	0.15	0.18	0.21	0.26	0.30	0.31	0.31	0.28	0.20	0.15	0.16	**0.22**	2.7
	167-209m²	0.11	0.12	0.14	0.16	0.24	0.27	0.28	0.27	0.23	0.16	0.13	0.11	**0.18**	2.2
	230-418m²	0.07	0.08	0.10	0.11	0.17	0.20	0.21	0.21	0.19	0.11	0.07	0.07	**0.13**	1.6
Sahiwal	21-42m²	0.41	0.47	0.56	0.74	0.96	1.00	1.05	1.14	0.90	0.85	0.58	0.48	**0.76**	9.1
	63m²	0.30	0.31	0.46	0.55	0.63	0.71	0.70	0.64	0.58	0.47	0.35	0.32	**0.50**	6.0
	84m²	0.22	0.23	0.27	0.34	0.38	0.46	0.47	0.47	0.40	0.33	0.24	0.21	**0.34**	4.0
	105m²	0.19	0.18	0.23	0.30	0.42	0.50	0.48	0.49	0.41	0.31	0.23	0.19	**0.33**	3.9
	125-146m²	0.20	0.19	0.23	0.29	0.38	0.43	0.43	0.45	0.39	0.27	0.22	0.19	**0.30**	3.7
	167-209m²	0.14	0.15	0.19	0.20	0.26	0.34	0.33	0.33	0.30	0.25	0.14	0.13	**0.23**	2.8
	230-418m²	0.08	0.08	0.10	0.12	0.18	0.19	0.19	0.18	0.17	0.13	0.08	0.09	**0.13**	1.6
Multan	21-42m²	0.32	0.39	0.38	0.66	0.68	0.68	0.92	0.74	0.94	0.54	0.40	0.35	**0.58**	7.0
	63m²	0.19	0.19	0.23	0.34	0.36	0.40	0.39	0.41	0.45	0.35	0.22	0.20	**0.31**	3.7
	84m²	0.10	0.09	0.14	0.21	0.23	0.24	0.26	0.27	0.27	0.20	0.12	0.11	**0.19**	2.2
	105m²	0.12	0.12	0.15	0.22	0.24	0.26	0.25	0.27	0.28	0.22	0.13	0.12	**0.20**	2.4
	125-146m²	0.09	0.09	0.12	0.16	0.18	0.19	0.20	0.20	0.19	0.15	0.10	0.09	**0.15**	1.8
	167-209m²	0.08	0.08	0.11	0.14	0.17	0.20	0.21	0.21	0.19	0.13	0.08	0.07	**0.14**	1.7
	230-418m²	0.06	0.06	0.08	0.10	0.15	0.16	0.17	0.18	0.16	0.11	0.06	0.06	**0.11**	1.3
Bahawalpur	21-42m²	0.58	0.60	0.70	0.91	1.28	1.51	1.70	1.67	1.51	1.04	0.70	0.60	**1.07**	12.82
	63m²	0.27	0.30	0.33	0.47	0.55	0.65	0.69	0.72	0.67	0.48	0.34	0.28	**0.48**	5.76
	84m²	0.21	0.21	0.24	0.29	0.39	0.46	0.49	0.53	0.50	0.41	0.24	0.20	**0.35**	4.16
	105m²	0.17	0.18	0.20	0.26	0.36	0.42	0.45	0.45	0.41	0.32	0.21	0.17	**0.30**	3.61
	125-146m²	0.15	0.16	0.19	0.25	0.33	0.40	0.41	0.41	0.37	0.27	0.18	0.15	**0.27**	3.26
	167-209m²	0.10	0.11	0.12	0.17	0.21	0.27	0.28	0.29	0.26	0.19	0.11	0.09	**0.18**	2.21
	230-418m²	0.07	0.09	0.10	0.13	0.16	0.18	0.20	0.20	0.19	0.12	0.08	0.07	**0.13**	1.57
D.G.Khan	21-42m²	0.19	0.25	0.45	0.52	0.62	0.63	0.84	0.72	0.61	0.57	0.27	0.16	**0.49**	5.8
	63m²	0.15	0.13	0.20	0.29	0.34	0.32	0.40	0.41	0.38	0.33	0.16	0.13	**0.27**	3.2
	84m²	0.15	0.14	0.19	0.27	0.34	0.31	0.33	0.41	0.33	0.28	0.14	0.14	**0.25**	3.0
	105m²	0.10	0.08	0.13	0.18	0.23	0.24	0.27	0.29	0.21	0.21	0.09	0.09	**0.18**	2.1
	125-146m²	0.09	0.08	0.13	0.17	0.21	0.22	0.23	0.25	0.20	0.16	0.08	0.08	**0.16**	1.9
	167-209m²	0.09	0.09	0.10	0.14	0.23	0.28	0.25	0.25	0.27	0.16	0.10	0.09	**0.17**	2.1
	230-418m²	0.09	0.12	0.15	0.17	0.40	0.39	0.38	0.39	0.31	0.24	0.11	0.12	**0.24**	2.9

5.5.2.3 Area required to produced energy demand

Step-3 Active Solar PV area required to produced energy demand (m^2)

After calculating the production potential and required demand of electrical energy per m^2, we calculated the active solar area required to meet the average annual demand of each house size of all divisions. The formula used to calculate the active solar PV area required is given as:

Active solar area required= (house size(m^2) X energy required per m^2)/ energy produced per m^2_{PV}

By utilizing the above formula, we calculated the active area required, and the results are shown in Table 5.21 & Table 5.22 for per household and per capita, respectively. For instance, the very first house size in Lahore division is $42m^2$, and average monthly energy required per m^2 is 3.5 (kWh), so the active solar area required is calculated using the above formula as, Active area required= **(42 X 3.5)/19.8**

Active solar area = **7.4 m^2** (to meet the average monthly electrical energy demand)

All calculations are done similarly, and this formula can also be used to know the roof area required for 25ile%, mean and 75ile% values of the energy demand of all house sizes (provided in Appendices D) Table 5.21 & Table 5.22, shown as step 3 in the tables. As anticipated, the active solar PV cells or units' areas required for small houses are less in number than we need for larger houses due to higher overall energy demand.

Table 5.21 Solar PV generation potential summary for all house sizes by division, per household

Solar PV generation potential summary for per Household								
Divisions	House Sizes(m^2)	Step-1 Average monthly energy produced per m^2_{PV} (Solar PV)(kWh)	Step-2 Average monthly energy required per m^2 (kWh)	Step-3 Active Solar PV area required to produced average monthly energy demand (m^2_{PV})	Step-4 Average rooftop area available to meet required demand (m^2)	Step-5-A Percentage of average roof area used	Step-5-B Average monthly required demand met from 100% area used (%)	Step-6 Average area available for other technologies (Solar Thermal) (m^2)
Lahore	42	19.8	3.5	7.4	38	19.5	510	30.6
	63	19.8	3.1	9.9	58	17.0	590	48.1
	84	19.8	2.6	11.0	78	14.1	710	67.0
	105	19.8	2.6	13.8	85	16.2	620	71.2
	146	19.8	2.3	17.0	103	16.5	610	86.0
	209	19.8	1.8	19.0	135	14.1	710	116.0
	418	19.8	1.4	29.6	215	13.7	730	185.4
Sheikhupura	42	19.8	3.1	6.6	38	17.3	580	31.4
	63	19.8	3.1	9.9	58	17.0	590	48.1
	84	19.8	2.8	11.9	78	15.2	660	66.1
	105	19.8	2.8	14.8	85	17.5	570	70.2
	146	19.8	2.2	16.2	103	15.7	630	86.8
	209	19.8	2.1	22.2	135	16.4	610	112.8
	418	19.8	1.8	38.0	215	17.7	570	177.0
Gujranwala	42	20.8	4.3	8.7	38	22.8	440	29.3
	63	20.8	2.5	7.6	58	13.1	770	50.4
	84	20.8	2.4	9.7	78	12.4	800	68.3
	105	20.8	2.2	11.1	85	13.1	770	73.9
	146	20.8	2.1	14.7	103	14.3	700	88.3
	209	20.8	1.9	19.1	135	14.1	710	115.9
	418	20.8	0.6	12.1	215	5.6	178	202.9
Faisalabad	42	20.5	1.9	3.9	38	10.2	980	34.1
	63	20.5	1.5	4.6	58	7.9	1260	53.4
	84	20.5	1.7	7.0	78	8.9	1120	71.0
	105	20.5	1.6	8.2	85	9.6	1040	76.8
	146	20.5	1.8	12.8	103	12.4	800	90.2
	209	20.5	1.6	16.3	135	12.1	830	118.7
	418	20.5	1	20.4	215	9.5	1050	194.6
Sargodha	42	20.5	2.2	4.5	38	11.9	840	33.5
	63	20.5	2	6.1	58	10.6	940	51.9
	84	20.5	1.7	7.0	78	8.9	1120	71.0
	105	20.5	1.4	7.2	85	8.4	1190	77.8
	146	20.5	1.4	10.0	103	9.7	1030	93.0
	209	20.5	1.2	12.2	135	9.1	1100	122.8
	418	20.5	0.9	18.4	215	8.5	1170	196.6
Rawalpindi	42	19.4	4.5	9.7	38	25.6	390	28.3
	63	19.4	2.4	7.8	58	13.4	740	50.2
	84	19.4	2.1	9.1	78	11.7	860	68.9
	105	19.4	1.7	9.2	85	10.8	920	75.8
	146	19.4	1.6	12.0	103	11.7	860	91.0
	209	19.4	1.4	15.1	135	11.2	900	119.9
	418	19.4	1	21.5	215	10.0	1000	193.5
Sahiwal	42	20.6	2.7	5.5	38	14.5	690	32.5
	63	20.6	2.8	8.6	58	14.8	680	49.4
	84	20.6	2	8.2	78	10.5	960	69.8
	105	20.6	2	10.2	85	12.0	830	74.8
	146	20.6	2.2	15.6	103	15.1	660	87.4
	209	20.6	1.9	19.3	135	14.3	700	115.7
	418	20.6	1	20.3	215	9.4	1060	194.7
Multan	42	21	1.8	3.6	38	9.5	1060	34.4
	63	21	1.9	5.7	58	9.8	1020	52.3
	84	21	1.1	4.4	78	5.6	1770	73.6
	105	21	1.3	6.5	85	7.6	1310	78.5
	146	21	1.1	7.6	103	7.4	1350	95.4
	209	21	1.1	10.9	135	8.1	1230	124.1
	418	21	0.8	15.9	215	7.4	1350	199.1
Bahawalpur	42	21.4	4.1	8.0	38	21.2	470	30.0
	63	21.4	2.7	7.9	58	13.7	730	50.1
	84	21.4	2.2	8.6	78	11.1	900	69.4
	105	21.4	2.1	10.3	85	12.1	820	74.7
	146	21.4	2	13.6	103	13.2	750	89.4
	209	21.4	1.4	13.7	135	10.1	990	121.3
	418	21.4	1.1	21.5	215	10.0	1000	193.5
D.G.Khan	42	21	2.1	4.2	38	11.1	900	33.8
	63	21	1.7	5.1	58	8.8	1140	52.9
	84	21	1.7	6.8	78	8.7	1150	71.2
	105	21	1.2	6.0	85	7.1	1420	79.0
	146	21	1.1	7.6	103	7.4	1350	95.4
	209	21	1.2	11.9	135	8.8	1130	123.1
	418	21	1.4	27.9	215	13.0	770	187.1

Table 5.22 Solar PV generation potential summary for all house sizes by division, per capita

Solar PV generation potential summary for per Capita								
Divisions	House Sizes(m^2)	Step-1 Average monthly energy produced per m^2_{PV} (Solar PV)(kWh)	Step-2 Average monthly energy required per m^2 (kWh)	Step-3 Active Solar PV area required to produced energy demand (m^2_{PV})	Step-4 Average rooftop area available to meet required demand (m^2)	Step-5-A Percentage of average roof area used	Step-5-B Average monthly required demand met from 100% area used (%)	Step-6 Average area available for other technologies (Solar Thermal) (m^2)
Lahore	42	19.8	1	2.1	8	26.5	380	5.9
	63	19.8	0.67	2.1	13	16.4	610	10.9
	84	19.8	0.47	2.0	19	10.5	950	17.0
	105	19.8	0.43	2.3	20	11.4	880	17.7
	146	19.8	0.32	2.4	23	10.3	970	20.6
	209	19.8	0.27	2.9	34	8.4	1190	31.2
	418	19.8	0.21	4.4	59	7.5	1330	54.6
Sheikhupura	42	19.8	1	2.1	8	26.5	380	5.9
	63	19.8	0.75	2.4	13	18.4	540	10.6
	84	19.8	0.63	2.7	19	14.1	710	16.3
	105	19.8	0.54	2.9	20	14.3	700	17.1
	146	19.8	0.38	2.8	23	12.2	820	20.2
	209	19.8	0.34	3.6	34	10.6	950	30.4
	418	19.8	0.26	5.5	59	9.3	1070	53.5
Gujranwala	42	20.8	0.71	1.4	8	17.9	560	6.6
	63	20.8	0.48	1.5	13	11.2	890	11.5
	84	20.8	0.37	1.5	19	7.9	1270	17.5
	105	20.8	0.32	1.6	20	8.1	1240	18.4
	146	20.8	0.26	1.8	23	7.9	1260	21.2
	209	20.8	0.23	2.3	34	6.8	1470	31.7
	418	20.8	0.06	1.2	59	2.0	4890	57.8
Faisalabad	42	20.5	0.68	1.4	8	17.4	570	6.6
	63	20.5	0.44	1.4	13	10.4	960	11.6
	84	20.5	0.38	1.6	19	8.2	1220	17.4
	105	20.5	0.31	1.6	20	7.9	1260	18.4
	146	20.5	0.27	1.9	23	8.4	1200	21.1
	209	20.5	0.22	2.2	34	6.6	1520	31.8
	418	20.5	0.12	2.4	59	4.1	2410	56.6
Sargodha	42	20.5	0.41	0.8	8	10.5	950	7.2
	63	20.5	0.34	1.0	13	8.0	1240	12.0
	84	20.5	0.25	1.0	19	5.4	1850	18.0
	105	20.5	0.18	0.9	20	4.6	2170	19.1
	146	20.5	0.16	1.1	23	5.0	2020	21.9
	209	20.5	0.16	1.6	34	4.8	2080	32.4
	418	20.5	0.1	2.0	59	3.5	2890	57.0
Rawalpindi	42	19.4	0.87	1.9	8	23.5	420	6.1
	63	19.4	0.49	1.6	13	12.2	820	11.4
	84	19.4	0.37	1.6	19	8.4	1190	17.4
	105	19.4	0.27	1.5	20	7.3	1370	18.5
	146	19.4	0.22	1.7	23	7.2	1390	21.3
	209	19.4	0.18	1.9	34	5.7	1750	32.1
	418	19.4	0.13	2.8	59	4.7	2110	56.2
Sahiwal	42	20.6	0.76	1.5	8	19.4	520	6.5
	63	20.6	0.5	1.5	13	11.8	850	11.5
	84	20.6	0.34	1.4	19	7.3	1370	17.6
	105	20.6	0.33	1.7	20	8.4	1190	18.3
	146	20.6	0.3	2.1	23	9.2	1080	20.9
	209	20.6	0.23	2.3	34	6.9	1460	31.7
	418	20.6	0.13	2.6	59	4.5	2240	56.4
Multan	42	21	0.58	1.2	8	14.5	690	6.8
	63	21	0.31	0.9	13	7.2	1400	12.1
	84	21	0.19	0.8	19	4.0	2500	18.2
	105	21	0.2	1.0	20	5.0	2000	19.0
	146	21	0.15	1.0	23	4.5	2210	22.0
	209	21	0.14	1.4	34	4.1	2440	32.6
	418	21	0.11	2.2	59	3.7	2690	56.8
Bahawalpur	42	21.4	1.07	2.1	8	26.3	380	5.9
	63	21.4	0.48	1.4	13	10.9	920	11.6
	84	21.4	0.35	1.4	19	7.2	1380	17.6
	105	21.4	0.3	1.5	20	7.4	1360	18.5
	146	21.4	0.27	1.8	23	8.0	1250	21.2
	209	21.4	0.18	1.8	34	5.2	1930	32.2
	418	21.4	0.13	2.5	59	4.3	2320	56.5
D.G.Khan	42	21	0.49	1.0	8	12.3	820	7.0
	63	21	0.27	0.8	13	6.2	1600	12.2
	84	21	0.25	1.0	19	5.3	1900	18.0
	105	21	0.18	0.9	20	4.5	2220	19.1
	146	21	0.16	1.1	23	4.8	2070	21.9
	209	21	0.17	1.7	34	5.0	2010	32.3
	418	21	0.24	4.8	59	8.1	1240	54.2

5.5.2.4 Area available to meet the required demand

Step-4 Average rooftop area available to meet required demand (m^2)

We asked questions from our respondents on how much roof areas they have if we need to install solar PV on rooftops in our field survey. The available areas of 25il%, average and 75ile% are shown in **Appendix-D-1** for per household and per capita, respectively, for all house sizes. We will be using the average values of the available area of all house sizes in our estimates. It must be noted that the rooftop area availability is calculated from the complete set of the data sample, i.e. 4597 responses because, in the whole Punjab, the conventional way of construction is similar in all divisions.

We also calculated the floor to roof area ratio and found that the smaller houses have higher ratios of roof area than larger houses. It indicates that the smaller houses have more covered areas of the plot area and mostly single-storeyed. While larger houses have a ratio of 0.51, which shows they are mostly double-storeyed (**Appendix-D-2**)

5.5.2.5 Percentage of required demand met

Step-5-A Percentage of average roof area used

For per household analysis, we found that for the smallest house size (21-42m^2) we need only 9.5-25.6% of the average rooftop available area to meet our current demand for electrical energy to be generated from solar PV in Punjab. For the largest house size(418m^2), we need 5.6-17.7% of the roof area for the required energy demand Table 5.21**.**

For per capita analysis, the smallest house needs to be covered with solar PV only for 10.5-26.5% of the average roof area in the whole Punjab. For the largest house, we only need 2-12.3% of the average roof area for solar PV for the current electrical energy demands Table 5.22. The above results are auspicious for the broader use of solar PV on the rooftops of domestic buildings of Punjab to meet their current energy demand. Roughly, 1/4th of the average available rooftop area is required to meet current electrical energy demands. It also shows that more significant parts of the roof area would still be available for the social activities, as it is a prevailing culture of Punjab society to use the rooftop for the evening and night-time outdoor seating and family gatherings.

Step-5-B Average annual required demand met from 100% area used (%)

We have calculated that if the complete average available roof area of respective house sizes is covered with solar PV, how much of the current demand can be met. We want to see if the current average demand of electric energy would increase in the future, what generation capacity each house would still have to meet future demand.

For per household analysis: for our smallest house size (42m^2) we can produce 440-1060% more of current energy demand in different divisions of Punjab when complete roof area is used. For the most common house size, i.e. 105m^2 we can produce 570-1490% more energy than current demand, and for the biggest house size (418m^2) we can meet 570-1780% of current demand Table 5.21. These results show that not only the current demands of energy for these houses are met, but also show very high capabilities to meet the potential future demands as calculated in section 2.9, for electrical energy by solar PV. If these authorities would take some serious measures to adopt this technology for the domestic sector, it can solve the problem for a substantial period as the future generation potentials are very high.

When we look at per capita level, using all roof area for solar PV, for the resident of the smallest house (42m^2) the generation potential is 380-950% of the current demand in different divisions of Punjab. For the house size of 105m^{2,} the potential is 700-2220% of electrical energy generation. For the largest house size(418m^2), this potential is 1070-5000% of current demand in different divisions of Punjab Table 5.22. It means per capita future demand, found to be 8-10 times (section 2.9) of current demand, can be easily met from the solar PV. So solar PV has huge potential for the adaptation as alternate technology to meet Punjab's domestic sector current and future demand from the non-renewable resource of energy and answer our objective 4 (generation potentials).

5.5.2.6 Roof area available for other technologies (like solar thermal)

Step-6 Average area available for other technologies (solar thermal) (m^2)

We have estimated the availability of roof area for the other technologies to be used to meet energy required for other activities in the house like as an alternate for gas energy after we have used the area for solar PV to meet current demand. The very last columns of Table 5.21 & Table 5.22. explain the remaining areas (m^2) we have for our next technology, i.e. solar thermal to meet our current demands for domestic hot water and space heating as a substitute for gas energy.

5.5.3 Results and analysis of generation calculation from solar thermal

Gas is the second leading source of domestic energy and is mostly used for cooking, water and space heating in Punjab. We have seen how much, and when the gas is used in houses (objectives 1,2 and 3). However, we do not have separate usage values of gas for individual activities like how much we use for cooking, water and space heating. Therefore, to calculate the generation potential of solar thermal to meet the domestic needs we have used the occupancy level of each house size in all ten divisions of Punjab, as the representation of the energy demand required for domestic water and space heating. In the next section, we will see how much DHW and space heating demand can be met by using solar thermal technology. We are not taking into our calculation of energy required for cooking as we do not have any reference data for the energy required by different households. The results and analyses are presented in two ways, i.e. (a) for DHW and (b) for combined DHW and space heating, for all house sizes and all divisions[12] of Punjab. The detailed simulation conditions, software used, required values for hot water and space heating taken, and all other conditions used for calculations are provided in chapter 4. Briefly, we used 42 litres of hot water at 60C as standard hot water requirement per person/day. For space heating requirement, heated all GIFA of each house size and maintained a temperature of 21C constant throughout the day. Both for DHW and space heating energy requirement, we run our simulations for six months of the year, i.e. Starting from October to March. We will present our results and analysis for solar thermal by using two major types of solar thermals, i.e. (a) Evacuated tube collectors (ETC) and (b) Flat tube collectors (FTC). We will discuss

[12] The divisional level calculations are carried out using the climatic files of 10 different divisions, for each divisional calculation the cities chosen were having the names of specific divisions, for instance, for Lahore division calculation, we used climatic data of Lahore city and vice versa.

results for Evacuated tube collectors in the main body of the thesis, and results for flat-tube collectors are provided in the **Appendices -E**.

5.5.3.1 The energy produced per m^2

The potential of solar thermal technology is calculated to meet the requirement for DHW and space heating by all house sizes in all ten divisions of Punjab.

Domestic Hot water: The occupancy level of each household is taken from the survey data we collected from the whole Punjab, and the requirement for hot water for l/p/d is taken from literature. We have calculated the solar thermal potential to meet the per capita and household requirements for all house sizes in all divisions. Table 5.23 shows the area required per capita to meet DHW we need to meet daily requirements. We see that in most of the divisions 3.6-7.2m^2 of the solar thermal area is required to meet daily hot water demands (up to 98-100%) by generation of 313-351 kWh of energy. We have calculated the rooftop area required by using ETC and FTC both. However, ETC results are shown in the main body of the thesis, while FTC results are provided in Appendices-E. For DHW per capita produced from FTC, it is given in Appendix-E-DHW-Capita. It must be noted that all calculations are carried out for units of solar thermal available, their numbers and area they need to install are given in all tables of solar thermal generation potential calculations.

Table 5.23 Solar thermal energy produced per capita for domestic hot water (DHW) by evacuated tube collectors (ETC)

Solar Thermal generation potential summary per Capita (DHW) by ETC											
Evacuated Tube Collectors(ETC)		1 Unit		2 Units		3 Units		4 Units		5 Units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved
Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
1	Lahore	74.9	249	96.5	321	99.4	331	100	333		
1	Sheikhupura	75.1	250	96.6	321	99.5	331	100	333		
1	Gujranwala	84.7	277	99.6	325	100	326				
1	Faislabad	84	265	99.8	316	100	316				
1	Sargodha	82.5	269	99.6	324	100	325				
1	Rawalpindi	64	229	89.6	321	96	344	98	351	99.2	355
1	Sahiwal	86.6	271	100	313						
1	Multan	84.5	276	100	326						
1	Bahawalpure	89.3	272	100	305						
1	D.G.Khan	88.3	276	100	313						

The solar energy produced per household by solar thermal units varies for different house sizes in different divisions of Punjab. We found that for the smallest house size (21-42m^2) 948-1672 kWh of energy is produced to meet the daily hot water requirement in Punjab. For the house sizes of 63m^2, 84m^2 & 105m^2, solar thermal units (using 8-10 units) produced 1248-1869 kWh, 1647-2189kWh & 1622-2258kWh of fine energy respectively Table 5.24. The energy produced by FTC for house sizes 21-105m^2 per household is given in ***Appendix-E-DHW-Household-21-105m^2***

For the larger houses in our data set, the solar thermal units (9-10) produced fine energy of 1935-2348kWh, 1931-2417 & 1999-2745kWh for the house sizes ranges of 125-146m^2, 167-207m^2 & 230-

418m^2 respectively to meet the hot water needs in different divisions of Punjab Table 5.25. The energy produced by FTC for house sizes 125-418m^2 per household is given in ***Appendix-E-DHW-Household-125-418m²***

Table 5.24 Solar thermal energy produced per household for domestic hot water (DHW) by evacuated tube collectors (ETC) for house sizes 21-105m^2

Solar Thermal generation potential summary for per Household (DHW) by ETC																					
Households (21-42 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
4	Lahore	25	333	45.5	606	62	825	74.9	997	84.8	1128	90.6	1205	94.3	1255	99.2	1298	-	-	-	-
3	Sheikhupura	32.4	324	57.1	570	75.1	750	87.5	874	93.4	932	96.6	964	98	978	-	-	-	-	-	-
6	Gujranwala	20.7	406	38.6	755	53.7	1051	66.3	1298	76.7	1502	84.7	1659	90.6	1774	97.8	1823	-	-	-	-
3	Faisalabad	37.8	359	65.3	618	84	796	94.4	895	98.2	932	99.8	947	100	948	-	-	-	-	-	-
5	Sargodha	23.3	379	42.9	698	59	961	72.1	1174	82.5	1343	90.2	1468	94.8	1543	99.6	1611	-	-	-	-
5	Rawalpindi	16.6	297	31.2	558	43.8	784	54.7	979	64	1145	71.8	1285	77.8	1393	83.5	1459	91.5	1568	98.4	1672
4	Sahiwal	30.7	384	54.8	686	73.1	915	86.6	1084	95.3	1193	98.6	1234	100	1252	-	-	-	-	-	-
3	Multan	37.9	371	65.5	641	84.5	827	95.3	932	99	969	100	979	-	-	-	-	-	-	-	-
4	Bahawalpur	32.2	392	57.2	697	75.9	925	89.3	1088	97.4	1186	99.7	1215	100	1218	-	-	-	-	-	-
4	D.G.Khan	31.6	395	56.2	703	74.8	935	88.3	1104	96.6	1207	100	1250	-	-	-	-	-	-	-	-
Households (63 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
5	Lahore	20.4	339	37.8	629	52.6	874	64.8	1079	74.9	1246	83	1381	88.7	1476	92.56	1568	97.9	1689	-	-
4	Sheikhupura	25.1	334	45.7	608	62.2	827	75.1	1000	85	1131	90.7	1208	94.5	1257	99.8	1358	-	-	-	-
5	Gujranwala	24.5	400	44.9	733	61.5	1004	74.8	1221	84.7	1383	91.6	1495	95	1550	98.5	1628	-	-	-	-
4	Faisalabad	29.4	372	52.7	666	70.6	893	84	1062	92.7	1172	96.9	1226	98.7	1248	-	-	-	-	-	-
6	Sargodha	19.7	385	36.8	718	51.4	1003	63.7	1244	74	1446	82.5	1611	89.2	1741	95.2	1834	99.8	1957	-	-
5	Rawalpindi	16.6	297	31.2	558	43.8	784	54.7	979	64	1145	71.8	1285	77.8	1393	82.5	1438	89.8	1647	96.58	1741
6	Sahiwal	21.2	398	39.4	740	54.8	1028	67.6	1269	78.1	1467	86.6	1625	92.9	1745	96.7	1869	100	1935	-	-
6	Multan	20.3	398	37.9	741	52.8	1035	65.5	1282	75.9	1487	84.5	1654	91	1782	98.2	1825	-	-	-	-
6	Bahawalpur	22.3	408	41.3	754	57.2	1045	70.3	1285	80.9	1478	89.3	1632	95.4	1743	99.6	1835	-	-	-	-
5	D.G.Khan	25.8	404	47.1	736	64.3	1005	77.9	1217	88.3	1380	95.3	1489	99.3	1551	-	-	-	-	-	-
Households (84 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
6	Lahore	17.2	343	32.3	645	45.5	908	56.9	1136	66.7	1331	74.9	1495	81.8	1633	88.7	1754	93.4	1836	99.6	1896
5	Sheikhupura	20.4	340	37.9	631	52.7	877	65	1082	75.1	1250	83.2	1385	88.9	1479	94.6	1521	97.9	1647	-	-
7	Gujranwala	18	410	33.8	771	47.5	1085	59.4	1356	69.5	1588	78.1	1783	84.7	1936	89.5	2014	94.6	2113	99.8	2189
5	Faisalabad	24	380	44.1	696	60.5	956	73.6	1164	84	1327	91.3	1444	95.6	1511	100	1681	-	-	-	-
7	Sargodha	17.1	388	32.1	732	45.4	1034	56.9	1297	66.9	1523	75.4	1717	82.5	1880	88.9	1954	94.6	2047	99.5	2111
6	Rawalpindi	14	301	26.5	570	37.7	810	47.6	1023	56.4	1210	64	1374	70.6	1516	78.5	1598	86.4	1687	94.5	1758
6	Sahiwal	21.2	398	39.4	740	54.8	1028	67.6	1269	78.1	1467	86.6	1625	92.9	1745	96.8	1847	99.8	1898	-	-
6	Multan	20.3	398	37.9	741	52.8	1035	65.5	1282	75.9	1487	84.5	1654	91	1782	96.8	1854	100	1897	-	-
7	Bahawalpur	19.3	412	36.2	772	50.7	1082	63.1	1346	73.6	1569	82.2	1753	89.3	1904	94.5	1957	99.4	2047	-	-
6	D.G.Khan	21.9	410	40.5	760	56.2	1054	69.2	1298	79.8	1497	88.3	1656	94.3	1769	99.7	1859	-	-	-	-
Households (105 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
7	Lahore	14.9	346	28.2	656	40.1	933	50.6	1178	59.9	1394	67.9	1582	74.9	1745	81.2	1824	88.9	1935	96.8	2049
5	Sheikhupura	20.4	340	37.9	631	52.7	877	65	1082	75.1	1250	83.2	1385	88.9	1479	95.4	1542	99.9	1622	-	-
7	Gujranwala	18	410	33.8	771	47.5	1085	59.4	1356	69.5	1588	78.1	1783	84.7	1936	90.2	1998	96.8	2048	100	2123
6	Faisalabad	20.3	385	37.8	717	52.7	999	65.2	1237	75.6	1433	84	1593	90.3	1713	96.5	1835	100	1935	-	-
8	Sargodha	15	391	28.5	743	40.6	1058	51.4	1337	60.8	1584	69.1	1800	76.3	1987	84.6	2058	92.6	2185	97.9	2258
7	Rawalpindi	12.1	303	23.1	579	33.1	829	42.1	1056	50.2	1259	57.5	1441	64	1603	71.5	1698	78.5	1725	85.6	1836
7	Sahiwal	18.4	403	34.5	756	48.5	1063	60.6	1327	70.8	1551	79.4	1740	86.6	1896	92.6	1935	97.5	2036	-	-
7	Multan	17.6	402	33.1	757	46.7	1067	58.5	1337	68.7	1568	77.3	1765	84.5	1930	90.5	1998	97.8	2058	-	-
7	Bahawalpur	19.3	412	36.2	772	50.7	1082	63.1	1346	73.6	1569	82.2	1753	89.3	1904	95.6	1987	100	2058	-	-
7	D.G.Khan	18.9	414	35.5	776	49.8	1090	62.1	1359	72.5	1586	81.2	1776	88.3	1931	94.6	2010	100	2087	-	-

Table 5.25 Solar thermal energy produced per household for domestic hot water (DHW) by evacuated tube collectors (ETC) for house sizes 125-418m^2

Solar Thermal generation potential summary for per Household (DHW) by ETC																					
Households (125-146 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
8	Lahore	13.1	348	25	665	35.8	952	45.5	1211	54.2	1443	62	1650	68.9	1833	74.5	1899	82.3	1957	90.2	2019
6	Sheikhupura	17.3	344	32.4	647	45.7	911	57.1	1140	66.9	1335	75.1	1500	82	1637	89.5	1769	94.8	1856	99.7	1976
9	Gujranwala	14.2	416	27	793	38.6	1132	48.9	1436	58.1	1708	66.3	1947	73.5	2158	80.5	2247	88.9	2347	94.5	2419
7	Faisalabad	17.6	389	33.1	732	46.6	1032	58.3	1291	68.4	1513	76.9	1701	84	1858	92.5	1958	97.8	2061	-	-
9	Sargodha	13.4	393	25.7	752	36.8	1076	46.8	1369	55.7	1632	63.7	1866	70.8	2074	76.8	2156	83.5	2269	92.6	2364
8	Rawalpindi	10.6	305	20.4	585	29.5	844	37.7	1080	45.3	1297	52.1	1493	58.4	1671	64.5	1754	71.4	1866	84.6	1935
8	Sahiwal	16.2	406	30.7	768	43.5	1089	54.8	1371	64.6	1618	73.1	1831	80.4	2013	86.5	2099	93.6	2188	99.6	2276
8	Multan	15.5	405	29.4	768	41.8	1092	52.8	1379	62.5	1632	71	1852	78.2	2043	85.4	2141	91.3	2233	97.8	2289
8	Bahawalpur	17.1	416	32.2	785	45.5	1110	57.2	1393	67.3	1639	75.9	1849	83.2	2027	88.5	2147	93.8	2247	99.7	2296
8	D.G.Khan	16.7	418	31.6	789	44.7	1117	56.2	1405	66.2	1655	74.8	1871	82.1	2054	87.4	2114	93.6	2218	100	2348
Households (167-209 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
7	Lahore	14.9	346	28.2	656	40.1	933	50.6	1178	59.9	1394	67.9	1582	74.9	1745	81.5	1823	88.9	1934	95.6	2019
6	Sheikhupura	17.3	344	32.4	647	45.7	911	57.1	1140	66.9	1335	75.1	1500	82	1637	88.6	1762	94.8	1874	99.8	1924
9	Gujranwala	14.2	416	27	793	38.6	1132	48.9	1436	58.1	1708	66.3	1947	73.5	2158	79.8	2247	86.4	2378	94.5	2417
8	Faisalabad	15.5	392	29.4	743	41.8	1056	52.7	1333	62.3	1575	70.6	1786	77.8	1968	84.5	2078	91.8	2172	97.6	2248
8	Sargodha	15	391	28.5	743	40.6	1058	51.4	1337	60.8	1584	69.1	1800	76.3	1987	82.6	2069	89.5	2163	93.8	2216
7	Rawalpindi	12.1	303	23.1	579	33.1	829	42.1	1056	50.2	1259	57.5	1441	64	1603	71.8	1716	79.6	1837	86.7	1931
9	Sahiwal	14.5	408	27.6	777	39.4	1110	49.9	1407	59.3	1671	67.6	1904	74.8	2108	80.1	2178	88.7	2249	94.7	2344
9	Multan	13.9	407	26.5	777	37.9	1112	48.1	1413	57.3	1683	65.5	1922	72.7	2134	79.2	2217	86.9	2247	93.8	2377
8	Bahawalpur	17.1	416	32.2	785	45.5	1110	57.2	1393	67.3	1639	75.9	1849	83.2	2027	88.7	2049	94.8	2147	100	2251
8	D.G.Khan	16.7	418	31.6	789	44.7	1117	56.2	1405	66.2	1655	74.8	1871	82.1	2054	87.6	2083	94.4	2175	99.7	2274
Households (230-418 m^2)																					
Evacuated Tube Collectors(ETC)		1 unit		2 units		3 units		4 units		5 units		6 units		7 units		8 units		9 units		10 units	
Collectors unit area and energy saved		Area(m^2) 1.8	Energy saved	Area(m^2) 3.6	Energy saved	Area(m^2) 5.4	Energy saved	Area(m^2) 7.2	Energy saved	Area(m^2) 9.0	Energy saved	Area(m^2) 10.8	Energy saved	Area(m^2) 12.6	Energy saved	Area(m^2) 14.4	Energy saved	Area(m^2) 16.2	Energy saved	Area(m^2) 18.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
8	Lahore	13.1	348	25	665	35.8	952	45.5	1211	54.2	1443	62	1650	68.9	1833	74.9	1937	82.5	2049	90.2	2218
7	Sheikhupura	14.9	347	28.3	659	40.2	936	50.8	1182	60	1398	68.1	1587	75.1	1750	81.8	1844	89	1926	96.5	2049
12	Gujranwala	10.8	421	20.7	812	30	1175	38.6	1510	46.4	1818	53.7	2101	60.3	2360	68.4	2469	75.6	2610	82.4	2745
9	Faisalabad	13.9	395	26.4	752	37.8	1076	48	1366	57.1	1625	65.2	1855	72.3	2058	77.9	2137	85.6	2243	92.8	2379
8	Sargodha	15	391	28.5	743	40.6	1058	51.4	1337	60.8	1584	69.1	1800	76.3	1987	83.6	2047	90.2	2198	96.7	2287
8	Rawalpindi	10.6	305	20.4	585	29.5	844	37.7	1080	45.3	1297	52.1	1493	58.4	1671	64.5	1741	72.6	1832	79.8	1999
9	Sahiwal	14.5	408	27.6	777	39.4	1110	49.9	1407	59.3	1671	67.6	1904	74.8	2108	83.6	2213	92.4	2348	99.2	2457
9	Multan	13.9	407	26.5	777	37.9	1112	48.1	1413	57.3	1683	65.5	1922	72.7	2134	79.5	2247	86.4	2349	92.7	2488
9	Bahawalpur	15.3	418	29	795	41.3	1132	52.2	1431	61.9	1695	70.3	1927	77.6	2128	86.9	2211	92.4	2317	98.6	2459
8	D.G.Khan	16.7	418	31.6	789	44.7	1117	56.2	1405	66.2	1655	74.8	1871	82.1	2054	88.7	2144	94.6	2231	99.6	2311

Combined domestic hot water (DHW) and space heating analysis:

North Punjab divisions: When we look at the energy produced by using different numbers of solar thermal units, to meet the combined demand of DHW and space heating of different households. We found that for Lahore division 6228-7219 kWh of fine energy is produced to meet 95-100% of the demand of different house sizes. We see that solar thermal units produce different amounts of heating energy in Sheikhupura, Gujranwala, Faisalabad and Sargodha divisions. They produced 5857-6488kWh, 6574-8117kWh, 4522-6138kWh & 6606-7585kWh of green energy respectively, to meet their varying requirements of daily DHW and space heating of different house sizes Table 5.26. The actual area used against each house size and piping lengths used (inside & outside) to estimate in the simulations are shown in Table 5.26 & Table 5.27 for references. The amount of energy produced by FTC's is provided in ***Appendix-E-DHW & Space heating-north Punjab***.

Table 5.26 Solar thermal energy produced per household for domestic hot water (DHW) & space heating by evacuated tube collectors (ETC) for most north Punjab divisions

Solar Thermal generation potential summary for per Household (DHW + Space Heating) by ETC															
Area used in simulations(m²)		50		60		80		100		130		200		300	
Piping used in simulations (m)		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m	
Lahore Division															
Average (OCC)		4		5		6		7		8		7		8	
House GIFA (m²)		21-42m²		63m²		84m²		105m²		125-146m²		167-209m²		230-418m²	
Evacuated tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m²	27.9	1416	25.7	1361	23.7	1315.4	21.2	1231.7	18.7	1130.5	18.3	1025	16.6	961
2	4.3m²	45.5	2559.2	43.5	2559.4	41	2500	37.5	2368	34.4	2242.3	34	2032	31.1	1931.4
3	6.51m²	57.7	3436.4	55.2	3448	52.5	3418.3	48.8	3274.3	45	3084.8	44	2812	41.1	2677.2
4	8.68m²	66.4	4006.8	63.6	3985.8	61.1	4011.5	58.1	4009	54.7	398.6	54.3	3631	51	3487.5
5	10.85m²	72.7	4391.7	70.3	4421.5	67.8	4460	64.3	4429.3	61	4393	61	4144.4	57.8	4042.4
6	13.2m²	78.1	4792.5	77	4936	74	4942	71	4942	68	4992	68.1	4700	65.4	4695
7	15.19m²	82.1	5049	81.4	5218	79	5254	76	5285	73	5270	73	5013	70.4	5068
8	17.36m²	85.3	5254	85	5467	83	5543	80	5598	77.2	5613	77.5	5381	75.3	5465
9	19.53m²	88.6	5473	88	5669	86	5770	84	5911	82	6081	82.2	5792	80.1	5818
10	21.7m²	90.4	6173	91	5954	89	6137	87.2	6264	85.1	6339	85.5	6039	84	6091
11	25.6 m²	95.4	6192	94.4	6306	93.6	6473	95.7	6738	90.3	6751	96.8	7108	88.9	6362
12	30.72 m²	98	6228	97	6503	96.7	6727	97.8	6894	94.3	6910	98.2	7219	93.2	6682
13	35.84 m²	-	-	-	-	-	-	-	-	-	-	-	-	96	6896
Sheikhupura Division															
Average (OCC)		3		4		5		5		6		6		7	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m²	29.1	1453.8	26.8	1397.2	24.8	1356.4	23.2	1248.3	20.4	1142.7	19.1	1046.8	17.3	985.3
2	4.3m²	47.2	2635.4	44.8	2612.6	42.4	25712	40.4	2395.3	37	2274.1	34.8	2069	32.3	1975.1
3	6.51m²	59.3	3483.5	56.9	3514.3	54	3479	52	3293.3	47.4	3095.1	45.6	2879	42.6	2752.8
4	8.68m²	67	3949	64.7	3963.5	62.6	4016.5	61.2	3943.3	57.7	3892	56	3705	52.7	3575.7
5	10.85m²	73.2	4331.3	70.7	4350.5	68.8	4426	67.3	4333.6	63.9	4313.1	62.5	4184.6	59.4	4107.5
7	15.36m²	84.5	5008	82.7	5137	81.2	5263	80	5157	76.7	5173	75.3	5042	73	5109
9	19.53m²	91.4	5544	90.4	5783	89.5	5986.3	88.5	5897	86.5	6009	85.8	5880	83.9	5934
12	25.6m²	95.2	5857	94.5	6071	93.8	6397	93.1	6221	91.8	6256	91.2	6136	89.7	6337
14	30.72m²	-	-	97.2	6240	96.5	6461	96	6292	95	6477	94.4	6375	93.3	6488
Gujranwala Division															
Average (OCC)		6		5		7		7		9		9		12	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m²	25.3	1514	25.3	1411	22.4	1379	20.9	1268	17.7	1176	16.5	1077	13.5	995
2	4.3m²	42.8	2819	43	2641	39.3	2645	37.4	2474	33	2352	31.1	2163	26.8	2091
3	6.51m²	52.7	3579	54	3468.3	50.6	3599	48.5	3388	43.4	3256	41.4	3031	36.3	2953
4	8.68m²	61.7	4239	62.8	4062	58.4	4131	57.3	4087	52.8	4108	51.3	3909	45.7	3857
5	10.85m²	68.5	4734	69.5	4518	65.5	4663	63.7	4516	59	4572	57.5	4440	52	4660
6	15.36m²	80.6	5616	81.3	5342	78.3	5604	77.3	5526	72.6	5611	71.2	5473	65.6	5678
9	19.53m²	88.4	6269	89.2	6049	87.1	6418	86.4	6341	83	6562	82.2	6435	77.8	6780
11	23.87m²	93.6	6734	94	6399	92.3	6828	91.5	6728	88.8	7047	88.1	6927	84.7	7410
14	30.72m²	96.2	6924	96.5	6574	95.4	7079	95	7005	93	7384	92.2	7264	89.2	7804
16	34.72m²	-	-	-	-	-	-	-	-	-	-	-	-	92.7	8117
Faisalabad Division															
Average (OCC)		3		4		5		6		7		8		9	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m²	44.3	1615	40.3	1556	37.2	1530	33.3	1446	29.3	1335	26.4	1264	23.8	1189
2	4.3m²	68.5	2962	63.5	2856	60.3	2866.3	55.6	2750	51	2595	47	2482	43.4	2391
3	6.51m²	82.2	3631	78.6	3680	74.3	3665	70	3721	63.5	3434	60	3364	55.8	3256
4	8.68m²	89	4019	86.4	4088	84.5	4229	81	4268	76	4295	71.4	4215	67.4	4143
5	10.85m²	93.6	4245	91.4	4354	89.6	4523	87	4623	84	4685	80	4707	75.4	4660
6	15.36m²	99	4522	98.6	4767	97.7	4986	96.5	5173	94.2	5312	92	5398	90	5587
9	19.53m²	-	-	-	-	-	-	-	-	99	5789	98.5	5968	98	6138
Sargodha Division															
Average (OCC)		5		6		7		8		9		8		8	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m²	25.8	1463	23.7	1397	21.9	1346	19.6	1249	17.4	1152	17	1046	16	960
2	4.3m²	43	2705	40.6	2626	38.4	2580	35.3	2439	32	2263	31.4	2079	30.3	1964
3	6.51m²	54.7	3598	51.7	3531	49.5	3513	46.1	3367	42.5	3183	42	2897	40	2706
4	8.68m²	62.2	4081	59.5	4039	57.4	4075	54.7	4086	51.7	4022	51.5	3756	50	3534
5	10.85m²	68.2	4498	65.8	4487	64	4546	60.8	4510	57.8	4493	58	4266	56.2	4090
7	15.36m²	80.2	5321	78.7	5431	76.6	5480	73.8	5493	70.6	5460	70.7	5220	69.7	5129
9	19.53m²	88	5982	86.7	6137	85.4	6292	83.6	6383	81.5	6450	81.7	6011	81	6013
11	23.87m²	93.2	6373	91.8	6530	90.7	6708	89.1	6821	87.1	6776	87.4	6453	87	6465
14	30.72m²	96.5	6606	95.3	6794	94.5	6998	90.4	7123	91.3	7129	91.6	6775	91	6763
16	34.72m²	-	-	-	-	-	-	96	7218	94.6	7395	94.8	7024	94.2	6891
19	41.23m²	-	-	-	-	-	-	-	-	97	7585	97.1	7206	96.8	7100

South Punjab divisions: The combined energy demand produced by solar thermal units for DHW and Space heating is given in Table 5.27. we found that for Sahiwal division 6566-7732 kWh of fine energy is produced to meet 95-100% of the demand of different house sizes. We see that solar thermal units produce different amounts of heating energy in Multan, Bahawalpur and Dera Ghazi Khan divisions. They produced 5760-7200kWh, 4800-6145kWh, & 4800-5934kWh of green energy respectively, to meet their varying requirements of daily DHW and space heating of different house sizes Table 5.27. The 6901-7693kWh of energy is produced in Rawalpindi division which is part of north Punjab. The amount of energy produced by FTC's is provided in ***Appendix-E-DHW & Space heating-south Punjab***.

Table 5.27 Solar thermal energy produced per household for domestic hot water (DHW) & space heating by evacuated tube collectors (ETC) for most South Punjab divisions

Solar Thermal generation potential summary for per Household (DHW + Space Heating) by ETC															
Area used in simulations(m^2)		50		60		80		100		130		200		300	
Piping used in simulations (m)		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m	
Rawalpindi Division															
Average (OCC)		5		5		6		7		8		7		8	
House GIFA (m^2)		21-42m^2		63m^2		84m^2		105m^2		125-146m^2		167-209m^2		230-418m^2	
Evacuated tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m^2	25.2	1574	24.1	1476	22.4	1423	20.1	1324	18	1223	17.5	1109	15.8	1036
2	4.3m^2	42.6	2933	41.5	2787	39	2697	36.1	2576	33.1	2431	32.7	2230	30.3	2110
3	6.51m^2	53.7	3851	52.7	3699	50.7	3727	47.4	3583	43.6	3370	43	3077	40.4	2954
4	8.68m^2	61	4336	60.6	4271	58.8	4322	56	4285	53.1	4231	53	3971	50.2	3834
5	10.85m^2	67.1	4789	66.8	4720	65	4778	62	4753.4	59.3	4728	59.5	4504	56.7	4409
7	15.19m^2	76.8	5498	76.6	5415	75.1	5541	72.9	5595	70.4	5598	70.9	5353	68.9	5375
9	19.53m^2	84.2	6108	84.3	6098	83.2	6280	81.4	6390	79.5	6455	80	6158	78.7	6205
11	23.98m^2	89.5	6586	89.3	6515	88.2	6691	86.7	6824	85	6895	85.5	6570	84	6632
14	30.38m^2	93.2	6868	93	6797	92	6992	90.6	7113	88.8	7223	89.3	6881	88.1	6976
15	32.55m^2	95.3	6901	95.2	6833	94.4	7047	93.4	7341	92	7382	92.4	7123	91.2	7228
16	34.72m^2	-	-	-	-	-	-	-	-	94.2	7563	94.5	7293	93.8	7441
17	36.89m^2	-	-	-	-	-	-	-	-	95.7	7693	-	-	95	7458
Sahiwal Division															
Average (OCC)		4		6		6		7		8		9		9	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m^2	25.1	1484.1	24	1397	22.4	1365	20.1	1270	17.8	1171	16	1082	15.1	1004
2	4.3m^2	42.3	2755.4	41.2	2620	39	2586	35.9	2457	33	2323	30.1	2168.3	28.8	2034
3	6.51m^2	54.8	3788	53.8	3661	50.8	3586	47.3	3435	43.5	3223	40.4	3066	38.8	2865
4	8.68m^2	62.4	4296.5	62	4232	59.2	4207.4	56.4	4201	53.1	4097	50.1	3952	48.4	3728.4
5	10.85m^2	68.5	4712	68	4632	65.4	4669	62.6	4653	59.5	4616.3	56.6	4526	55.1	4334
7	15.36m^2	80	5245	77	5527	76.6	5460	74	5495	70.8	5467	68.5	5485	67.7	5388
9	19.53m^2	87.8	5901	85.6	6300	85.2	6235	83.4	6345	81.2	6391	79.2	6429	78.7	6293
11	23.98m^2	93	6310	91	6721	90.7	6657	89	6802	87.1	6880	85.5	6940	84.6	6684
14	30.72m^2	96.2	6543	94.6	7010	94.7	6951	93	6960	91.4	7094	89.8	7191	89.3	7062
17	36.89m^2	98.1	6566	97	7060	97	7119	96	7187	94.5	7358	93.4	7496	93	7499
18	39.06m^2	-	-	-	-	-	-	98	7312	96.7	7534	96.2	7732	95.6	7590
21	46.08m^2	-	-	-	-	-	-	-	-	-	-	-	-	97	7710
Multan Division															
Average (OCC)		3		6		6		7		8		9		9	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m^2	34.2	1593	28.8	1584.5	27.8	1517	25	1421	22.8	1355.5	20.5	1205	19.5	1115
2	4.3m^2	55	2883	48.3	2941	47.1	2823	44.2	2763	41.1	2667	38.1	2425	36.8	2269
3	6.51m^2	68.5	3751	60.8	3855	60	3785	56.4	3725	53.4	3667	49.8	3340	48	3104
4	8.68m^2	77.7	4317	71.4	4584	71	4553	67.1	4524	64	4516.3	61	4274	59.4	4061
5	10.85m^2	83	4534.4	78.8	5075	78	5016	74.6	5017	71.5	5032	68.4	4846	67	4648
7	15.36m^2	91.6	4140	87.7	5699	87.3	5642	86.1	5560	82.9	5818	80.6	5866	79.5	5782
9	19.53m^2	97.1	5493	95.3	6312	95.2	6342	94.5	6279	91.3	6534	89.7	6685	89	6575
11	23.98m^2	99.2	5760	98.4	6606	98.2	6566	98	6525	96.4	6960	95.2	6982	94.7	6881
14	30.72m^2	-	-	-	-	-	-	-	-	99	7004	98	7200	97.5	7102
Bahawalpur Division															
Average (OCC)		4		6		7		7		8		8		9	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m^2	42.5	1631	36.8	1612	34	1574	32	1460	28.3	1355.4	26.4	1249	23.9	1185
2	4.3m^2	66.6	2993	60.3	3022.4	57.2	3001	54.6	2809.2	49.8	2651	47.5	2470	44	2380.6
3	6.51m^2	82.1	3859	75.1	3917	71	3896	68.2	3721	63.4	3594	60.2	3311.1	56.4	3227
4	8.68m^2	89.1	4213.5	86	4560	83.2	4602	81.4	4544	76	4501	73.4	4311.1	68.8	4170
5	10.85m^2	94	4500	90.8	4840	89	4994	87.7	4903	84.5	4994	82.3	4875	77.5	4793
7	15.36m^2	99	4800	97.6	5274	96.7	5475	96	5417	90	5485	92.2	5400	90.3	5542
9	19.53m^2	-	-	-	-	-	-	100	5730	99	5934	98.6	5890	97.9	6145
Dera Ghazi Khan Division															
Average (OCC)		5		6		7		8		9		8		8	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Evacuated tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	2.17m^2	34	1589	31.4	1551.6	29	1500.2	26	1409.5	22.9	1300.2	21.7	1207.5	20.3	1112
2	4.3m^2	54.7	2891	51.5	2826.2	48.8	2796.7	45.5	2725.7	41.7	2582	39.6	2394	38	2250
3	6.51m^2	69	3818.4	65.1	3760.7	62	3756	57.8	3639	54	3539	51.5	3288	49.4	3070
4	8.68m^2	78.5	4373.5	76	4431.4	73.3	4515	69.3	4522	65.1	4442	62.8	4216.5	60.8	3989
5	10.85m^2	84.3	4741	82.3	4836.2	80.4	4969	77	4981	73	4968	70.7	4801	68.3	4594
7	15.36m^2	99	4800	98.1	5013	97.6	5114	97.4	5258	93.3	5485	92.2	5400	91.1	5349
9	19.53m^2	-	-	-	-	-	-	-	-	99	5934	98.6	5890	98	5891

5.5.3.2 The energy required per m^2

The energy required per m^2 or number of solar thermal units needed varies in different house sizes. It depends on the occupancy of any house and space heating areas of varying house sizes. It is given in Table 5.26 & Table 5.27. It must be noted that the energy produced by solar thermal units, as discussed before, is the amount of energy required in each division to meet DHW (only), and DHW & space heating requirements. Its values are shown as 'Energy Saved(kWh)' in Table 5.26 & Table 5.27.

5.5.3.3 Area required & area available to produced energy demand

DWH: the solar thermal area required to meet the heating energy required per capita is from 5.4-9.0m^2 in all divisions of Punjab Table 23. It is not more than the average area available per capita (5.9-57m^2 per capita, Table 5.22, last column) after utilizing the roof area for solar PV. So, we can say that for solar thermal installation we have average rooftop area available in all house sizes of Punjab to meet the current demands.

For households, for DHW only we need a rooftop area of 12.6-18m^2 for solar thermal units for all house sizes in all divisions of Punjab Table 5.24 & Table 8.25. When we look at the available average rooftop area, after meeting current roof area required for electrical energy generation by solar PV, we come to know that we have an average area of 28.3-202.9m^2 available for solar thermal units Table 5.21(last column). It means that the current demand of DHW can be easily met in all house sizes in the whole of Punjab**.**

For combined demand of DHW and space heating: To generate the heating energy from solar thermal units for DHW & space heating in all house sizes we need 15.36-40.1m^2 of the active area, in all divisions of Punjab Table 5.26 & Table 5.27. The area available for solar thermal, (after utilizing the required area for solar PV), is between 28.3-202.9m^2 Table 5.21. It indicates that to meet all the requirements of current electrical and heating energy from solar PV and solar thermal, we have sufficient rooftop area available in all house size ranges in all ten divisions of Punjab. Please note that the average area required, and average roof area we have in different divisions is shown in the above discussion, we have also seen each divisional requirement they all fall in the same ranges. It means the results apply to all divisions.

5.5.3.4 Percentage of required demand met

In all house sizes ranges (21-418m^2), to generate the current heating energy required either for DHW (only) or for the combined need of DHW & space heating, we saw that we have sufficient average rooftop areas in all divisions of Punjab. This means it is meeting 100% requirement of current energy demand.

5.5.4 Summary and conclusion of objective 4 (generation potentials)

We have adopted step-wise measurement procedures to calculate the rooftop energy generation potentials to meet the current electrical and heating energy demands in all house size ranges (21-418m^2) in all divisions of Punjab. We utilised the **solar-area and statistical model**, using solar PV (for electricity generation) and solar thermal (for DHW only and DHW & space heating energy generation) technologies.

For the electrical energy generation, we found that the solar PV active area required to meet the current demand of every household is minimal when compared to the average area available on rooftops. In all house sizes, we (not only) have roof area for energy generation to meet our current demands, but also we can generate approximately 400-1700% of current 'per household' needs and 380-500% of current 'per capita' energy needs from solar PV. Hence, it enables us to meet the future needs Table 5.21 & Table 5.22.

After we calculated the solar PV area required for each house size rooftops, we estimated how much area we have left to install solar thermal for heating energy requirements for DHW and space heating.

For the heating energy generation potential, we conducted two measurement procedures, i.e. for DHW only and (for) combined DHW & space heating needs.

For the domestic hot water needs (shown in step 1 in Table 5.27 Solar thermal energy produced per household for domestic hot water (DHW) & space heating by evacuated tube collectors (ETC) for most South Punjab), we tried to meet the 95-100% of the demand. The roof area remaining after meeting the current DHW demands by solar thermal is shown in Table 5.28 (ST-1). If we only want to meet the DHW needs from solar thermal, the area shown in this column would be available for the future demands of electrical energy, and the percentage (%) of future electric demand that can be met is shown in ST-3-A.

We see that even after meeting the current electrical and heating (DHW) energy requirements, we still have a reasonable area available for the additional generation of electricity. It must be noted that the future need for DHW and space heating would be the same for every house size, as it is calculated for all DHW needs of all occupants and complete space heating is estimated in current needs. The heating demand would only change if the occupancy of the household would change, which is very unlikely, as currently, the average occupancy is around 6 in all divisions per household. The future demand increase would only be for electrical energy, and to meet that demand we would have roof area available to generate energy for almost 110-1140% of current demands in all house sizes (ST-3-A, Table 5.28).

Finally, we calculated the generation potential for DHW & space heating (ST-2, Table 5.28) from solar thermal units. We found that only for the smallest house size (21-42m^2) (ST-2, Table 5.28) in some of the divisions (Lahore, Gujranwala, Rawalpindi and Sahiwal), the roof area is slightly less than the required area to meet (95-100%) heating demands. Whereas, in all other house size ranges in all divisions, we can easily produce current combined heating demands (ST-2, Table 5.28). We further calculated the roof area available after meeting all current electrical and heating energy demands and shown in ST-3-B, which shows we will still have roof area for future electrical energy demand generations. Approximately 100-1390% of future electric demand could be generated (except in some smallest house sizes, as mentioned above) from different house sizes and divisions of Punjab. These results indicate that domestic buildings can play an instrumental role in meeting current and future energy demands of this sector, and it can help to achieve this thesis aims of achieving low carbon and resilient energy supply future for Punjab.

Table 5.28 Summary of Solar thermal generation potential, per households (21-418m²)

Solar Thermal generation potential summary for per Household of (DHW) & (DHW +Space Heating)							
Average occupancy and average rooftop area available for Solar Thermal of different house sizes in all Divisions				Step -1 Domestic hot water demand (DHW)	Step-2 Domestic hot water and space heating demand (DHW + Space Heating)	Step-3 Roof area available for additional electric demand generation by Solar PV as percentage (%) of current demands	
Divisions	House Sizes(m^2)	Average occupancy	Average area available for Solar Thermal) (m^2) after meeting current Solar PV area requirement	(ST-1) Rooftop area left after meeting Solar Thermal requirement for DHW (m^2)	(ST-2) Rooftop area left after meeting Solar Thermal requirement for DHW & Space heating (m^2)	(ST-3-A) if Solar thermal is only used for DHW (%)	(ST-3-B) if Solar thermal is used for DHW & Space heating (%)
Lahore	42	4	30.6	16.2	-0.1	220	0.0
	63	5	48.1	31.9	17.4	320	180
	84	6	67.0	49	36.3	440	330
	105	7	71.2	53.2	40.5	390	290
	146	8	86.0	68	55.3	400	330
	209	7	116.0	98	85.3	520	450
	418	8	185.4	167.4	149.5	570	510
Sheikhupura	42	3	31.4	18.8	5.8	290	90
	63	4	48.1	33.7	17.4	340	180
	84	5	66.1	49.9	35.4	420	300
	105	5	70.2	54	39.5	360	270
	146	6	86.8	68.8	56.1	420	350
	209	6	112.8	94.8	82.1	430	370
	418	7	177.0	159	146.3	420	390
Gujranwala	42	6	29.3	14.9	-1.4	170	-20
	63	5	50.4	36	19.7	480	260
	84	7	68.3	50.3	37.6	520	390
	105	7	73.9	55.9	43.2	500	390
	146	9	88.3	70.3	57.6	480	390
	209	9	115.9	97.9	85.2	510	450
	418	12	202.9	184.9	168.2	1530	1390
Faisalabad	42	3	34.1	21.5	18.7	550	480
	63	4	53.4	40.8	38	890	820
	84	5	71.0	56.6	55.6	810	800
	105	6	76.8	60.6	61.4	740	750
	146	7	90.2	74	70.7	580	550
	209	8	118.7	100.7	99.2	620	610
	418	9	194.6	176.6	175.1	870	860
Sargodha	42	5	33.5	19.1	2.8	420	60
	63	6	51.9	35.7	21.2	580	340
	84	7	71.0	53	40.3	760	580
	105	8	77.8	59.8	43.1	830	600
	146	9	93.0	75	51.8	750	520
	209	8	122.8	104.8	81.6	860	670
	418	8	196.6	178.6	155.4	970	850
Rawalpindi	42	5	28.3	10.3	-4.3	110	-40
	63	5	50.2	32.2	17.6	410	230
	84	6	68.9	50.9	36.3	560	400
	105	7	75.8	57.8	43.2	630	470
	146	8	91.0	73	54.1	610	450
	209	7	119.9	101.9	85.2	680	560
	418	8	193.5	175.5	156.6	810	730
Sahiwal	42	4	32.5	19.9	-4.4	360	-80
	63	6	49.4	33.2	12.5	390	150
	84	6	69.8	53.6	32.9	660	400
	105	7	74.8	58.6	35.7	570	350
	146	8	87.4	69.4	48.3	450	310
	209	9	115.7	97.7	76.6	510	400
	418	9	194.7	176.7	148.6	870	730
Multan	42	3	34.4	21.8	10.4	610	290
	63	6	52.3	37.9	28.3	660	500
	84	6	73.6	57.4	49.6	1300	1130
	105	7	78.5	62.3	54.5	960	840
	146	8	95.4	77.4	64.7	1001	850
	209	9	124.1	106.1	93.4	970	850
	418	9	199.1	181.1	168.4	1140	1060
Bahawalpur	42	4	30.0	17.4	14.6	220	180
	63	6	50.1	35.7	34.7	450	440
	84	7	69.4	53.2	54	620	630
	105	7	74.7	58.5	55.2	570	540
	146	8	89.4	71.4	69.9	520	510
	209	8	121.3	103.3	101.8	760	740
	418	9	193.5	175.5	174	820	810
D.G.Khan	42	5	33.8	21.2	18.4	500	440
	63	6	52.9	40.3	37.5	790	740
	84	7	71.2	56.8	55.8	840	820
	105	8	79.0	62.8	63.6	1090	1060
	146	9	95.4	77.4	75.9	1010	990
	209	8	123.1	105.1	103.6	880	870
	418	8	187.1	169.1	167.6	610	600

5.6 Discussion

Pakistan, a developing country with a population of 210M, is facing many challenges. It has become a challenge to sustain and maintain the rapidly increasing demands of its energy-consuming sectors like transport, agriculture, industry and especially the domestic sector which is identified as the primary consumer of energy (48%) in Pakistan. In recent years, an energy crisis is occurring in the domestic sector, where the energy supplies (both electricity & gas) must be cut-off for many hours in a day to cope with the demand pressure. This thesis looked at the role that domestic buildings can play in Pakistan's move towards a low carbon and resilient energy supply system.

The thesis examines how domestic supply might exceed domestic demand by time of day and month of the year through analysis of demand drivers and potential domestic renewable energy generation. In comparison to other countries, the thesis findings suggest that Pakistan could take a micro-generation dominated route towards a low carbon and resilient supply system. This would be unusual amongst countries with large populations, where generation capacity is normally dominated by central generation plant.

To understand how to achieve a low carbon resilient energy system for Pakistan, the research undertaken examined the current energy demands, supplies, resources, and significant consumers of the energy in Pakistan. We found that the energy demand in Pakistan is increasing rapidly. To meet current demands, the energy sources are mostly (65-67%) non-resilient and non-renewables like oil, gas, and coal. The use of non-renewables for future demand increases are currently the government's intentions. This supports the view that the current and future energy supplies of Pakistan are unsustainable and are non-resilient. On the consumption side, we found that transport, industry, agriculture, and domestic sectors are the primary consumers, and the domestic sector is the largest consumer taking 48% of total energy usage of the country. As the domestic sector is the dominant energy consumer, we focussed our research to this sector. In-depth understanding of the domestic sector enabled us to show that the energy demand in the sector could be met from domestic renewable sources of energy. This finding has significant implications for the development of a resilient energy supply system for Pakistan.

The research suggests future domestic demands could be much higher than current figures (section 2.9). We also found that the current official Pakistani demands of domestic electrical energy per capita are far less (230kWh/a to the average requirements of 2655kWh/a) than the average demand per capita of most advanced countries. The research undertaken in this thesis found an average electrical demand per capita of 391kWh/a, which suggests that the official figures are low and that the growth in electrical demand is already happening. Both figures suggest a significant un-met domestic energy demand exists in Pakistan. The research suggests that domestic renewable energy supply systems could meet up-to **8.1** times the current average demand found from the survey undertaken. This suggests that domestic renewable energy supply could meet part of the potential un-met future demand but is unlikely to meet all future needs without either increase in renewable generation efficiency and/or reductions in electrical demand by installed appliances.

To understand the current energy demands, required us to know that what causes this demand is the domestic sector? (or demand drivers). The occupant's space conditioning behaviour, occupancy, GIFA, number of appliances and their power rating, are found as the key demand drivers by other researchers internationally. At the national level, very scarce research is conducted, electrical appliances are found as main drivers in another province of Pakistan, with limited samples. What are the future energy prediction models for the accurate estimations of demands, and to do necessary mitigations for the supplies of energy are missing. We could not find any reasonable answers to these questions.

To achieve sustainable and resilient supply systems (available in the world mainly in the UK & EU), we found apart from other measures taken, one of the possibilities to achieve low carbon resilience was to mitigate the renewable resources like sun and wind. It provided us with the idea of how much renewable energy we can generate from the rooftops of these domestic buildings. With this understanding, we calculated the generation potentials of the domestic sector. Further, we looked at the energy demand timings, to see if we need to have storage capacities or batteries, for the better mitigations of these resources.

Broadly, this thesis investigated the critical questions raised to understand the demand drivers and develop prediction models. Then it went on to explore the timings of demands and generation potentials of the domestic sector of Punjab, to give a feel of the demand that could be met with its own energy generation. We see, among the individual variables of electrical energy demand per household, that the space conditioning for cooling is the strongest driver of electricity (9 out of 10 divisions), either in the form of number and area of conditioned rooms, or the number of air-conditioners owned. We observed the similar drivers of electricity demand per capita Figure 5.31. So, it is the cooling energy which causes a significant demand in all divisions of Punjab. These drivers are similar to the findings of some other research conducted in different province of Pakistan that claimed air conditioners for cooling are the main consumers of electrical energy in domestic sector [170]. We suggest that all cooling appliances like air conditioners and ceiling fans should be made as much energy efficient as we can, to reduce electricity demand. The local market supplies of these appliances should be properly checked to ensure their excellent efficiencies, and any in-efficient cooling appliances must be controlled in the local manufacturing and their imports. On the physical side of the conditioned rooms, the number of rooms may not be reduced (as the average occupancy of house is 6), but the GIFA of these rooms can be controlled to reduce cooling loads.

Further, the construction materials can be made efficient of conditioned rooms. We found that the number of usage hours of appliances is not a major contributor to the demand change of electrical energy. We also noticed that the people of Punjab have varying economic stability and affordability, which may also boost the overall demand for electricity in future when these factors would change.

The most predictive variable for gas energy consumption per household we have is the GIFA of the Sheikhupura division (r=0.756). Occupancy is the other possible driver of gas consumption. We have limited variable data to understand the domestic gas energy consumption Figure 5.31. For per capita gas consumption we have only one demand driver, i.e. GIFA. We found different correlations of domestic gas consumption with GIFA and occupancy, and most of these correlations are weak Table 5.10. The findings suggest that there are other sources of domestic energy for cooking, water and space heating (as electricity is not used for these activities) like bio-fuels. It confirms our findings in the literature that most of the bio-fuel (89%) is being used in the domestic sector. It also draws our attention to the possible increase in gas usage in the domestic sector. Many factors, like urbanization, change of lifestyle, population growth, change in construction materials, the shift from slums to modern living standards, may increase the demand. When these changes happen, the current winter gas crisis would also increase. There are possibilities that electricity will replace gas as a domestic fuel for cooking, and for water and space heating. This shift in fuel usage would exacerbate the electricity crisis in the country.

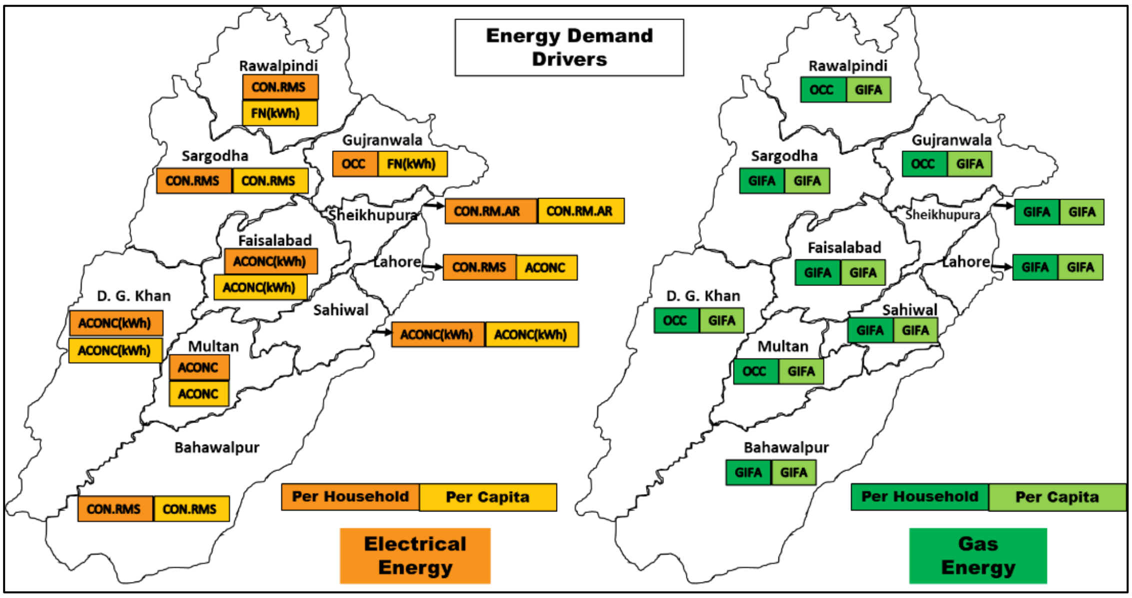


Figure 5.31 Overview of energy demand drivers in different divisions of Punjab of direct variables

The average electrical energy usage per household has a vast range in Punjab, it is highest in the Lahore division (3036 kWh) and lowest in the D.G.Khan division(1569). It means within different divisions of Punjab, there is a potential of average annual demand increase. Due to economic, social, accessibility and affordability factors, households in remote and less developed areas of Punjab are using almost half of the electrical energy as consumed by most developed divisions close the provincial capital, i.e. Lahore divisions Figure 5.32. Per capita electrical energy (kWh/a) consumption also shows huge variations in different divisions. It is highest in Sheikhupura (563 kWh/a) and lowest in D.G.Khan (233 kWh/a). It may have the same reasons for variations as we discussed in per household consumptions. The per capita domestic electrical energy consumption range (233-563 kWh/a) informs us that the residents of Punjab are consuming a much smaller amount of electrical energy when compared with advanced countries Figure 5.9 (discussed in detail in a summary of whole Punjab analysis). It indicates that Punjab has a huge potential of increase in electrical energy consumption.

The overall, electricity consumption analysis suggests that (a) the different divisions of Punjab are at different stages of development, (b) People of different divisions have different social and economic status, hence varying lifestyles (c) the electricity demand of less developed divisions have a huge potential of increase, at least it will become equal to the advanced divisions (d) even the residents of advanced divisions of Punjab consume far less electricity as compared to advanced nations of the world. (e) in the current electricity crisis, effective measures are required to be taken, as there is an inherent potential for demand increase. (f) Apart from catering current demand needs and their possible future projections, there is a severe need to consider all additional demand increase factors (perspectives 1 & 2) in our mitigation strategies.

We found vast variations of gas usage per households in different divisions of Punjab; it is highest in Gujranwala division (8633 kWh/a) and five times more than lowest demand in Sargodha division (1681 kWh/a), for per capita its range is from 1237 kWh/a to 239kWh/a Figure 5.32. These huge ranges of domestic gas consumption suggest that there would be an inevitable increase in its consumption if it would be available for domestic use, in the lower consumption areas.

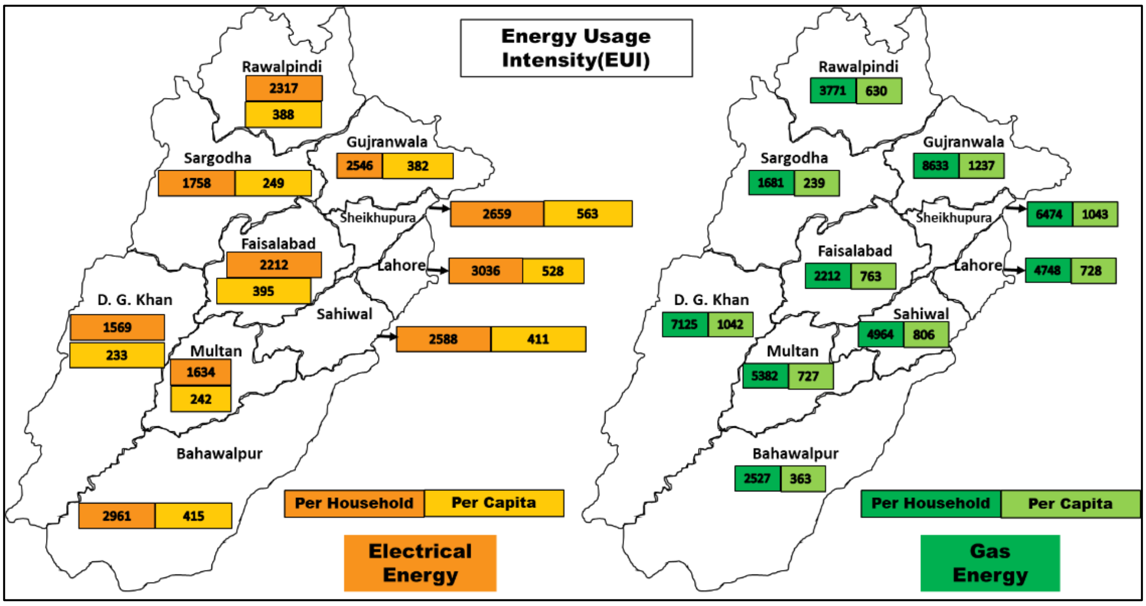


Figure 5.32 Overview of energy usage intensity (kWh) of all divisions of Punjab

The data sets available for the different divisions of Punjab produced various prediction models of varying strengths. The weakest model produced is for the Sargodha division (R^2=0.289) and the strongest model we have for the Faisalabad division (R^2=0.867). We recommend, based on the CL & CI, that electrical energy predictions models of Lahore (R^2=0.545), Sheikhupura(R^2=0.791) and Multan (R^2=0.662) could be used for future estimates, both for per household and capita electrical energy predictions Figure 5.33. Further, we found that the variables relating to the energy required for cooling (like conditioned rooms and fans) are the most influential in most of these models Table 5.9. Mitigation of their energy efficiencies would help to reduce the current and future energy demands. There are no prediction models available in the literature in the context of Punjab, therefore, we cannot compare our models with any existing models. The electricity consumption prediction models produced in this research are unique and first of their kind available for Punjab. They can be used by the policymakers to estimate the actual current demand and future increase with the possible variations in the variables of these models. It will help to reduce the uncertainty in the energy supply system of Punjab for domestic use.

We can see that the strength of gas prediction models in different divisions of Punjab has a vast variation. The most robust model that can be recommended for the gas prediction is of Sheikhupura division (R^2=0.57). In most of the divisions, the prediction models produced are very weak. It indicates that the GIFA and occupancy are not the reliable variables for gas prediction models. There may be other drivers of gas consumption, or maybe other sources of energy like biofuels are being used in place of gas in less advanced and remote areas of Punjab. It implies that there are chances of enormous gas demand in future when these less developed divisions of Punjab (5 out of 10) would need gas energy for the modern lifestyles Table 5.10.

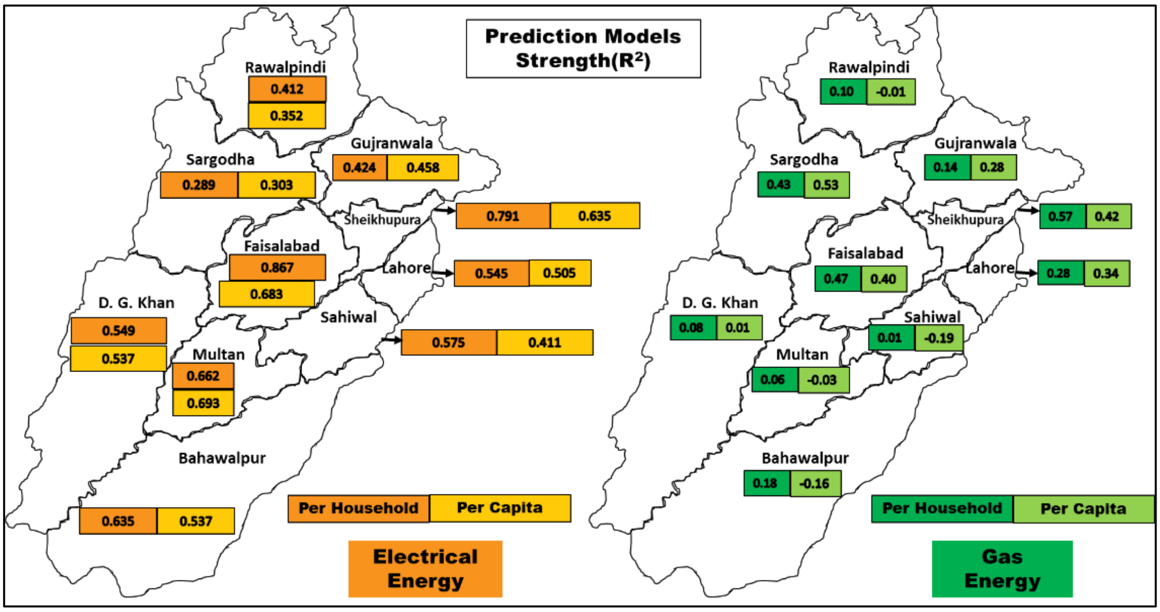


Figure 5.33 Overview of prediction models strength(R^2) of all divisions of Punjab

Before conducting the research to look for the domestic demand drivers at divisional level, we found that at whole Punjab level the main drivers of demands were number and area of conditioned rooms for cooling, and the power rating of appliances and lights. In the divisional level research, we found similar key drivers of domestic energy demands. It means now we have much higher CL & CI to say that the efficiency of the appliances, especially for cooling, is a necessary measure that should be taken by the authorities to reduce demand.

We were interested to understand what causes the energy demand in the domestic sector of Punjab, and we realised that increasing the efficiencies of appliances would bring us close to the aim of this thesis to achieve the energy resilience. By doing so, we can do little demand-side management of energy by reducing its demand after increasing the efficiencies of appliances. On the supply side management, we wanted to explore how much of energy demand can be met by producing its energy from the domestic rooftops. So, we were interested to see how much green energy we can deliver. Producing clean energy would also help us to achieve resilience, with low carbon and renewable resources. Before, looking into the generation potentials, we needed to know when this energy demand occurs in a year, i.e. timings of the demand. We explored this objective to know whether we essentially need to have the storage capacity to meet a substantial amount of energy demand. How much of this demand occurs during the daytime, when readily sunlight is available for exploitation if most of the demand occurs during night time then maybe we need to have more extensive storage capability and vice versa.

The demand timings analysis showed that throughout the year, there are four different clear demand periods, which coincide with the seasonal variations. The summer demands for electricity, and winter demands for gas, are more than double the demands of the rest of the year. We observed moderate demands for Autumn and Spring months for both electricity and gas. Almost **58.2%** (survey data) of electrical energy demand occurs during summer months (only in four months), and out of which 60% (Smart meter data) occurs during the daytime (while 58% winter electrical demand occurs during night-time). It reveals that if we produce all our summer electrical energy demand from solar PV, we can meet **35%** of current annual consumption, without having the storage capabilities (like batteries). Further, the demand timing analysis informed that if we produce all our daytime demands of the whole year, almost **54.5%** of annual electrical energy demand can be met with clean energy without having any storage capacity. If we want to achieve all our domestic electrical energy demand from solar PV, we need to have a storage capacity of approximately (45.5%) of the annual demand. We found that the electrical energy demand is concentrated more during summer periods, it is **16.5%** (average of summer months) higher in summer months than the average demand of other months. Further, we see that the weekdays and weekends days summer demands are 2-3% higher (either for weekdays or weekends of different months) than the normal day's demands, and peak hourly demands have further 2-4% increase in electrical energy demand. We can say overall summer peak day and peak hours demands are **20%** more than the average demands of other months. It implies as this daily increase is not too much, the households are mostly occupied throughout the week. This also goes with our findings of having higher average occupancy level (6) in each house. The houses are always occupied, and electrical energy is constantly being used in them. This phenomenon we also observed in the daily profiles, as there are 2-4% variations in demand on an hourly basis. It also informs us of the way Pakistani households work over the year, and we can say they are occupied continuously throughout the year. It is because the dependency ratio of households is very high, usually one out of average 6 members household goes for work [7]. This thesis describes the current situation in the domestic sector of Punjab, if in future the dependency ratio changes, the weekly and daily energy usages profiles may change, as more of the members of household would start going to work. Hence, we may see clear daily demand change profiles as seen in the advanced world.

The different house sizes in our data set consume 10-13% (58.2% in total) of their annual demands in summer. So, while designing the renewable system for summer months, we need to cater to these respective demand ranges. The peak daily demands of different house sizes (ranges) are 10-29% more than average daily demands, and it should also be considered while designing a PV system. Similarly, weekdays and weekend days demands of different house sizes (ranges) are 2-20% higher than other days, whatever the case it is, either weekdays or weekends for different seasons of the year.

Moreover, 47% of gas demand occurs during the winter season. We do not have data to know the gas demand on a daily and hourly basis, but we can say that clean energy generation would help to overcome the gas energy demands for cooking, water, and space heating Figure 5.29.

This research looked for the potentials of clean energy generation from the domestic rooftops. We saw previously that most of the electrical energy demand occurs during summer months and daytimes. We were expecting to produce a substantial amount of electricity to meet this demand. The mitigation measures undertook the simulation-based '**Statistical area solar models'** for the potential generation estimates of Solar PV and Solar thermals. The reality-based Statistical area solar models {actual average roof area (38-215m^2), occupancy and energy usage(m^2)} ensured that there are vast potentials of electrical energy generation. Comparing the monthly clean energy generated per m^2 of floor area[13]$_{(HH)}$ of the household and required demand ranges (per m^2) of different house sizes (for example 21-42m^2, 105m^2 & 230-418m^2) showed auspicious results in Figure 5.34. It indicates that we need a very small electrical energy (kWh/m^2/ month, the right side of Figure 5.34) as compared to what we can generate for per m^2 area$_{(HH)}$ (household floor area) in all divisions of all house sizes. We can design our solar (PV) systems for average summer monthly requirements; it would be useful for the whole year around.

[13] Energy produced (per m^2) floor area$_{(HH)}$ of the house= rooftop area/GIFA * energy produced per m^2_{PV} of active solar (PV) area.

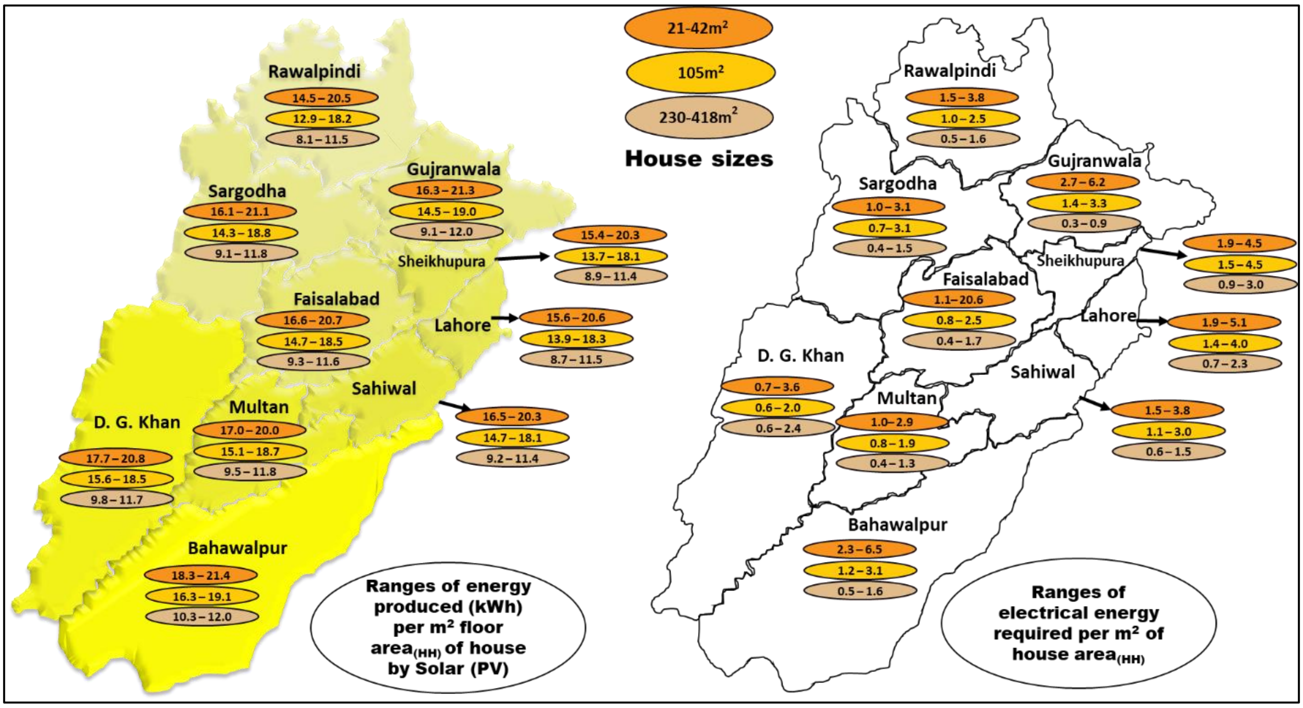


Figure 5.34 Overview of ranges of monthly energy supply and demand per m² in all divisions of Punjab from solar (PV)

Further, we found that the roof areas we need to generate all our current electrical, DHW and space heating requirements in all of ten divisions are readily available Figure 5.35. The average rooftop area (survey data) we have in all divisions of all house sizes ranges from 38-215m^2. We calculated the electrical energy required per m^2 on the average demand over the year. It must be noted (as we discussed earlier) that the electrical energy demand is higher during the summer period (20%), so the roof area required (for solar PV) would increase by 20% if we want to design our solar system for the peak period (summer months16.5%) and peak days (of peak periods 2-4%) of the year. It must also be noted that the electrical energy demand would increase in the future. However, the need for DHW and space heating would not increase, as currently it is estimated with the optimal requirements (i.e. maximum occupancy level, and for total GIFA space heating). We found massive potential for electrical energy demand increase in future, as currently, per capita consumption is meagre as compared to advanced countries need. This research found that with the average rooftop area available of all house sizes, we can fully meet our current demand for electricity, DHW & space heating Figure 5.35. Still, also we would be left with substantial roof area for the clean energy generation to meet future needs. The Figure 5.36 highlights the huge future electrical generation potentials for the different house sizes if all of the roof areas are utilized for solar PV alone, as well as with solar thermals (for DHW & space heating) in all divisions of Punjab.

Further, it must be noted that the solar PV roof areas calculated while taking total energy demand from the whole year and throughout the day. If we do not want to spend money on the storage batteries, we can still produce almost half (60%) of the electrical energy, with half of the area required for solar PVs[14]. It must also be noted that solar thermals are only being used to generate hot water for DHW & space heating. As it would only be used for the winter season, and we know that solar thermals can also be used for electricity generation, they can be used for other months. Solar thermals can be used for individual households or in the form of combined generation plants of many households and vice versa. If some households have installed both the technologies, their electrical load would be shifted, and they may have smaller Solar PV panels. We saw in the literature that solar energy generation potentials are very high in Pakistan (2.12) and found the same in our research. We do not find detailed solar PV and thermal models or calculations in literature, incorporating actual occupancy level, GIFA and actual demand of respective households or capita. Therefore, these results are not comparable to any such unique work. However, we do find individual efforts of some case studies calculations (2.12).

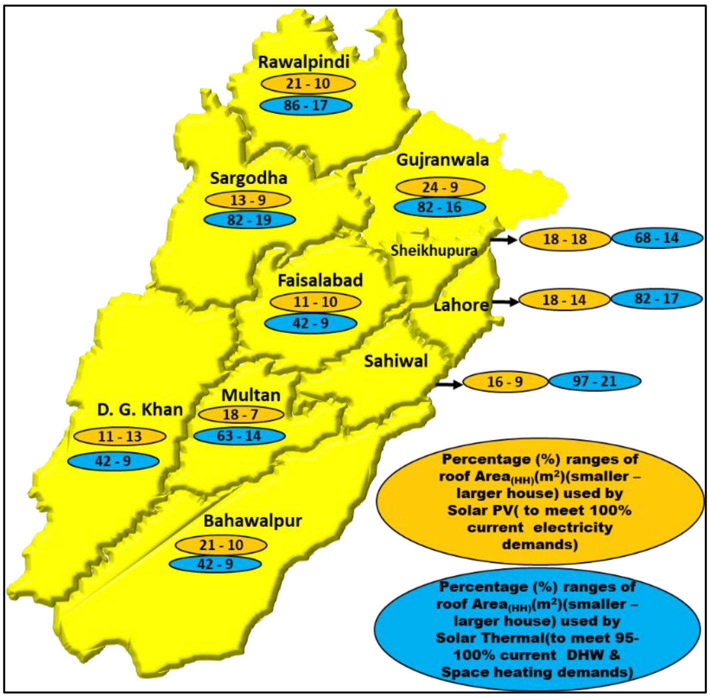


Figure 5.35 Overview of ranges of rooftop areas (m^2) used by solar technology in all divisions of Punjab

Our calculations showed that we could produce 0.66-0.76 kWh/m^2/day fine solar energy. These calculations have considered all losses and minimum efficiency (17%) of solar PVs (Table 4.2). It indicates that if we use highly efficient panels and minimize all losses, the clean energy prospects are much higher than shown in our calculations; but to avoid overestimations, we will stick to our values.

[14] As approximately 45% of electricity demand occurs during night-time, if we are not interested to produce for night demands and store in batteries, the active solar area required to generate only for daytime demand would be reduced.

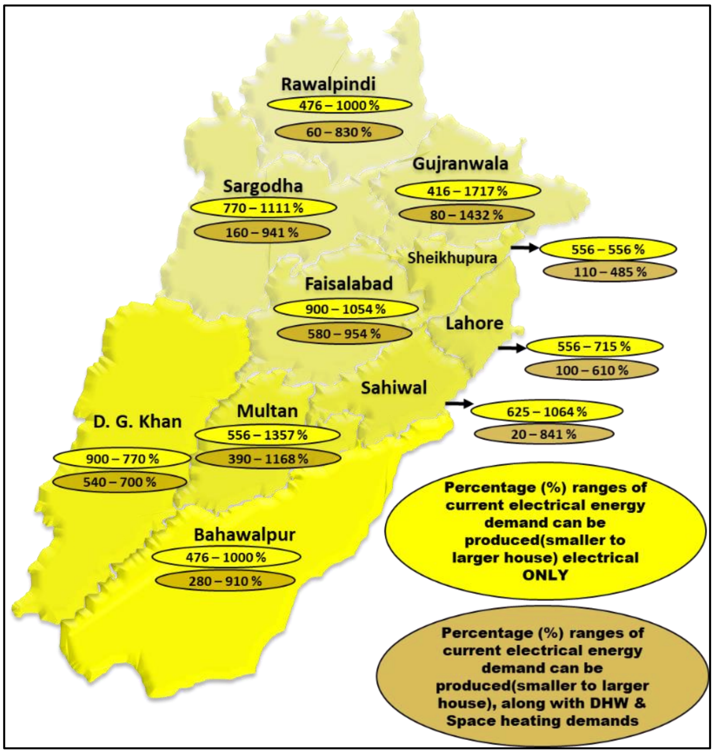


Figure 5.36 Overview of percentage ranges of current electrical demands that can be produced from rooftops by Solar (PV)

On the supply side management, we saw that clean energy technologies (solar PV & solar thermals) had shown very promising results for their adaptation as a solid step forward to achieve a low carbon resilient supply system for Punjab. Adaptation of Solar PV and Solar thermal on the domestic rooftops by all house sizes would reduce the current energy crisis Punjab is facing. When the domestic demands loads are taken out from the main grid, there would be a substantial amount of energy (both electric & gas) available for the use by other sectors like agriculture, transport and industry. It means domestic sector can play an essential role in reducing the energy crisis and giving its energy loads to other sectors. It must also be noted that there would be still more roof area available almost in all house sizes to generate clean energy. The domestic sector can be used for the power generation, and it can supply electricity to the primary grid to fulfil energy deficiency to other sectors. Further, energy generation using Solar technology is a more reliable renewable resource. It will also help to reduce the risk factors involved in the current energy supply system of Punjab due to its mostly non-renewable resources (67%).

The success of these low carbon generation moves to adopt solar technologies would mainly depend on (a) Government initiatives or subsidies, (b) higher Public acceptability. The government should take adequate measures to incorporate solar technology and give subsidies/incentives (as we find in literature) to homeowners. Since its requirement is huge, it might be possible to establish a full-fledged solar manufacturing industry in the country, rather than to import it at higher costs. There is tremendous awareness and willingness to adopt solar technology in the residents of all divisions of Punjab. In our physical survey, we also asked about it,(it was not the primary objective), and there lies huge awareness (72%) and willingness (77%) by the public to adopt solar technologies in Punjab

Figure 5.37. This research came up with the findings that domestic buildings play a vital role in the move towards low carbon resilient energy future of Punjab's energy supply, and informs about the demand drivers, and provides novel prediction models for each division of Punjab.

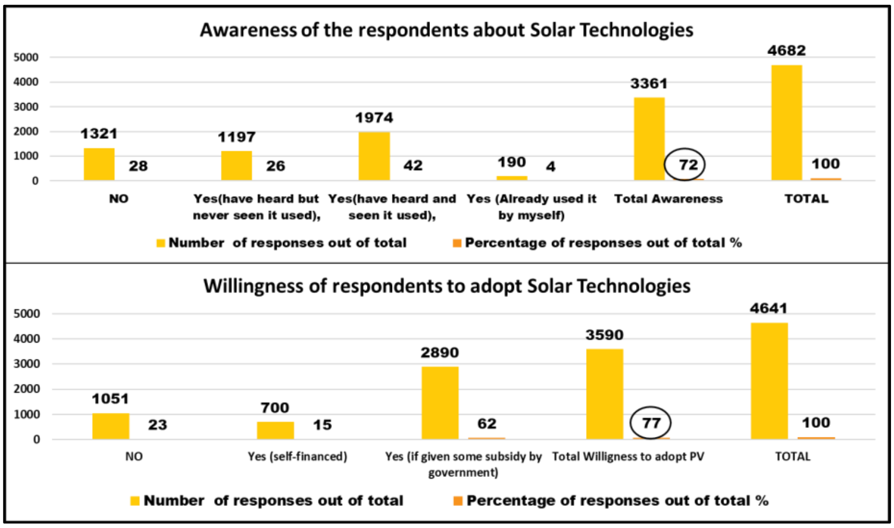


Figure 5.37 Public awareness and willingness to adopt solar technologies

Chapter 6

Conclusions

6 conclusions

6.1 Conclusion

This thesis provided novel data and informed the demand drivers and produced unique prediction models of all divisions of Punjab. It further went on to explore and gave a feel for how its own clean energy generation could meet the domestic energy demand.

This thesis aimed to provide an evidence-based set of proposals on the role that domestic buildings could play in the move towards a low carbon and resilient energy supply systems of Punjab, Pakistan. The research looked at the current energy supply systems and primary consumers of energy in Pakistan. It also explains how low carbon resilience has been achieved by other countries, and the supply of renewable resources is found an effective measure. The domestic sector is identified as a major consumer of energy and addressing its energy supply challenges would help in achieving energy resilience in Pakistan. This research broadly fills the gap in current knowledge of four primary areas of the domestic sector, i.e. (a) extensive field survey based understanding of energy demand drivers, (b) and provision of statistically robust prediction models covering all house sizes and divisions of Punjab, Pakistan for the accurate future demand estimations. (c) identifications of percentages of energy demand timings on monthly, daily and hourly bases, (d) development of 'statistical area solar models', incorporating actual roof areas, occupancy levels and energy demands of all house sizes and divisions (utilizing geographical potentials of Solar PV and Solar thermals), to measure clean energy generation from domestic rooftops. The research also informed about the energy usage intensity (EUI) of all ten divisions of Punjab. To make Pakistan a low carbon economy, we looked at the immediate obstacles and addressed them. We found that the domestic sector is the main obstacle. Therefore, we have done a survey which has never been done before to see what exactly the demand drivers are in the domestic sector and based on this what the simplistic renewable energy generation potentials would be. All of these questions are answered using the data-sets obtained by physical questionnaire survey conducted in 2018, consists of 4597 and 2901 responses for electricity and gas usage respectively, and 10 case studies smart meters data for electrical energy consumptions.

Pearson coefficient analysis (r) was used to identify demand drivers (out of 76 predictive variables), and descriptive statistics like average values were used to understand EUI (energy usage intensity). The regression analysis was conducted to develop the prediction models (six electric and two gas models for each division of Punjab). All these results are presented at two levels, i.e. per household and capita. The five steps 'generation potential models' are used to estimate the electrical energy generation from Solar PV, and DHW (only) and DHW & space heating demands are met by Solar Thermals for all ten divisions. The 'Statistical area solar models' are produced using software simulations and calculations.

The thesis outcomes and findings in literature as per thesis objectives are the following:

- ### To derive the domestic energy demand drivers and find out energy use intensity (EUI) for Punjab Pakistan

Broadly, we found in literature that occupancy, floor area, power ratings, number of appliances owned, and user's behaviour are the key energy demand factors in the domestic sector, internationally. On the local level in a limited research air-conditioners for cooling are identified as key driver of electrical energy demand. Our results showed that the annual demand for electricity use per household and capita could be significantly predicted from knowledge of numbers and types of appliances and lights, their installed power ratings, and most importantly the number and floor area of conditioned rooms (especially for cooling) in all divisions. Gross internal floor area and occupancy are not very significant factors in predicting electrical consumption. We do not find gas energy demand factors in the literature locally, we only know that gas demand increases during winter months, which seems like it is due to space heating or domestic hot water usage. But no clear drivers are identified in literature. In our research we had only gross internal floor area and occupancy as predictive drivers for gas usage.

Further, there is no data available on the energy use intensity of Punjab. we did find annual domestic electrical energy usage (EUI) per capita for Pakistan. Our research showed domestic EUI not only for the Punjab as a whole but also provided its details at each divisional level both for electricity and gas. Annual energy usage intensity (EUI) of gas is greater than electricity for both cases, i.e. per household and capita.

- ### To produce energy demand prediction models per household and capita

The energy demand prediction models produced are first of their kind. We do not find such models for the different divisions of Punjab. we produced models for per household and per capita which are unique in nature.

- ### To derive timings of Punjab domestic energy demand by day, month and year

We found in literature the change in annual energy demands during different seasons of the year provided by the energy distribution companies. But we did not find monthly percentages of these demands during different months of the year, like how the demand changes in different months. We also do not find daily and hourly demand profiles, not even weekdays and weekend demand profiles, which this thesis provides and explains in detail.

- ### To estimate the potential for domestic sector renewable energy generation

In the wider research, Solar PV technology is identified as most effective measure to generate green energy in many countries, and results are very promising. Most of this research covers small scale utilization of this technology. We did not find a large-scale calculation made for the whole state or province incorporating actual occupancy levels, available rooftop areas and energy demand of respective households as we did in this thesis.

At the local level, we found some attempts are made to calculation the solar irradiations levels, limited generation potentials and some case studies, and identified Solar PV technology suitable for larger use. There is no local literature available to ascertain our findings on such an elaborate scale. However, 0.15-0.22kWh/m2/day electrical energy generation we found in literature is similar to our findings during different times of the year. This research suggests that the electrical generation potential by solar PV indicates we need a small fraction of the average rooftop available area to meet the current demands of all house sizes in all divisions and can meet a substantial amount of future need too.

We found in literature that Solar Thermal technology has shown huge potentials for its wider utilizations. At the local level in individual studies, solar thermals are found very effective for the domestic hot water usage. We do not find any elaborate research on the domestic rooftop usage of solar thermal in Punjab as shown by this research, where the needs of DHW and space heating are calculated utilizing the occupancy and gross floor areas and, secondly, detailed requirement of solar thermal units and rooftop areas are estimated to meet current demands. Because of the continuous sunshine throughout the year, the solar thermal was able to meet all the current demands of DHW and space heating of the houses.

However, it is expected that as the heat becomes available then higher levels of thermal comfort would be desired, so it is likely that attention would also need to be paid to the fabric of the buildings. It is required to build more energy-efficient houses in future to bring thermal standards up, as just to meet current minimum demands supplied, because of the black-outs of gas and electrical supplies interruptions that are currently happening. The rooftops installed systems overall have the potential to meet 8.1 times of current electrical energy demand, which would meet some of the un-met predicted future demands.

Further, we found that after utilizing the combined area required to meet electrical, DHW & space heating demands, we still have a substantial amount of area left to generate energy for future needs. Moreover, most of the annual electricity demand occurs during the daytimes of summer months. It can be met straightway by solar energy, without the losses and costs incurred from storage, though some storage would be required to meet night-time electrical loads for cooling.This thesis findings suggest that increasing the efficiency of appliances (especially air conditioners for cooling) and lights would help significantly in reducing the current electrical energy consumption of the domestic sector of Punjab and in achieving low carbon economy goals. It is suggested this efficiency improvement should happen as quickly as possible to both ease the current impact of daily electrical supply interruptions and to prepare the country for managed growth in increasing energy use. Comparison of the per capita electricity use in Punjab with the average electricity use per capita internationally suggests there is an enormous potential for domestic electricity growth which will exacerbate existing power shortages in Pakistan. On the demand & supply-side management, Identifying the variables of domestic energy demand and huge generation potentials will be of value to the energy supply and policy-making authorities when formulating policies to address supply capacity issues and carbon emissions. The research helps the policy-makers broadly in four ways:

a) to understand what causes the energy demand in the domestic sector of Punjab so that policies can be put in place to mitigate the demands,
b) the prediction models would help the policymakers to predict future energy demand based on predicted population growth, enabling effective measures to be implemented to meet this likely future demand down to the level of individual buildings,
c) to know the timings of demands, so that clean energy produced can be used straightway when it is required the most; and to know that approximately half of the demand can be met without storage capabilities
d) to mitigate solar technologies on the domestic rooftops for its more extensive usage, as results are very promising. They can be a significant alternative to non-renewable resources of energy being used. The wide-scale adaptation of solar technologies might have political and economic constraints, and it could be adopted in different phases or periods. The findings are also of use to Engineers and Architects looking to design or renovate domestic properties to meet Zero Carbon or Positive Energy Housing standards.

The domestic sector has huge potential to meet its not only current energy demands but also to cater to future needs. When the domestic sector would be shifted to solar technologies, it would withdraw its 25% (without biofuel) energy demand from the main grid. This much energy would be available for the use of other sectors. Since domestic rooftops would still be available for more energy generation, other than their own needs, they can also produce energy for the central supply system. This is how, the domestic sector of Punjab can play its vital role in achieving low carbon and resilient supply systems, with a sufficient capability to meet its future needs.

6.1.1 Final observations

The findings of this thesis suggest the following:

- All inefficient appliances and lights should be replaced by the most efficient ones, especially the air-conditioners and fans for cooling. The government should have solid checks on the locally manufactured and on imports of electrical appliances and lights.
- To ensure the continuous supply of energy, the estimations of demands should be made utilizing prediction models produced
- The per capita electricity consumption is much higher than what is previously known and should be met accordingly
- The domestic rooftops are freely and secure areas available for the installation of solar technologies, they should be utilised to meet the low carbon resilient supply system’s needs. Domestic solar can be major contributors to our power security, and therefore, state-level interventions are needed.
- The findings of this research can also be applied to other provinces of Pakistan, as there is not very substantial cultural, social and economic difference in most cities. Broadly, we

recommend that our research results can be used by some of the neighbouring and developing countries like India, Bangladesh, Sri Lanka, Afghanistan, Iran, Nepal, and other south-Asian countries. Notably, in those countries which have similar social, cultural and economic societal set-ups and developments.

6.1.2 Limitations

- Smart meter data, which we used to understand the daily break-up of electrical energy usage is derived from only 10 case study houses, extensive case studies samples should have been added for more robust results.
- The solar PV and solar thermal potential calculations are done using software; the actual results might differ slightly, as each software has its limitations.
- While calculating the solar potentials, some factors are ignored like shadowing may affect the generation potential from any neighbouring buildings or trees.
- Adequate sample collection should have been done from all 36 districts of Punjab. We have reasonable sample sizes for each division, but for each district within the division, more samples were required, as we received few samples in some districts.
- The prediction models produced have varying strengths; some of the models are weak like for Sargodha division(R^2=0.386); such models are not very reliable. So, more data is required to develop stronger models.
- Pakistan is not a financially sound country; large scale adoption of the solar technology at once would have strong financial constraints. The shift to move on renewable technology might take much longer time. Since then, the current demands we estimated might have changed as the lifestyle of people is changing rapidly.

6.1.3 Future research

- Research should be conducted to reduce cooling loads of conditioned rooms of the households. Appropriate construction materials should be developed.
- The physical dimensions of the conditioned rooms should be monitored. The research is needed to recommend the reasonable rooms sizes for different household sizes, especially considering the occupancy levels.
- Detailed research is required to estimate the domestic gas energy consumption, more variables, other than GIFA and occupancy, must be explored to understand the drivers better and to produce more robust prediction models.
- Elaborate research is required using smart meters to ascertain the findings we discussed for timings of electrical energy demands (we did this with ten case study houses only)
- For the daily break-up of daytime and night-time gas energy consumption, elaborate research is required.
- Research is required to estimate and understand the break-up of domestic gas used for cooking, DHW & space heating.
- Large scale study is to be done by putting solar PV on each house size and checking of what we claimed to be produced from these rooftops.

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8 Appendixes

Appendix A

Statement 1

This thesis is being submitted in partial fulfilment of the requirements for the degree of **PhD**

Signed ____Usman Awan _ ____________________

Date ______**13-01-2021**___________________

Statement 2

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is it being submitted concurrently for any other degree or award (outside of any formal collaboration agreement between the University and a partner organisation)

Signed_______Usman Awan ___ ______________

Date __________**13-01-2021**_______________

Statement 3

I hereby give consent for my thesis, if accepted, to be available in the University's Open Access repository (or, where approved, to be available in the University's library and for inter-library loan), and for the title and summary to be made available to outside organisations, subject to the expiry of a University-approved bar on access if applicable.

Signed __________Usman Awan __ _____________

Date ____________**13-01-2021**_____________

Declaration

This thesis is the result of my own independent work, except where otherwise stated, and the views expressed are my own. Other sources are acknowledged by explicit references. The thesis has not been edited by a third party beyond what is permitted by Cardiff University's Use of Third Party Editors by Research Degree Students Procedure.

Signed__________Usman Awan _ ______________

Date __________**13-01-2021**_______________

Word Count ____64116_______________

(Excluding summary, acknowledgements, declarations, contents pages, appendices, tables, diagrams and figures, references, bibliography, footnotes and endnotes)

Appendix B

Survey form

How do we move towards a low carbon and resilient energy future for Punjab, Pakistan?

This academic research project is being conducted to understand and feed into the debate on how Punjab's energy supply will need to evolve to meet future demands.
This is your opportunity to ensure your voice is heard in the discussions concerning how we achieve the energy and power needs we have as a society, as we try to improve standards of living and our economy.
The study is considering everything from energy supply through to end-use energy demand. For this part of the study, we are looking to understand:

1. How much is energy (power & gas) being used in relation to household size and a number of occupants?
2. Potential future increases of energy demand. For example, if more energy is made available, how much is demand likely to increase?
3. What produces this energy demand in a typical household?
4. When is this energy being used?

All information provided is confidential and will only be used for this study.
This study is being undertaken by Usman Awan, University of Engineering and Technology, Lahore Pakistan in conjunction with the Welsh School of Architecture, Cardiff University, the U.K. for my PhD thesis.

Your consent to keep information for this and latter studies (like research papers): **Yes** **No**

Q1. Name/Roll Number
Q2. Address
Q3. How many people are usually living in the house? (also include house worker(s)/servant(s) who live(s) in the same house?
Total Adults- children- servants-
Q4. What is the total covered area of your house? (Including each floor covered area of the ground floor, first-floor basement etc., and excluding outer spaces?
A.4
Q5. What are the total number of conditioned rooms (rooms which are heated and/or cooled) in your house?
A5.
Q6. What is the total combined area of conditioned rooms? (sq. Ft, sq.m, Dimensions)
A6.
Q7. How many rooms would you like to condition in total if you could afford? (heating or cooling)
A7.
Q8. What would the new total combined area of conditioned rooms then be? (sq. Ft, or sq.m)
A8.
Q9. How much electricity do you use per month(kWh)? AND power cut, hours per day in each month?
A9. January - / , Feb- / Mar- / , April / , May / , June /
July / , Aug / , Sep. / , oct. / , Nov. / , Dec. /
Q10. How much Gas do you use per month(hm3)? AND Gas cut, hours per day in each month?
A9. January - / , Feb- / Mar- / , April / , May / , June /
July / , Aug / , Sep. / , oct. / , Nov. / , Dec. /
Q11. Are you aware of the use of solar cell (PV) to help supplement the electrical energy you purchase from the national grid?
A11. 1-NO, 2-Yes (have heard but never seen it used),
3-Yes (have heard and seen it used), 4-Yes (Already used it by me
Q12. If you answered 'Yes' to the last question, what is the size (generation capacity) of your Solar cells (PV)? (KW)
A12.
Q13. In which direction your solar cells are installed?
A13.
Q14. What is the angle of installation?

A14.
Q15. Would you be willing to install Solar cells (PV)? (or if it will not reduce the rooftop area for other activities)?
A15. 1-No, 2-Yes (self-financed) 3-Yes (if given some subsidy by the government)
Q16. How large is your rooftop area?
A16.
Q17. Please list all the lights in your house by type, wattage and average usage per day, AND additional required if you can afford?

Sr. No	Type	No.	Wattage /size (W)	Winter Usage hrs	Summer Usage hrs	Autumn Usage hrs	Spring Usage hrs	additional required no.	additional usage hrs
1	Fluorescent tube lights								
2	Incandescent Bulbs								
3	Energy Saver (C.F.L)								
4	LED, SMD								
5	Others								

Q18 Please list all the electrical appliances in your house by type, wattage and average usage per day, AND additional required if you can afford?

Sr. No	Type	No.	Wattage /size (W)	Winter Usage hrs	Summer Usage hrs	Autumn Usage hrs	Spring Usage hrs	additional required no.	additional usage hrs
1	Fan(s) (bracket, ceiling, Pedestal, etc.)								
2	Air conditioner(s) (cooling only)								
3	Air conditioner(s) (heating only)								
4	Air conditioner(s) (both cooling & heating)								
5	Direct electric heater (rod, fan heaters, etc.)								
6	Fridge(s)								
7	Freezer(s)								
8	Television(s)								
9	Computer(s), Laptop(s)								
10	Microwave(s)								
11	PlayStation/video games etc								
12	Stove exhaust fan								
13	Exhaust fan (kitchen, bathrooms etc)								
14	Internet Modem/router/hub etc								

15	washing machine								
16	vacuum cleaner								
17	water cooler/Desert cooler								
18	central heating or cooling system								

Kindly WhatsApp your electricity bill picture on this number: **0044-7459935619,** this would authenticate your response and validate this research, please give the name to bill picture as your roll number/address, so that it can be traced back. I will highly appreciate it.

Usman Awan
Assistant Professor
UET Lahore
PK Mob. No. 00923147565712

Appendix C

8.1 Appendix-C-Sheikhupura (demand drivers & prediction models)

The house sizes covered in the survey range from $20.9m^2$ to $418m^{2,}$ which covers the dominant house sizes in the Sheikhupura division. The average house size is 87.1 $m^{2,}$ and the house size of $62.7m^2$ is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is $18.4m^2$. The minimum and maximum values of m^2 per capita are $6.3m^2$ and $m^{2,}$ respectively (Appendix-C-1). These variations show the data set covers the full range of Punjab society and provide further confidence in the general application of the findings

8.1.1 Domestic demand drivers of Sheikhupura division

Per household(electricity): The results of modelling the **direct and indirect** variables per household show CON.RM.AR (r=0.806), ACONC (kW) (r=0.738), and CON.RMS (r=0.715) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP (kW)+LTS (kW) (r=0.840), APP(KW) (r=0.835) and APP (r=0.815) have a good correlation with the dependent variable (Figure 8.1 & Figure 8.2).

Per Capita(electricity): The results of modelling the **direct and indirect** variables per capita show CON.RM.AR (r=0.666), ACONC (kWh) (r=0.613), and ACONC (r=0.573) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP (kW)+LTS (kW) (r=0.728), APP(KW) (r=0.724) and APP (r=0.669) have good correlations with the dependent variable (Figure 8.1 & Figure 8.2).

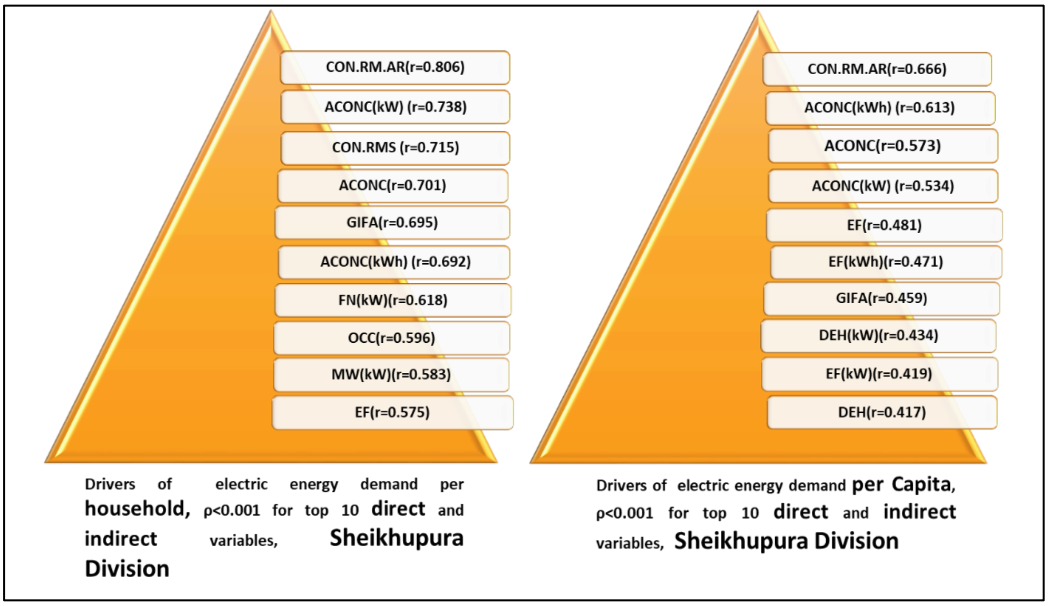


Figure 8.1 Hierarchical presentation of electricity demand drivers per household and per capita in Sheikhupura division, Punjab for direct and indirect variables

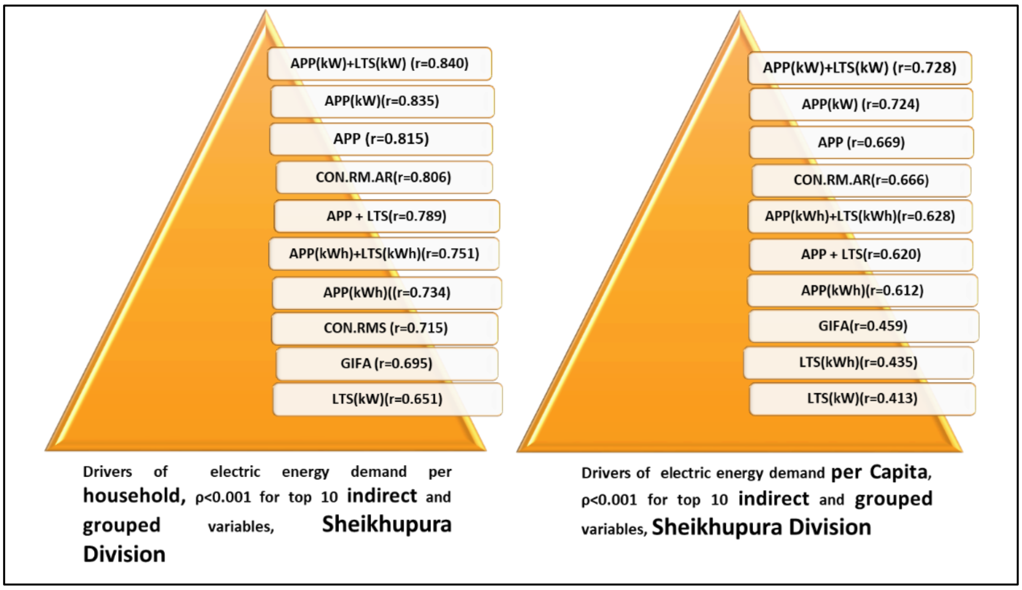


Figure 8.2 Hierarchical presentation of electricity demand drivers per household and per capita in Sheikhupura division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-1. It shows the strongest correlation is with the total number of APP (kW)+LTS (kW)(r=0.840) for the per household model, and with an installed electrical capacity of the appliances and lights, APP (kW)+LTS (kW) (r=0.728) for the per capita model.

Per household and capita(gas): Acceptable gas correlations are with GIFA and occupancy (OCC), where r= 0.756 & 0.351 for the per household and for per capita model it is only with GIFA, where r= 0.658.

8.1.2 Energy usage intensity (EUI) of Sheikhupura division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix C-3-1):

- The average household electric and gas energy use is around 2658.6 kWh/a and 6474 kWh/a respectively.
- Per capita, the average energy use is 563 kWh/capita/a and 1042.5 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 32 kWh/m^2/a and 44 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 7.5 kWh/m^2.capita/a and 7.7 kWh/m^2.capita.a for electricity and gas, respectively.
- The ranges of electric and gas demand are large in both per household and per capita models.

8.1.3 Energy consumption prediction models of Sheikhupura division

Descriptive Statistics of final predictive variables selected for the Sheikhupura division are presented in Appendix C-Sheikupura -1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-1 and Appendix C-Sheikupura-2

8.1.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known than the following equation is valid to an accuracy of **R^2=0.784**, RMSE=771.4, strongest predictive variable =**CON.RM.AR** (**β**=0.373, $p<0.001$)

$$\bar{Y} = 155.7 + 305.6 * ACONC(KW) + 792.8 * DEH(KW) + 1622 * FRG(KW) + 1567.5 * FRZ(KW) + 391.8 * FN(KW) + 670 * MW(KW) + 107.8 * CON.RM.AR \quad (1)$$

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.756** and RMSE= 823.3, strongest predictive variable = **LTS(KW)** (**β**=0.652, $p<0.001$)

$$\bar{Y} = 17.63 + 8.4 * GIFA + 700.5 * APP(KW) + LTS(KW) \quad (2)$$

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**=0.791**, RMSE=744.7), strongest predictive variable =**CON.RM.AR** (**β**=0.354, $p<0.001$)

$\bar{Y}$**= 130.67 +249.9*ACONC(KW) + 179.5*FN(KW) + 571.9 *MW(KW) +100.4*CON.RM.AR +38.5 *(APP+LTS) + 1229.3 *FRG(KW) + 1382.3 * FRZ(KW) + 705.7* DEH(KW) (3)**

8.1.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model Explained & Equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.635**, RMSE= 169.7, strongest predictive variable =**CON.RM.AR/ capita** (**β**=0.349, p<0.001)

$\bar{Y}$**= 13.9+ 3.2*GIFA + 314.1*ACONC(KW) + 716.7*DEH(KW) + 1593.5*FRG(KW) + 420.9*FN(KWH) + 556.5*MW(KWH) + 96.1*CON.RM.AR (4)**

Grouped Model Explained & Equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.592**, RMSE= 185.2, strongest predictive variable = **(APP +LTS) (kW)/capita** (**β**=0.642, p<0.001)

$\bar{Y}$**= 11.74 + 9.23 *GIFA + 659.9*(APP+LTS) (KW) (5)**

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.631**, RMSE= 170.4, strongest predictive variable = **CON.RM.AR/ capita** (**β**=0.352, p<0.001)

$\bar{Y}$**= -30.1 + 2.8*GIFA + 254.2 *ACONC(KW) + 560.3*DEH(KW) + 234*FN(KWH) + 431.9* MW(KWH) + 97.1*CON.RM.AR + 90.3* APP + 363.3 * FRG (6)**

8.1.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: R^2= 0.565, RMSE= 3983.6 strongest predictive variable =GIFA (**β**=0.756, p<0.001)

$\bar{Y}$**= -1113.9 + 53.7*(**GIFA**) (7)**

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: R^2= 0.423, RMSE= 611.2), strongest predictive variable =GIFA/capita (**β**=0.658, p<0.001)

$\bar{Y}$**= -115.5 + 50.5*(**GIFA/capita**) (8)**

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.2 Appendix -C-Gujranwala (demand drivers & prediction models)

The house sizes covered in the survey range from 20.9m^2 to 334.4m^2, which covers the dominant house sizes in the Gujranwala division. The average house size is 82.3m^2, and the house size of 104.5m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 12.9m². The minimum and maximum values of m² per capita are 2.3m² and 146.3m²' respectively (Appendix-C-1). These variations show the data set covers the full range of Punjab society and provides further confidence in the general application of the findings.

8.2.1 Domestic demand drivers of Gujranwala division

Per household(electricity): The results of modelling the **direct and indirect** variables per household show OCC (r=0.494), FN (kW) (r=0.492), and FN (kWh) (r=0.484) have a reasonable correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP+LTS (r=0.521), APP (r=0.497) and OCC (r=0.494) have a good correlation with the dependent variable (Figure 8.3 & Figure 8.4).

Per Capita(electricity): The results of modelling the **direct and indirect** variables per capita show FN (kWh) (r=0.512), FN(KW) (r=0.494) and FN (r=0.486) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP (r=0.570), APP+LTS (r=0.569) and APP(kWh)+LTS(kWh) (r=0.493) have good correlations with the dependent variable (Figure 8.3 & Figure 8.4).

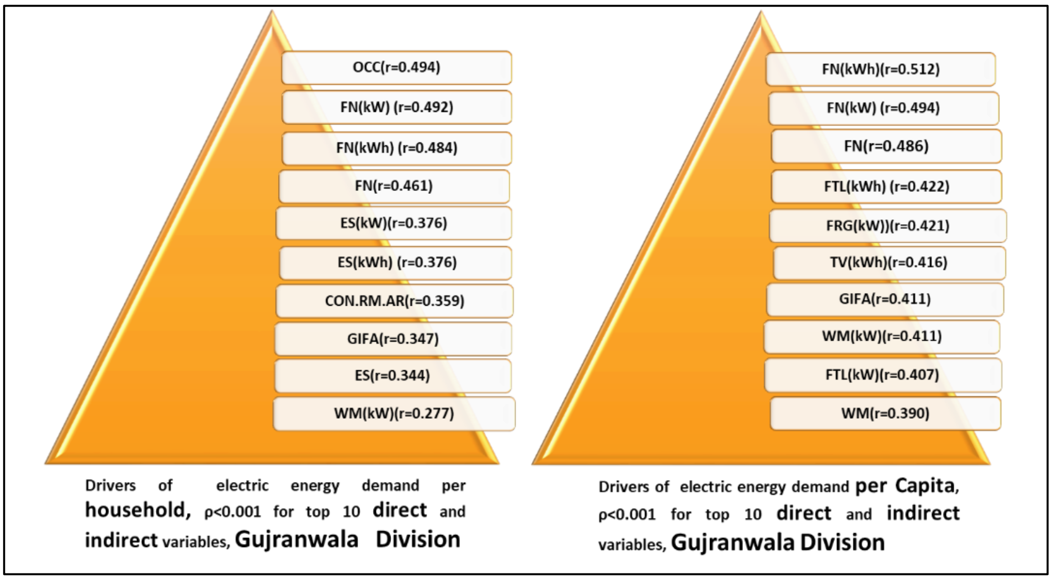


Figure 8.3 Hierarchical presentation of electricity demand drivers per household and per capita in Gujranwala division, Punjab for direct and indirect variables

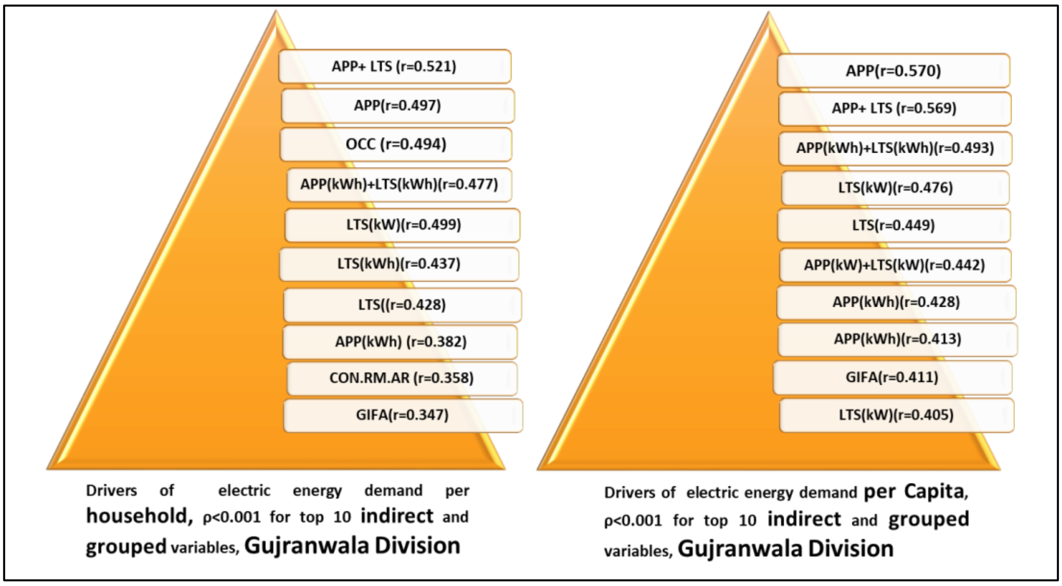


Figure 8.4 Hierarchical presentation of electricity demand drivers per household and per capita in* Gujranwala *division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-1, which shows the strongest correlation is with the total number of APP+LTS (r=0.521) for the per household model, and with the number of electrical appliances APP (r=0.570) for the per capita model.

Per household and capita (gas): Acceptable gas correlations are with GIFA and occupancy (OCC), where r= 0.293 & 0.304 for the per household and for the capita model it is only with GIFA, where r= 0.529.

8.2.2 Energy usage intensity (EUI) of Gujranwala division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix B-3-1):

- The average household electric and gas energy use is around 2546 kWh/a and 8633 kWh/a respectively.
- Per capita, the average energy use is 381.7 kWh/capita/a and 1236.9 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 35 kWh/m^2/a and 117 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 5.5kWh/m^2.capita/a and 16.5 kWh/m^2.capita.a for electricity and gas, respectively.
- The ranges of electric and gas demand are significant in both per household and per capita models.

8.2.3 Energy consumption prediction models of Gujranwala division

Descriptive Statistics of final predictive variables selected for the Lahore division are presented in Appendix C-Gujranwala-1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-1 and Appendix C-Gujranwala-2

8.2.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2=0.405**, RMSE=1145.7, strongest predictive variable =**CON.RM.AR** (**β**=0.242, p<0.001)

$$\bar{Y} = 308.3 + 136.4 *OCC + 3.3*GIFA + 1092.1*FN(KW) + 244.7 * FN(KWH) + 66.8 *CON.RM.AR \quad (1)$$

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.390** and RMSE= 1160.3, strongest predictive variable = **OCC** (**β**=0.275, p<0.001)

$$\bar{Y} = -97.3 + 159.6*OCC + 40.3 *(APP+LTS) + 60.3* APP(KW)+LTS(KW) + 41.0 * CON.RM.AR \quad (2)$$

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of (**R^2=0.424**, RMSE=1127.2), strongest predictive variable =**FN(KW)** (**β**=0.280, p<0.001)

$$\bar{Y} = 48.1 + 145.5 *OCC + 1487.1*FN(KW) + 42.7 * CON.RM.AR + 71.1 *APP(KWH)+LTS(KWH) \quad (3)$$

8.2.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.394}$, RMSE= 171.7, strongest predictive variable =**FN (kWh)/ capita** (**β**=0.358, $p<0.001$)

$\bar{Y}$= 184.9 + 500.6*FN(KHW) + 555.2 * COM/LAP (kWh) + 2581.5 *FTL (kW) + 72.3* CON.RM.AR + 136.8 *TV (kWh) (4)

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.458}$, RMSE= 174.7, strongest predictive variable = **APP /Capita** (**β**=0.370, $p<0.001$)

$\bar{Y}$= 103.3 + 88.6* APP + 262.8 * LTS (kWh) + 199* (APP+LTS) (kW) (5)

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.424}$, RMSE= 167.3, strongest predictive variable =**FN (kW)/Capita** (**β**=0.410, $p<0.001$)

$\bar{Y}$= 154.2 + 404.1 *COM/LAP (kWh) +1730*FTL(Kw) + 42.4*CON.RM.AR + 257.5 *APP(KW)+LTS(KW)+ 2006.4*FN(KW) (6)

8.2.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household Model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: (R^2= 0.136, RMSE= 2925.4), strongest predictive variable =OCC (**β**=0.239, $p<0.001$)

$\bar{Y}$= 4529.6 + 17.94*(GIFA) + 334.2*(OCC) (7)

Gas per Capita Model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: (R^2= 0.279, RMSE= 566.9), strongest predictive variable =GIFA/capita (**β**=0.529, $p<0.001$)

$\bar{Y}$= -52.87 + 36.59*(GIFA/capita) (8)

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.3 Appendix -C- Faisalabad (demand drivers & prediction models)

The house sizes covered in the survey range from 20.9m^2 to 418$m^{2,}$ which covers the dominant house sizes in the Faisalabad division. The average house size is 128.9$m^{2,}$ and the house size of 104.5m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 22.5m^2. The minimum and maximum values of m^2 per capita are 5.9m^2 and 104.5$m^{2,}$ respectively (Appendix-C-1). These variations show the data set covers the full range of Punjab society and provide further confidence in the general application of the findings

8.3.1 Domestic demand drivers of Faisalabad division

Per household(electricity): The results of modelling the **direct and indirect** variables per household show ACONC (kWh) (r=0.811), ACONC (r=0.785) and CON.RMS (r=0.781) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP (r=0.888) , APP+LTS (r=0.882) and APP(kW)+LTS(kW) (r=0.874) have a good correlation with the dependent variable (Figure 8.5 & Figure 8.6).

Per Capita(electricity): The results of modelling the **direct and indirect** variables per capita show ACONC (kWh) (r=0.659), CON.RM.AR (r=0.617) and ACONC(KW) (r=0.592) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP(kW) (r=0.748), APP+LTS (r=0.742) and APP(kW)+LTS(kW) (r=0.734) have good correlations with the dependent variable (Figure 8.5 & Figure 8.6).

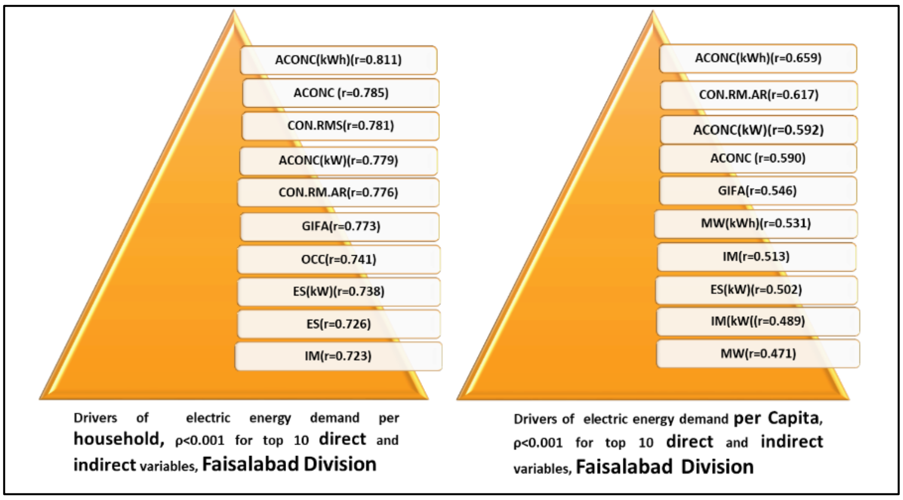


Figure 8.5 Hierarchical presentation of electricity demand drivers per household and per capita in Faisalabad division, Punjab for direct and indirect variables

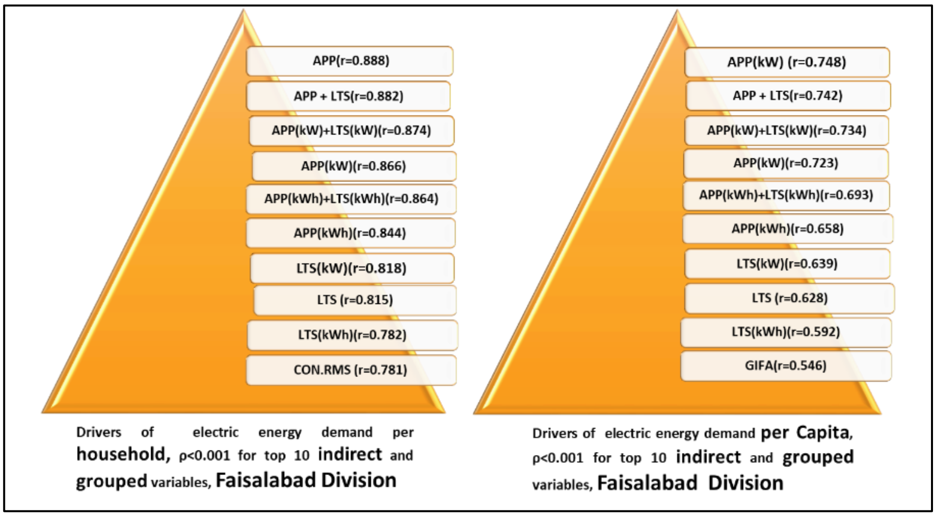


Figure 8.6 Hierarchical presentation of electricity demand drivers per household and per capita in Faisalabad division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-1, which shows the strongest correlation is with the total number of APP (r=0.888) for the per household model, and with an installed electrical capacity of the appliances and lights, ACONC (kWh) (r=0.659) for the per capita model

Per household and capita(gas): Acceptable gas correlations are only to the size of the house (GIFA), where r= 0.686 & 0.633 for the per household and for the capita models respectively. The other variable, i.e. occupancy of the house does not show any reasonable correlation with the dependent variable; it is close to zero.

8.3.2 Energy usage intensity (EUI) of Faisalabad division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix B-3-1):

- The average household electric and gas energy use is around 2211.9 kWh/a and 5126 kWh/a respectively.
- Per capita, the average energy use is 394.5 kWh/capita/a and 763.4 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 19 kWh/m^2/a and 29 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 4.5kWh/m^2/capita/a and 5.2 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are significant in both per household and per capita models.

8.3.3 Energy consumption prediction models of Faisalabad division

Descriptive Statistics of final predictive variables selected for the Lahore division are presented in Appendix C-Faisalabad-1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-1 and Appendix C-Faisalabad-2

8.3.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2=0.867**, RMSE=514.5, strongest predictive variable =**ACONC (kWh)** (**β**=0.285, p<0.001)

$\overline{Y}$= 217.7 + 49.1 * OCC + 241.2 * FRG + 450.6 * IM + 1646.1 * FN(KW) + 103.9* ACONC(kWh) + 290.9 *MW(kWh) + 2788.5 *EF(kWh) + 152.1* IB + 52.8 *ES + 1383.4 * FTL(KW) + 19.9 *CON.RM.AR (1)

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.793** and RMSE= 641.9, strongest predictive variable = **OCC** (**β**=0.518, p<0.001)

$\overline{Y}$= -837.3 + 260* OCC + 43.5 *CON.RM.AR + 8.87*GIFA + 337.9 *(APP+LTS) (2)

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of (**R^2=0.865**, RMSE=518.6), strongest predictive variable =**ACONC (kWh)** (**β**=0.278, p<0.001)

$\bar{Y}$= 232.3 + 46.5*OCC + 224.7* FRG + 450*IM + 1724* FN(KW) + 101.3 * ACONC(kWh) + 269.4* MW(kWh)+ 2643.3 * EF(kWh) +20.3*CON.RM.AR + 1910.3 *LTS(Kw) (3)

8.3.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.677**, RMSE= 96.2, strongest predictive variable =**ACONC (kWh)/capita** (**β**=0.247, p<0.001)

$\bar{Y}$= 100.5 + 1.9*GIFA + 429.7*IM + 176.5 * WM + 1142.3 *FN(Kw) +186.9*FN(KW) + 69.9 * ACONC(KWH) + 315.8*MW(KWH) + 3405.8*EF(KWH) + 124.8*CON.RMS (4)

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.620**, RMSE= 106.9, strongest predictive variable = **APP/Capita** (**β**=0.574, p<0.001)

$\bar{Y}$= 70.2 + 2.1*GIFA + 137.6* APP + 118.9* LTS (KWH) (5)

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.683**, RMSE= 95.23, strongest predictive variable = **ACONC (kWh)/capita** (**β**=0.238, p<0.001)

$\bar{Y}$= 98.7 + 383.9*IM + 123.3*WM + 1354.6* FN(KW) + 67.2*ACONC (kWh) + 290.4 *MW (kWh) + 2324.9*EF (kWh) + 96.2 *CON.RMS + 31.2* APP + 1637.3* LTS(KW) (6)

8.3.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household Model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: (R^2= 0.468, RMSE= 4031.5), strongest predictive variable =GIFA (**β**=0.686, p<0.001)

$\bar{Y}$= -742.2 + 32.2*(GIFA) (7)

Gas per Capita Model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: (R^2= 0.398, RMSE= 636.1), strongest predictive variable =GIFA/capita (**β**=0.633, p<0.001)

$\bar{Y}$= -101.7 + 34.0*(GIFA/capita**) (8)**

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.4 Appendix-C-Sargodha (demand drivers & prediction models)

The house sizes covered in the survey range from 41.8m^2 to 418m^{2,} which covers the dominant house sizes in the Sargodha division. The average house size is 105.5m^{2,} and the house size of 83.6m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 15.1m^2. The minimum and maximum values of m^2 per capita are 3.8m^2 and 104.5m^{2,} respectively (Appendix-C-1). These variations show that the data set covers the full range of Punjab society and provides further confidence in the general application of the findings.

8.4.1 Domestic demand drivers of Sargodha division

Per household(electricity): The results of modelling the **direct and indirect** variables per household show CON.RMS (r=0.449), CON.RM.AR (r=0.445) and ACONC (r=0.425) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP (kW)+LTS(kW) (r=0.475), APP(KW) (r=0.474) and CON.RMS (r=0.449) have a good correlation with the dependent variable (Figure 8.7 & Figure 8.8).

Per Capita (electricity): The results of modelling the **direct and indirect** variables per capita show CON.RMS (r=0.412), GIFA (r=0.388) AND ACONC (r=0.326) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP(kW)+LTS(kW) (r=0.418), APP(KW) (r=0.418) and CON.RMS (r=0.412) have good correlations with the dependent variable (Figure 8.7 & Figure 8.8).

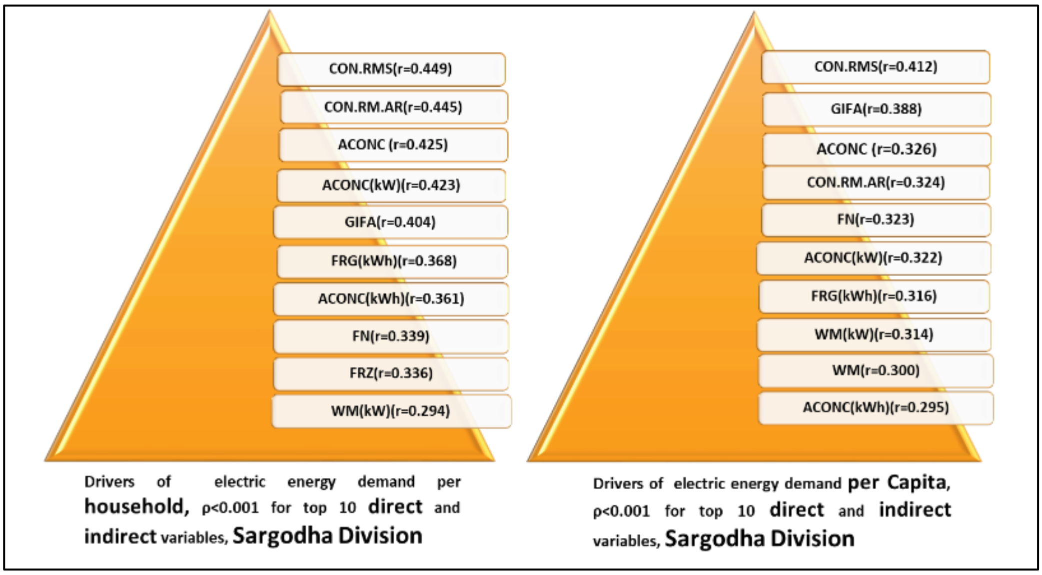


Figure 8.7 Hierarchical presentation of electricity demand drivers per household and per capita in Sargodha division, Punjab for direct and indirect variables

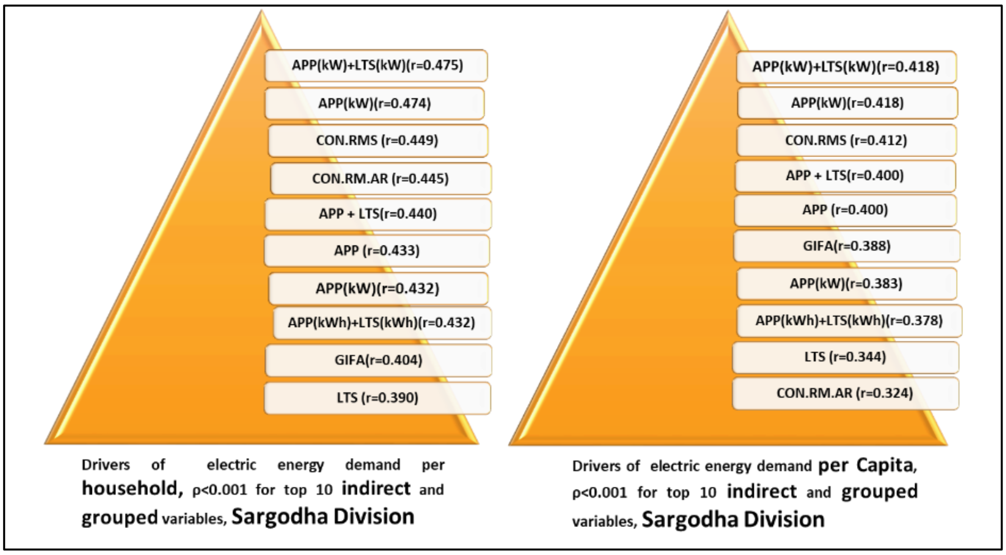


Figure 8.8 Hierarchical presentation of electricity demand drivers per household and per capita in Sargodha division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-1. It shows the strongest correlation is with the total number of APP (kW)+LTS (kW)(r=0.475) for the per household model, and with an installed electrical capacity of the appliances and lights, APP (kW)+LTS (kW) (r=0.418) for the per capita model.

Per household and capita(gas): Acceptable gas correlations are only to the size of the house (GIFA), where r= 0.653 & 0.730 for the per household and capita models, respectively. The other variable, i.e. occupancy of the house does not show any reasonable correlation with the dependent variable; it is close to zero.

8.4.2 Energy usage intensity (EUI) of Sargodha division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix B-3-1):

- The average household electric and gas energy use is around 1758.2 kWh/a and 1681 kWh/a respectively.
- Per capita, the average energy use is 248.8 kWh/capita/a and 239 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 19 kWh/m^2/a and 17 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 2.8kWh/m^2/capita/a and 2.6 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are large in both per household and per capita models.

8.4.3 Energy consumption prediction models of Sargodha division

Descriptive Statistics of final predictive variables selected for the Sargodha division are presented in Appendix C-Sargodha-1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-1 and Appendix C-Sargodha-2

8.4.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2=0.253**, RMSE= 908.9, strongest predictive variable =**ACONC** (**β**=0.286, p<0.001)

$\bar{Y}$= 916.1+4.35*(GIFA) +100.1*(FN) +797.1*(ACONC) (1)

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.264**, RMSE= 902.6, strongest predictive variable = **APP(Kw)+LTS(KW)** (**β**=0.265, p<0.001)

$\bar{Y}$= 1046.5 + 3.23*(GIFA) +295.5*(APP(KW)+LTS(KW) +38.72*(CON.RM.AR) (2)

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.289**, RMSE= 905.7, strongest predictive variable = **APP(kW)+LTS(kW)** (**β**=0.378, p<0.001)

$\bar{Y}$= 869.8 + 4.1*(GIFA) +414.6 *(APP(KW)+LTS(kW) (3)

8.4.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.259**, RMSE= 135.1, strongest predictive variable = **CON.RMS /capita** (**β**=0.243, p<0.001)

$\bar{Y}$= 48.1 + 4.61*(GIFA) +471.8*(WM) + 470.2*(CON.RMS) (4)

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.303**, RMSE= 138.5, strongest predictive variable = **APP (kW)+LTS (kW)/capita** (**β**=0.319, p<0.001)

$\bar{Y}$= 112.84 + 5.17*(GIFA/capita) + 389.3*(APP (kW)+LTS (kW)/capita) (5)

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.246**, RMSE= 136.3, strongest predictive variable =**GIFA/capita** (**β**=0.273, p<0.001)

$\bar{Y}$= 90.1 + 4.9*(GIFA/capita) + 396.4*(WM/ capita + 267.4*(APP (kW)+LTS (kW)/capita) (6)

8.4.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: (R^2= 0.425, RMSE= 1610.2), strongest predictive variable =GIFA (**β**=0.653, p<0.001)

$\bar{Y}$= -627.1 + 23.1*(GIFA) (7)

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: (R^2= 0.531, RMSE= 212.5), strongest predictive variable =GIFA/capita (**β**=0.730, p<0.001)

$\bar{Y}$= -73.31 + 21.85*(GIFA/capita) (8)

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.5 Appendix-C-Rawalpindi (demand drivers & prediction models)

The house sizes covered in the survey range from 20.9m^2 to 418$m^{2,}$ which covers the dominant house sizes in the Rawalpindi division. The average house size is 109.4$m^{2,}$ and the house size of 41.8m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 17.5m^2. The minimum and maximum values of m^2 per capita are 5.9m^2 and 66.8$m^{2,}$ respectively (Appendix-C-1). These variations show the data set covers the full range of Rawalpindi division and provides further confidence in the general application of the findings.

8.5.1 Domestic demand drivers of Rawalpindi division

Per household (electricity): The results of modelling the **direct and indirect** variables per household show CON.RMS (r=0.519), GIFA (r=0.446) and ACONC (kWh) (r=0.4112) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show CON.RMS (r=0.519), APP(kWh)+LTS(kWh) (r=0.461) and APP(kW)+LTS(kW) (r=0.454) have a good correlation with the dependent variable (Figure 8.9 & Figure 8.10).

Per Capita (electricity): The results of modelling the **direct and indirect** variables per capita show FN (kWh) (r=0.422), CON.RMS (r=0.381) and FN (r=0.367) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP(kWh)+LTS(kWh) (r=0.457), APP(kW)+LTS(kW) (r=0.446) and APP(kW) (r=0.434) have good correlations with the dependent variable (Figure 8.9 & Figure 8.10).

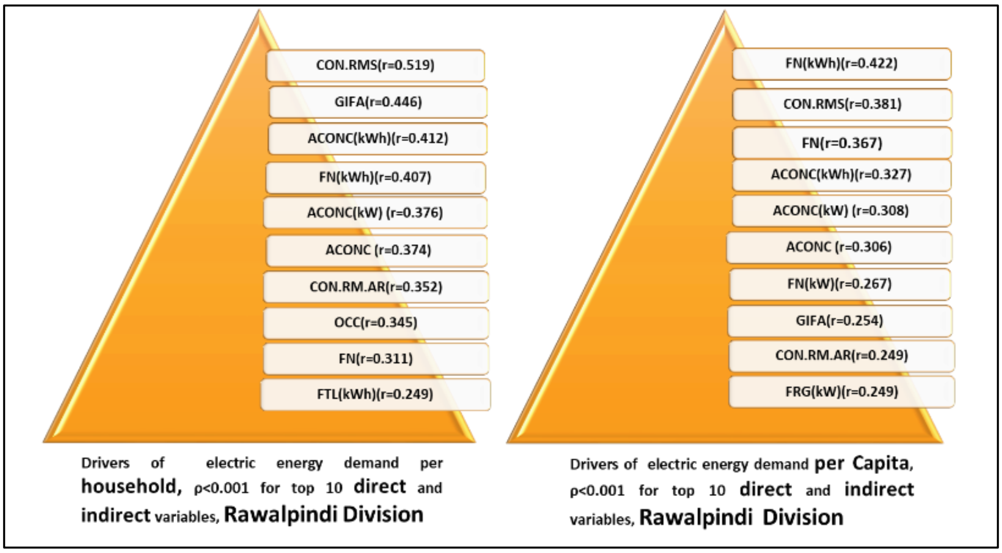


Figure 8.9 Hierarchical presentation of electricity demand drivers per household and per capita in Rawalpindi division, Punjab for direct and indirect variables

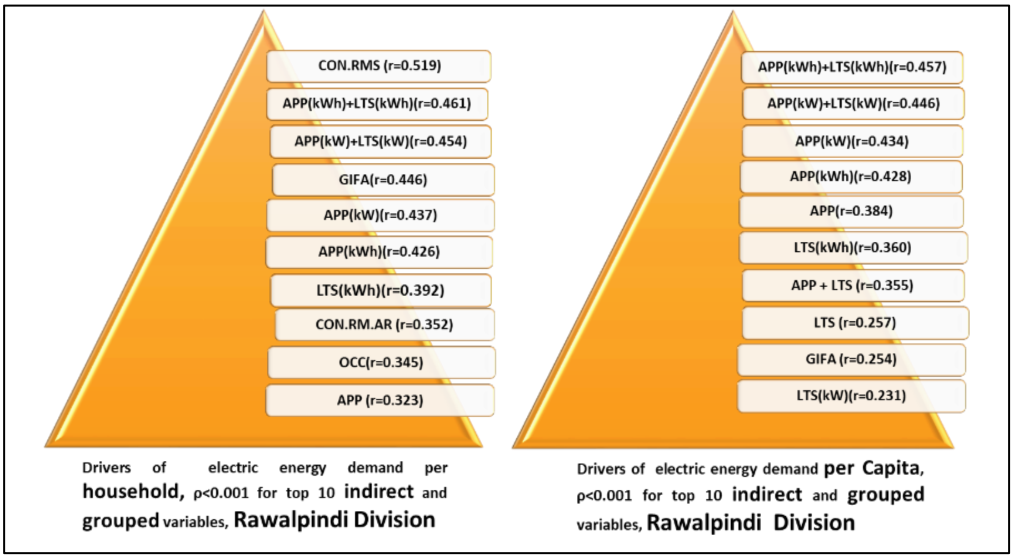


Figure 8.10 Hierarchical presentation of electricity demand drivers per household and per capita in Rawalpindi division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables is presented in Appendix C-2, which shows the strongest correlation is with the total number of CON.RMS (r=0.519) for the per household model, and with an installed electrical capacity of the appliances and lights, APP (kWh)+LTS (kWh) (r=0.457) for the per capita model.

Per household and capita (gas): Acceptable gas correlations are with (GIFA) and occupancy (OCC), where r= 0.175 & 0.181 for the per household, and capita models GIFA is an only predictable variable where r=0.044.

8.5.2 Energy usage intensity (EUI) of Rawalpindi division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix B-3-1):

- The average household electric and gas energy use is around 2317 kWh/a and 3771 kWh/a respectively.
- Per capita, the average energy use is 387.4 kWh/capita/a and 629.8 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 32 kWh/m^2/a and 67 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 5.5 kWh/m^2/capita/a and 11.9 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are significant in both per household and per capita models.

8.5.2.1 Energy consumption prediction models of Rawalpindi division

Descriptive Statistics of final predictive variables selected for the Rawalpindi division are presented in Appendix C-Rawalpindi-1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-1 and Appendix C-Rawalpindi-2

8.5.2.2 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2=0.393**, RMSE= 930.3, strongest predictive variable =**CON.RMS** (**β**=0.382, p<0.001)

$$\bar{Y} = 498.6 + 3.58 * GIFA + 562.5 * CON.RMS + 124.52 * FN \quad (1)$$

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.412**, RMSE= 961.2, strongest predictive variable = **GIFA** (**β**=0.344, p<0.001)

$$\bar{Y} = 872.2 + 5.44 * GIFA + 361.9 * LTS\ (kWh) + 399.2 * APP(KW)+LTS(KW) \quad (2)$$

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.410**, RMSE= 917.3, strongest predictive variable = **CON.RMS** (**β**=0.383, p<0.001)

$$\bar{Y} = 449.3 + 2.9 * GIFA + 563.7 * CON.RMS + 80.1 * FN + 254.2 * LTS\ (kWh) \quad (3)$$

8.5.2.3 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.317**, RMSE= 155.8, strongest predictive variable = **FN /capita** (**β**=0.433, p<0.001)

$$\bar{Y}\text{= 90.1 + 3.5 * GIFA + 141.5* FN+ 476.5* CON.RMS} \quad (4)$$

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.352**, RMSE= 160.4, strongest predictive variable = **APP/capita** (**β**=0.333, p<0.001)

$$\bar{Y}\text{= 143.8 + 5.9 * GIFA + 83.9 * APP + 53.7 * APP (kWh)+ LTS (kWh)} \quad (5)$$

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.326**, RMSE= 154.8, strongest predictive variable =**FN/capita** (**β**=0.361, p<0.001)

$$\bar{Y}\text{= 100.9 + 3.31* GIFA + 117.8* FN + 377.5* CON.RMS + 35.9 * APP (kWh)+ LTS (kWh)} \quad (6)$$

8.5.2.4 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: (R^2= 0.027, RMSE= 4405.6), strongest predictive variable =OCC (**β**=0.125, p<0.001)

$$\bar{Y}\text{= 1136.6 + 5.8*GIFA + 344.8*OCC} \quad (7)$$

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: (R^2= -0.006, RMSE= 708.1), strongest predictive variable =GIFA/capita (**β**=0.044, p<0.001)

$$\bar{Y}\text{= 598.4 + 2.61*(GIFA/capita)} \quad (8)$$

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.6 Appendix-C-Sahiwal (demand drivers & prediction models)

The house sizes covered in the survey range from 20.9m^2 to 418m^{2,} which covers the dominant house sizes in the Sahiwal division. The average house size is 109.4m^{2,} and the house size of 41.8m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 17.5m^2. The minimum and maximum values of m^2 per capita are 5.9m^2 and 66.8m^{2,} respectively (Appendix-C-1). These variations show the data set covers the full range of Rawalpindi division and provides further confidence in the general application of the findings.

8.6.1 Domestic demand drivers of Sahiwal division

Per household (electricity): The results of modelling the **direct and indirect** variables per household show CON.RMS (r=0.589), GIFA (r=0.559), and CON.RM.AR (r=0.538) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show, APP+LTS (r=0.643) , APP(kW)+LTS(kW) (r=0.641) and APP(kWh) (r=0.621) have a good correlation with the dependent variable (Figure 8.11 & Figure 8.12).

Per Capita (electricity): The results of modelling the **direct and indirect** variables per capita show APP (r=0.659), CON.RM.AR (r=0.617) and CON.RMS (r=0.589) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP(kW)+LTS(kW) (r=0.578), APP(kW) (r=0.563) and APP (r=0.557) have good correlations with the dependent variable (Figure 8.11 & Figure 8.12).

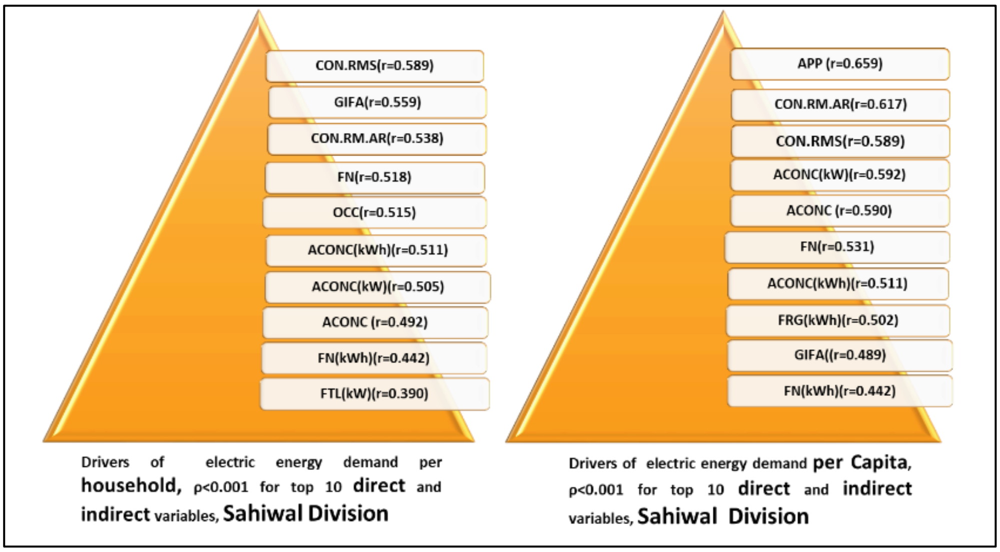


Figure 8.11 Hierarchical presentation of electricity demand drivers per household and per capita in Sahiwal division, Punjab for direct and indirect variables

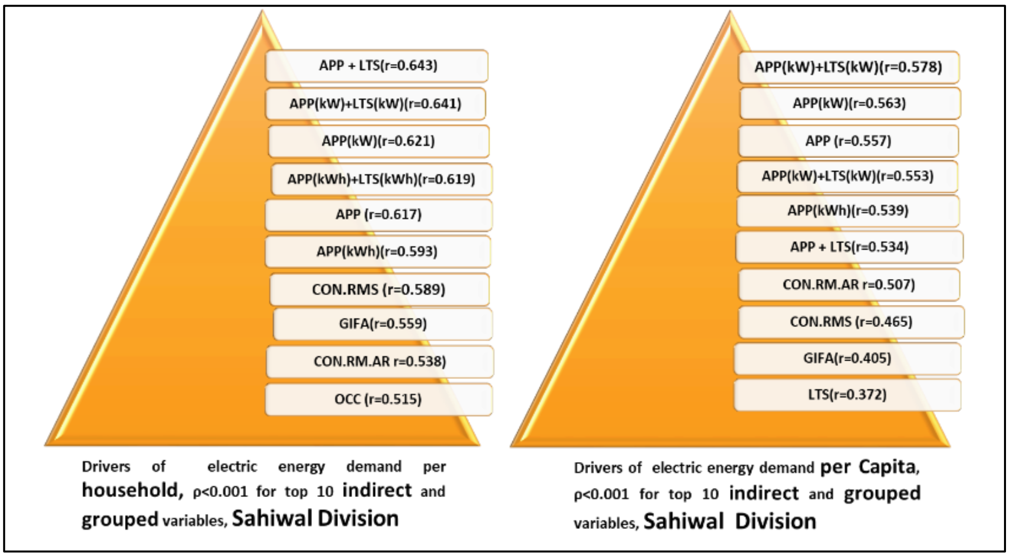


Figure 8.12 Hierarchical presentation of electricity demand drivers per household and per capita in Sahiwal division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-2, which shows the strongest correlation is with the total number of APP+LTS (r=0.643) for the per household model, and with an installed electrical capacity of the appliances and lights, APP (kW)+LTS (kW) (r=0.578) for the per capita model.

Per household and capita (gas): Acceptable gas correlations are only to the size of the house (GIFA), where r= 0.289 & 0.451 for the per household and capita models, respectively. The other variable, i.e. occupancy of the house does not show any reasonable correlation with the dependent variable; it is close to zero.

8.6.2 Energy usage intensity (EUI) of Sahiwal division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix C-3-2):

- The average household electric and gas energy use is around 2588.1 kWh/a and 4964 kWh/a respectively.
- Per capita, the average energy use is 410.5 kWh/capita/a and 806.1 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 26 kWh/m^2/a and 48 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 4.7kWh/m^2/capita/a and 8.4 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are large in both per household and per capita models.

8.6.3 Energy consumption prediction models of Sahiwal division

Descriptive Statistics of final predictive variables selected for the Sahiwal division are presented in Appendix C- Sahiwal -1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-2 and Appendix C- Sahiwal -2

8.6.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2=0.575}$, RMSE= 917.8, strongest predictive variable =**FN** (**β**=0.242, p<0.001)

$$\bar{Y} = 53.37 + 71.1*OCC + 4.8*GIFA + 171.1*FN + 35.4*ACONC(kWh) + 305.9*MW\ (kWh) + 1806.52*FTL(KW) + 280.6*CON.RMS \quad (1)$$

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.559}$, RMSE= 952.5, strongest predictive variable = **APP(KW)+LTS(KW)** (**β**=0.308, p<0.001)

$$\bar{Y} = 282.5 + 67.1*OCC + 5.1*GIFA + 36.5*(APP+LTS) + 238.3 * APP(KW)+LTS(KW) \quad (2)$$

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.566**, RMSE= 928.2, strongest predictive variable = **CON.RMS** (**β**=0.293, p<0.001)

$$\bar{Y} = 138.6 + 5.4 * GIFA + 123.3 *FN + 311.3 * MW\ (kWh) + 360.3 * CON.RMS$$

+ 30.9 * (APP+LTS) **(3)**

8.6.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.391**, RMSE= 148.8, strongest predictive variable = **CON.RM.AR /capita** (**β**=0.301, p<0.001)

$\bar{Y}$**= 160.7 + 4.2*GIFA + 1499.2 *FN(KW) + 235.7 * CON.RMS + 55.7 * CON.RM.AR** **(4)**

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.411**, RMSE= 149.9, strongest predictive variable = **APP (kWh)+LTS (kWh)/capita** (**β**=0.504, p<0.001)

$\bar{Y}$**= 171.8 + 4.3*GIFA + 63.9 * APP (kWh)+LTS (kWh)** **(5)**

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.410**, RMSE= 146.5, strongest predictive variable =**CON.RM.AR/capita** (**β**=0.220, p<0.001)

$\bar{Y}$**= 132.3 + 4.2 * GIFA + 1431.1* FN(KW) + 221.1* CON.RMS + 40.7 * CON.RM.AR**
+ 17.7 * APP(KW)+LTS(KW) **(6)**

8.6.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: R^2= 0.077, RMSE= 4070.8, strongest predictive variable =GIFA (**β**=0.289, p<0.001)

$\bar{Y}$**= 2874.9 + 18.12*GIFA** **(7)**

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: R^2= -0.198, RMSE= 611.4, strongest predictive variable =GIFA/capita (**β**=0.451, p<0.001)

$\bar{Y}$**= 350.52 + 25.4*(GIFA/capita)** **(8)**

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.7 Appendix-C-Multan (demand drivers & prediction models)

The house sizes covered in the survey range from 20.9m^2 to 418$m^{2,}$ which covers the dominant house sizes in the Multan division. The average house size is 121.8$m^{2,}$ and the house size of 104.5m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 17.7m^2. The minimum and maximum values of m^2 per capita are 6.3m^2 and 104.5$m^{2,}$ respectively (Appendix-C-1). These variations show the data set covers the full range of Punjab society and provide further confidence in the general application of the findings

8.7.1 Domestic demand drivers of Multan division

Per household (electricity): The results of modelling the **direct and indirect** variables per household show ACONC (r=0.691), ACONC (kW) (r=0.664), and FRG (kWh) (r=0.645) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP (kW)+LTS(kW) (r=0.774) , APP(KW) (r=0.773) and APP(kWh) (r=0.727) have a good correlation with the dependent variable (Figure 8.13 & Figure 8.14).

Per Capita (electricity): The results of modelling the **direct and indirect** variables per capita show ACONC (kW) (r=0.700), ACONC (kW) (r=0.670) and OCC (r=0.664) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show APP(kW) (r=0.764), APP(kW)+LTS(kW) (r=0.760) and APP(kWh) (r=0.686) have good correlations with the dependent variable (Figure 8.13 & Figure 8.14).

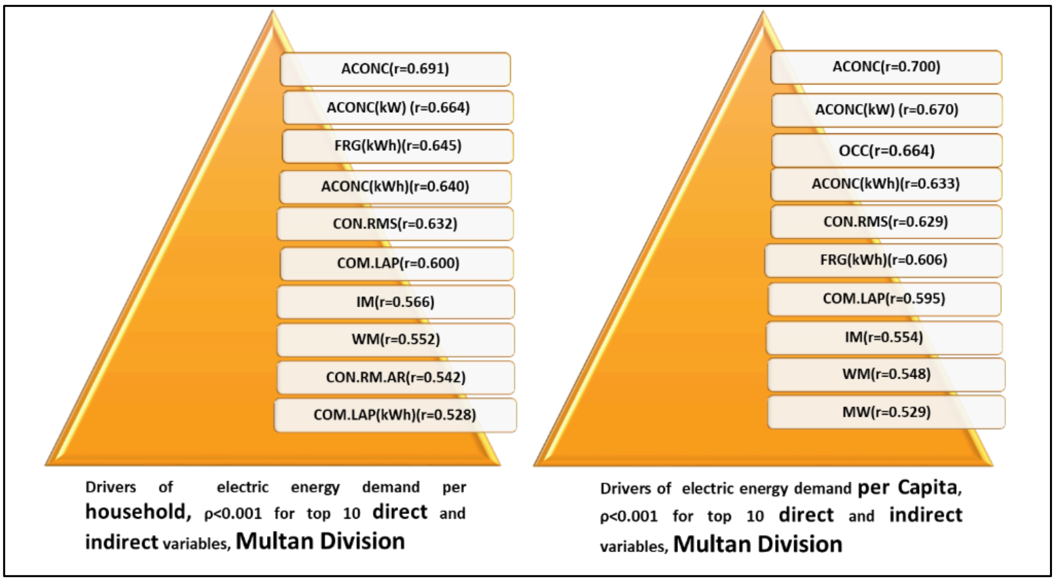


Figure 8.13 Hierarchical presentation of electricity demand drivers per household and per capita in Multan division, Punjab for direct and indirect variables

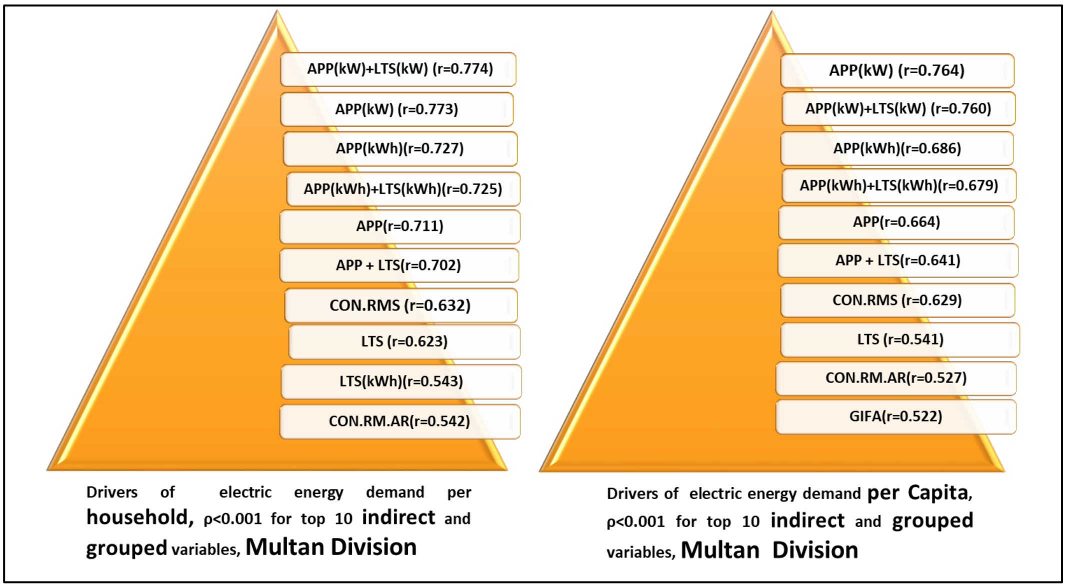


Figure 8.14 Hierarchical presentation of electricity demand drivers per household and per capita in Multan division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-2. It shows the strongest correlation is with the total number of APP (kW)+LTS (kW)(r=0.774) for the per household model, and with an installed electrical capacity of the appliances and lights, APP (kW) (r=0.764) for the per capita model.

Per household and capita (gas): Acceptable gas correlations are (GIFA) and occupancy (OCC), where r= 0.121 & 0.239 for the per household. Per capita models, acceptable gas correlations are (GIFA), where r= 0.163

8.7.2 Energy usage intensity (EUI) of Multan division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix C-3-2):

- The average household electric and gas energy use is around 1634.2 kWh/a and 5382 kWh/a respectively.
- Per capita, the average energy use is 241.5 kWh/capita/a and 726.7 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 14 kWh/m^2/a and 51 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 2.3kWh/m^2/capita/a and 7.1 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are large in both per household and per capita models.

8.7.3 Energy consumption prediction models of Multan division

Descriptive Statistics of final predictive variables selected for the Multan division are presented in Appendix C-Multan-1, and the strengths and predictive coefficients of six electric and two gas models are presented in Appendix C-4-2 and Appendix C-Multan-2

8.7.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each individual variables, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2=0.660**, RMSE= 659.8, strongest predictive variable =**CON.RMS** (**β**=0.271, p<0.001)

$\bar{Y}$= 258 + 1.7 *GIFA + 271.2 * ACONC + 399.1* WM + 506.6 * VC + 686.8*FRG(KW) + 1328.8 * TV(KW) + 1505.1 * COM/LAP(KW) + 1229.4 * EF(kWh) + 285.8 * CON.RMS (1)

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.616**, RMSE= 700.4, strongest predictive variable = **APP(KW)+LTS(KW)** (**β**=0.588, p<0.001)

$\bar{Y}$= 584.9 + 2.1* GIFA + 397.5 * APP(KW)+LTS(KW) + 185.1 * CON.RMS (2)

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.662**, RMSE= 657.8, strongest predictive variable = **APP(KW)+LTS(KW)** (**β**=0.272, p<0.001)

$\bar{Y}$= 313.4 + 1.9* GIFA + 299.7 * WM + 605.4 * FRG(KW) + 1071.4 * TV(KW) + 1155.2 * COM/LAP(KW) + 983.8 * EF(kWh) + 279.1 * CON.RMS + 183.9 * APP(KW)+LTS(KW) (3)

8.7.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.691**, RMSE= 99.5, strongest predictive variable = **CON.RMS /capita** (**β**=0.321, p<0.001)

$\bar{Y}$= 45.7 + 2.5 * GIFA + 258.9 * ACONC + 130.2 * TV + 109.5 * EF + 423.1* WM + 711.9 * FRG(KW) + 923.9 *COM/LAP(KW) + 977.7 * VC(KW) + 219.5*MW(kWh) + 292.7* CON.RMS (4)

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.666**, RMSE= 103.4, strongest predictive variable = **APP (kW)/ capita** (**β**=0.575, p<0.001)

$\bar{Y}$= 76.4 + 2.7* GIFA + 417.9* APP(KW) + 224.5 * CON.RMS (5)

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.693**, RMSE= 99.2, strongest predictive variable = **APP(KW)+LTS(KW)/capita** (**β**=0.220, p<0.001)

$\bar{Y}$= 48.3 + 2.6* GIFA + 349.3*WM + 634.9 *FRG(KW) + 811.8* VC(KW) + 264.9* CON.RMS + 253.4 * APP(KW)+LTS(KW) (6)

8.7.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: R^2= 0.056, RMSE= 4264.8, strongest predictive variable =OCC (**β**=0.223, p<0.001)

$\bar{Y}$= 1241.9 + 3.9*GIFA + 492.9 *OCC (7)

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: R^2= -0.024, RMSE= 594.5, strongest predictive variable =GIFA/capita (**β**=0.163, p<0.001)

$\bar{Y}$= 582.9 + 8.9*(GIFA/capita) (8)

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.8 Appendix-C-Bahawalpur (demand drivers & prediction models)

The house sizes covered in the survey range from 20.9m^2 to 418m^{2,} which includes the dominant house sizes in the Bahawalpur division. The average house size is 150.6m^{2,} and the house size of 104.5m^2 is the most surveyed house in the data set shown in Appendix-C-1. The average size available per capita is 20.7m^2. The minimum and maximum values of m^2 per capita are 5.2m^2 and 83.6m^{2,} respectively (Appendix-C-1). These variations show the data set covers the full range of Bahawalpur division and provide further confidence in the general application of the findings

8.8.1 Domestic demand drivers of Bahawalpur division

Per household (electricity): The results of modelling the **direct and indirect** variables per household show CON.RMS (r=0.746), CON.RM.AR (r=0.586) and ACONC (r=0.493) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per household show CON.RMS (r=0.746), CON.RM.AR (r=0.586) and APP(kW)+LTS(kW) (r=0.496) have a good correlation with the dependent variable (Figure 8.15 & Figure 8.16).

Per capita (electricity): The results of modelling the **direct and indirect** variables per capita show CON.RMS (r=0.723), CON.RM.AR (r=0.550) and ACONC (r=0.467) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show CON.RMS (r=0.723), CON.RM.AR (r=0.550) and APP(kW)+LTS(kW) (r=0.488) have good correlations with the dependent variable (Figure 8.15 & Figure 8.16).

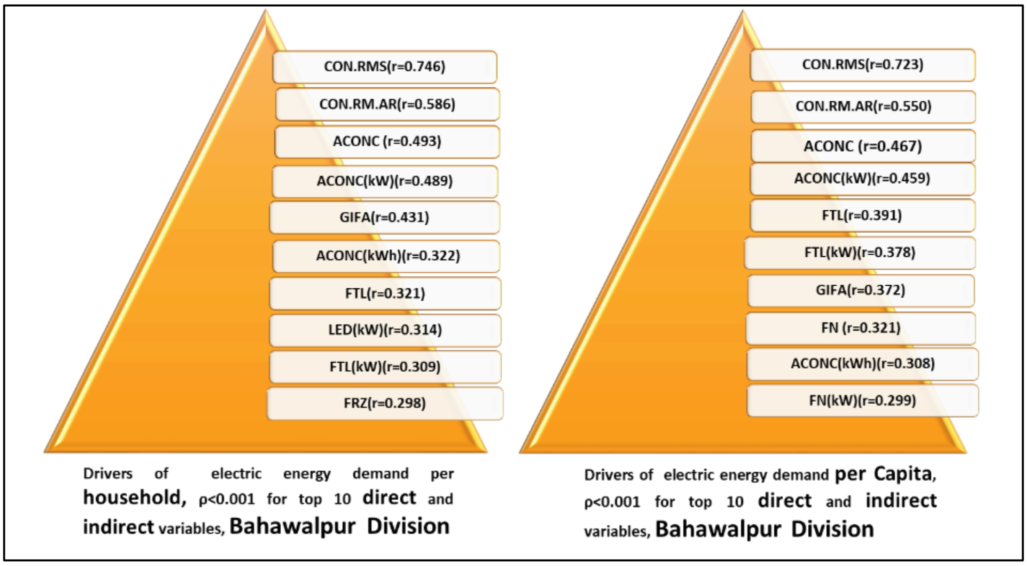


Figure 8.15 Hierarchical presentation of electricity demand drivers per household and per capita in Bahawalpur division, Punjab for direct and indirect variables

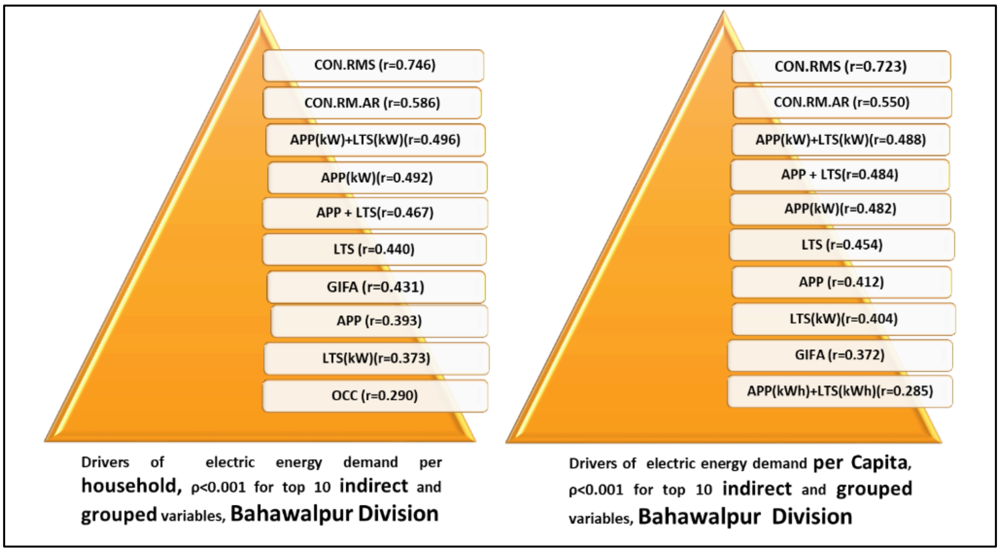


Figure 8.16 Hierarchical presentation of electricity demand drivers per household and per capita in Bahawalpur division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables is presented in Appendix C-2-2, which shows the strongest correlation is with the total number of CON.RMS (r=0.746) for the per household model, and with an installed electrical capacity of the appliances and lights, CON.RMS (r=0.723) for the per capita model.

Per household and capita (gas): Acceptable gas correlations are only to the size of the house (GIFA), where r= 0.422 & 0.400 for the per household and capita models, respectively. The other variable, i.e. occupancy of the house does not show any reasonable correlation with the dependent variable; it is close to zero.

8.8.2 Energy usage intensity (EUI) of Bahawalpur division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix C-3-2):

- The average household electric and gas energy use is around 2961.3 kWh/a and 2527 kWh/a respectively.
- Per capita, the average energy use is 415.4 kWh/capita/a and 362.8 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 23 kWh/m^2/a and 20 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 3.6kWh/m^2/capita/a and 3.4 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are large in both per household and per capita models.

8.8.3 Energy consumption prediction models of Bahawalpur division

Descriptive Statistics of final predictive variables selected for the Bahawalpur division are presented in Appendix C- Bahawalpur -1, and the strengths, and predictive coefficients of six electric and two gas models are shown in Appendix C-4-2 and Appendix C- Bahawalpur -2

8.8.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**=0.610**, RMSE= 1087.1, strongest predictive variable =**CON.RMS** (**β**=0.649, p<0.001)

$\bar{Y}$**= 169.9 + 68.1 * OCC + 3.7 * GIFA + 2375.3* FTL(KW) + 928.8* CON.RMS (1)**

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.382**, RMSE= 1391.5, strongest predictive variable = **APP(KW)+LTS(KW)** (**β**=0.437, p<0.001)

$\bar{Y}$**= 925.5 + 7.6 * GIFA + 367.3 * APP(KW)+LTS(KW) (2)**

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.635**, RMSE= 1051.7, strongest predictive variable = **CON.RMS** (**β**=0.669, p<0.001)

$\bar{Y}$**= 248.1 + 4.7 * GIFA + 2219.9 * FTL(KW) + 957.8 *CON.RMS + 47.2 * APP – 36.45 *APP(KW) (3)**

8.8.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.591**, RMSE= 148.5, strongest predictive variable = **CON.RMS /capita** (**β**=0.630, p<0.001)

$\bar{Y}$**= 53.5 + 3.62 * GIFA + 92.6 * FN + 1957.9* FTL(KW) + 879.9 * CON.RMS (4)**

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.350**, RMSE= 192.3, strongest predictive variable = **APP(KW)+LTS(KW)/capita** (**β**=0.326, p<0.001)

$\bar{Y}$**= 166.31 + 5.16* GIFA + 39.8 * LTS + 247.8 * APP(KW)+LTS(KW) (5)**

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.609**, RMSE= 145.2, strongest predictive variable = **CON.RMS/capita** (**β**=0.636, p<0.001)

$\bar{Y}$= 46.85 + 4.1* GIFA + 86.5 * FN + 2017.9* FTL(KW) + 888.8 * CON.RMS + 95.55 * APP(KW) – 32.38 * APP (kWh) (6)

8.8.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: R^2= 0.176, RMSE= 3303.1, strongest predictive variable =GIFA (**β**=0.422, p<0.001)

$\bar{Y}$= -222.9 + 18.17*GIFA (7)

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: R^2= -0.158, RMSE= 535.6, strongest predictive variable =GIFA/capita (**β**=0.400, p<0.001)

$\bar{Y}$= -59.45 + 20.58*(GIFA/capita) (8)

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

8.9 Appendix-C-Dera Ghazi Khan (demand drivers & prediction models)

The house sizes covered in the survey range from 41.8m^2 to 250m^{2,} which includes the dominant house sizes in the Dera Ghazi Khan division. The average house size is 103.6m^{2,} and the house size of 104.5m^2 is the most surveyed house in the data set shown in Appendix-B-1. The average size available per capita is 15.9m^2. The minimum and maximum values of m^2 per capita are 7.8m^2 and 125.4m^{2,} respectively (Appendix-C-1). These variations show the data set covers the full range of Dera Ghazi Khan division and provides further confidence in the general application of the findings.

8.9.1 Domestic demand drivers of Dera Ghazi Khan division

Per household (electricity): The results of modelling the **direct and indirect** variables per household show ACONC(kWh) (r=0.604), ACONC (r=0.597) and ACONC(kW) (r=0.594) have a good correlation with the dependent variable. The result of modelling **indirect and grouped** variables per household show APP(KW) (r=0.675), APP(kW)+LTS(kW) (r=0.673) and APP(kWh)(r=0.672) have a good correlation with the dependent variable (Figure 8.17 & Figure 8.18).

Per capita (electricity): The results of modelling the **direct and indirect** variables per capita show ACONC (kWh) (r=0.573), FRG (r=0.573) and ACONC (r=0.562) have a good correlation with the dependent variable. The results of modelling **indirect and grouped** variables per capita show

APP(kWh)(r=0.650) , APP(KW) (r=0.649) and APP(kW)+LTS(kW) (r=0.647) have good correlations with the dependent variable (Figure 8.17 & Figure 8.18).

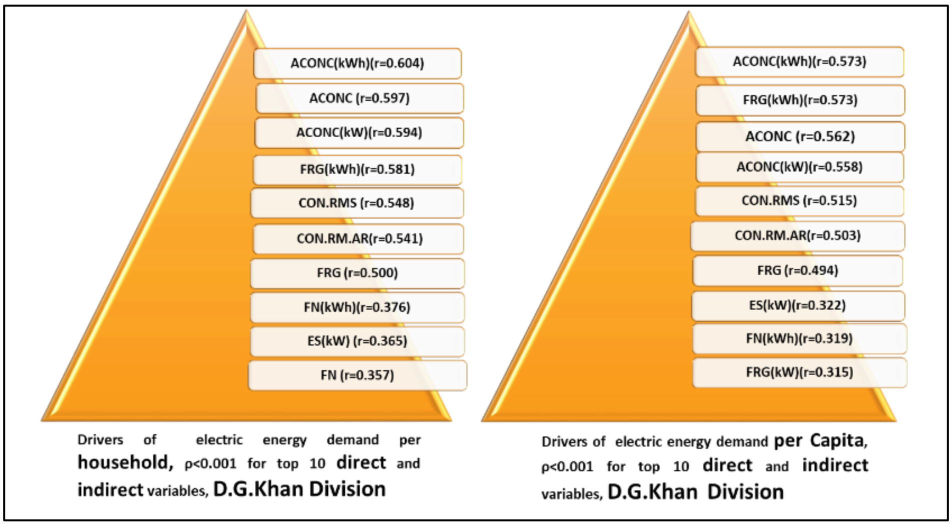


Figure 8.17 Hierarchical presentation of electricity demand drivers per household and per capita in D.G.Khan division, Punjab for direct and indirect variables

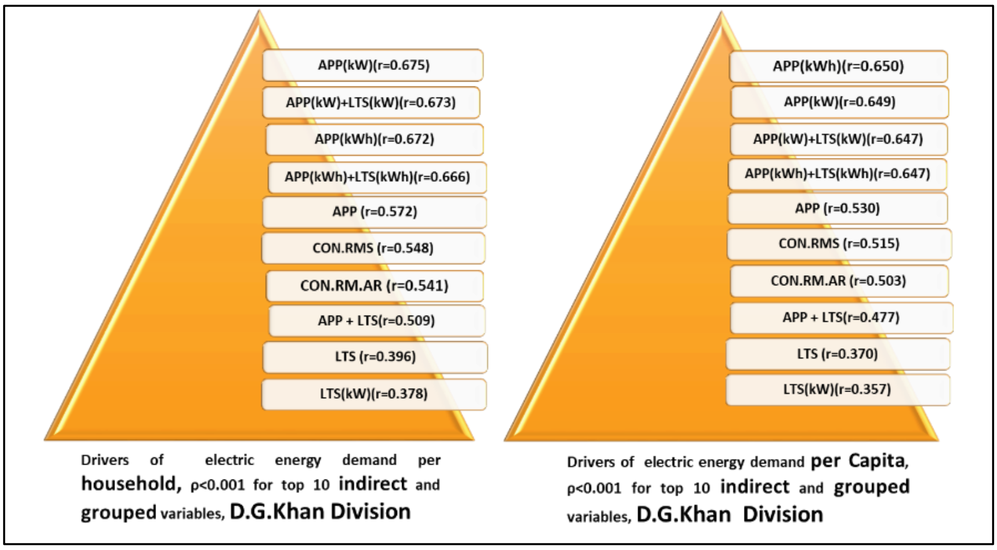


Figure 8.18 Hierarchical presentation of electricity demand drivers per household and per capita in D.G.Khan division, Punjab for indirect and grouped variables

The hierarchical relationship of drivers of electricity demand for **direct, indirect** and **grouped** variables are presented in Appendix C-2-2. It shows the strongest correlation is with the total number of APP(kW)(r=0.675) for the per household model, and with an installed electrical capacity of the appliances and lights, APP(kWh) (r=0.650) for the per capita model.

Per household and capita (gas): Acceptable gas correlations are occupancy (OCC), where r= 0.292 for the per household, and per capita model the acceptable variable is GIFA, where r= (0.073).

8.9.2 Energy usage intensity (EUI) of Dera Ghazi Khan division

Analysis of the average annual Energy Usage Intensity (EUI) reveals the following (appendix C-3-2):

- The average household electric and gas energy use is around 1568.9 kWh/a and 7125 kWh/a respectively.
- Per capita, the average energy use is 232.9 kWh/capita/a and 1041.5 kWh/capita/a for electricity and gas, respectively.
- The average energy use per m^2 per household is 16 kWh/m^2/a and 75 kWh/m^2/a for electricity and gas, respectively.
- The average energy use per m^2 per capita is 2.4kWh/m^2/capita/a and 11.2 kWh/m^2/capita/a for electricity and gas, respectively.
- The ranges of electric and gas demand are significant in both per household and per capita models.

8.9.3 Energy consumption prediction models of Dera Ghazi Khan division

Descriptive Statistics of final predictive variables selected for the Dera Ghazi Khan division are presented in Appendix C- Dera Ghazi Khan -1, and the strengths and predictive coefficients of six electric and two gas models are shown in Appendix C-4-2 and Appendix C- Dera Ghazi Khan -2

8.9.3.1 Annual electricity consumption prediction models per household analyses

A multiple regression analysis was done to develop refined models and to know the predictive strengths of each variable, and explained below in the following models:

Detailed model (direct and indirect variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2=0.533}$, RMSE= 787.8, strongest predictive variable =**FRG** (**β**=0.366, p<0.001)

$\bar{Y}$**= 616.1 + 728.6 * FRG + 1248.9* TV(KW) + 194.3* ACONC (kWh) + 53.43* CON.RM.AR (1)**

Grouped model (direct and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of $\mathbf{R^2= 0.484}$, RMSE= 828.2, strongest predictive variable = **APP (kWh)** (**β**=0.540, p<0.001)

$\bar{Y}$**= 809.4 + 139.1 * APP (kWh) + 56.1 * CON.RM.AR (2)**

Combined model (direct, indirect and grouped variables)

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of R^2**= 0.549**, RMSE= 774.1, strongest predictive variable = **APP(KW)** (**β**=0.441, p<0.001)

$\bar{Y}$**= 561.5 + 576.7 * FRG + 49.9 * CON.RM.AR + 586.2 * APP(KW) (3)**

8.9.3.2 Annual electricity consumption prediction models per capita analyses

Detailed model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.522**, RMSE= 113.5, strongest predictive variable = **ACONC (kWh) /capita** (**β**=0.353, p<0.001)

$\bar{Y}$= 40.35 + 675.7* FRG + 103.3* FN (kWh) + 206.8* ACONC (kWh) + 393.1 * CON.RMS (4)

Grouped model explained & equation:

Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.458**, RMSE= 124.5, strongest predictive variable = **APP (kWh) /capita** (**β**=0.678, p<0.001)

$\bar{Y}$= 130.28 + 167.33 * APP (kWh) (5)

Combined model explained & equation:

Equation: Where variables of the equations are known then the following equation is valid to an accuracy of **R^2= 0.537**, RMSE= 111.6, strongest predictive variable = **APP (kW)/capita** (**β**=0.411, p<0.001)

$\bar{Y}$= 29.48 + 574.3 * FRG + 396.4 * CON.RMS + 549.1 * APP(KW) (6)

8.9.3.3 Annual gas consumption prediction models of per household & per capita analyses

Gas per household model:

Equation: The equation for the prediction of annual gas consumption per household in kWh is: R^2= 0.081, RMSE= 3429.9, strongest predictive variable =GIFA (**β**=0.292, p<0.001)

$\bar{Y}$= 2016.7 + 738.7*GIFA (7)

Gas per capita model:

Equation: The equation for the prediction of annual gas consumption per capita in kWh/capita is: R^2= 0.001, RMSE= 522.1, strongest predictive variable =GIFA/capita (**β**=0.073, p<0.001)

$\bar{Y}$= 945.3 + 6.24*(GIFA/capita) (8)

Equations 1-8 present the regression coefficients from the study for all the models. If all independent variables are known, we can predict the dependent variable $\bar{Y}$.

Table 8.1 Appendix-C-1 Descriptive of samples house area for per household and capita

House area and per capita area of the sample houses																						
Values	**Whole Punjab**		**Lahore Division**		**Sheikhupura Division**		**Gujranwala Division**		**Faisalabad Division**		**Sargodha Division**		**Rawalpindi Division**		**Sahiwal Division**		**Multan Division**		**Bahawalpur Division**		**Dera Ghazi Khan Division**	
	House size (m^2)	Capita m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)	House size (m^2)	Capita (m^2)
Mean	109	17	115.1	19.5	87.1	18.4	82.3	12.9	128.9	22.5	105.5	15.1	109.4	17.5	117.9	17.9	121.76	17.7	150.6	20.7	103.6	15.9
Median	104.5	14.9	104.5	15.7	83.6	17.4	83.6	12.6	104.5	20.9	83.6	13.1	83.6	14.9	104.5	15.9	104.5	14.93	125.4	17.4	104.5	14.6
Mode	104.5	20.9	104.5	20.9	62.7	20.9	104.5	10.5	104.5	20.9	83.6	10.5	41.8	13.9	104.5	20.9	104.5	20.9	104.5	20.9	104.5	20.9
Std. Deviation	70.5	10.2	79.9	12.22	55.6	7.1	40.8	6.9	104.4	12.1	62.3	9.6	83.3	11.3	73.2	9.8	65.3	9.93	82.2	11.1	32.6	7.8
Minimum	20.9	2.9	20.9	5.97	20.9	6.3	20.9	2.9	20.9	5.9	41.8	3.8	20.9	5.9	20.9	4.8	20.9	6.27	20.9	5.2	41.8	7.8
Maximum	418	146.3	418	104.5	418	59.7	334.4	146.3	418	104.5	418	104.5	418	66.8	418	104.5	418	104.5	418	83.6	250	125.4
25%ile	62.7	11.9	62.7	11.9	62.7	13.9	41.8	10.5	62.7	14.5	418	104.5	41.8	10.5	62.7	12.5	83.6	12.54	104.5	13.1	83.6	11.9
50%ile	104.5	14.9	104.5	15.6	83.6	17.4	83.6	12.6	104.5	20.9	83.6	13.1	83.6	14.9	104.5	15.9	104.5	14.93	125.4	17.4	104.5	14.6
75%ile	125.4	20.9	125.4	20.9	104.5	20.9	104.5	15.7	167.2	26.2	104.5	15.7	125.4	20.9	146.3	20.9	125.4	20.9	209	25.1	125.4	17.9

Table 8.2 Appendix-C-2-1, Correlations of divisional models

Sr. No	Whole Punjab				Lahore Division				Sheikhupura Division			
	Model Electric kWh/yr. per Household		Model Electric kWh/yr. per Capita		Model Electric kWh/yr. per Household		Model Electric kWh/yr. per Capita		Model Electric kWh/yr. per Household		Model Electric kWh/yr. per Capita	
	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)
1	APP+LTS	0.636	APP (kW)	0.655	CON.RMS	0.651	APP (kW)+LTS (kW)	0.637	APP (kW)+LTS (kW)	0.840	APP (kW)+LTS (kW)	0.728
2	APP (kW)+LTS (kW)	0.629	APP (kW)+LTS (kW)	0.654	APP+LTS	0.635	APP(Kw)	0.627	APP(kW)	0.835	APP(kW)	0.724
3	APP	0.617	APP	0.637	APP (kW)+LTS (kW)	0.623	APP+LTS	0.586	APP	0.815	APP	0.669
4	APP (kW)	0.616	APP+LTS	0.626	ACONC (kW)	0.62	APP	0581	CON.RM.AR	0.806	CON.RM.AR	0.666
5	CON.RMS	0.604	APP(kWh)+LTS(kWh)	0.580	APP(Kw)	0.610	ACONC (kW)	0.578	APP+LTS	0.780	APP (kWh)+LTS(kWh)	0.628
6	LTS	0.556	ACONC (kW)	0.569	CON.RM.AR	0.598	CON.RMS	0.564	APP (KWh)+LTS(kWh)	0.751	APP+LTS	0.620
7	CON.RM.AR	0.554	ACONC	0.558	ACONC	0.59	ACONC	0.562	ACONC(kW)	0.738	ACONC(kW)	0.613
8	ACONC (kW)	0.553	APP (kWh)	0.566	LTS	0.583	CON.RM.AR	0.546	APP(kWh)	0.734	APP(kWh)	0.612
9	ACONC	0.543	CON.RMS	0.550	APP	0.576	ACONC (kWh)	0.516	CON.RMS	0.715	ACONC	0.573
10	APP (kWh)+LTS(kWh)	0.537	CON.RM.AR	0.538	GIFA	0.548	APP (kWh)+LTS(KWh)	0.480	ACONC	0.701	ACONC(kWh)	0.534
11	LTS (kW)	0.525	ACONC (kWh)	0.524	ACONC (kWh)	0.524	APP(Kwh)	0.474	GIFA	0.695	EF	0.481
12	APP (kWh)	0.514	LTS	0.504	LTS(Kw)	0.514	LTS	0.470	ACONC(kWh)	0.697	EF(kWh)	0.471
13	ACONC (kWh)	0.504	LTS (kW)	0.485	APP (kWh)+LTS(kWh)	0.478	GIFA	0.433	LTS(kW)	0.651	GIFA	0.459
14	GIFA	0.466	FTL	0.454	APP(Kwh)	0.455	LTS(Kw)	0.424	LTS(kWh)	0.631	LTS(kWh)	0.435
15	LTS (kWh)	0.437	FTL (kW)	0.412	LTS(Kwh)	0.433	FN	0.335	LTS	0.623	DEH(kW)	0.434
16	MW	0.390	GIFA	0.401	FN	0.41	LTS(Kwh)	0.352	FN(kW)	0.618	EF(kW)	0.419
17	MW (kW)	0.377	EF	0.400	LED	0.397	MW	0.323	OCC	0.596	DEH	0.417
18	FN	0.362	MW	0.392	OCC	0.377	EF	0.318	MW(kW)	0.583	LTS(kW)	0.413
19	COM.LAP	0.358	FTL (kWh)	0.388	COM.LAP	0.363	LED	0.316	EF	0.575	FTL(kWh)	0.403
20	FTL	0.350	LTS (kWh)	0.384	MW	0.361	LED(Kw)	0.310	FTL(kWh)	0.573	DEH(kWh)	0.401
21	FTL (kW)	0.350	WM	0.370	LED(KW)	0.359	-	-	FTL	0.566	MW(kW)	0.400
22	MW (kWh)	0.343	MW (kW)	0.355	MW (kW)	0.340	-	-	FTL(kW)	0.564	FTL	0.399
23	FTL (kWh)	0.333	FRG	0.350	EF	0.340	-	-	MW(kWh)	0.561	FTL(kW)	0.399
24	OCC	0.332	TV	0.348	IM	0.329	-	-	DEH(kW)	0.535	CON.RMS	0.395
25	FRG	0.330	EF (kW)	0.344	WM(Kw)	0.322	-	-	MW	0.533	WM(kWh)	0.394
26	TV	0.329	FRG (kWh)	0.346	TV	0.320	-	-	EF(kWh)	0.530	MW(kWh)	0.390
27	FN (kWh)	0.325	FN	0.326	ES	0.314	-	-	EF(kW)	0.515	FN(kW)	0.383
28	LED/SMD	0.318	FRG (kW)	0.325	FN(kW)	0.310	-	-	FN	0.514	LTS	0.378
29	ES	0.315	FN (kWh)	0.324	EF	0.309	-	-	DEH	0.510	MW	0.368
30	EF	0.311	MW (kWh)	0.319					DEH(kWh)	0.501	FN(kWh)	0.317
31	COM.LAP (kW)	0.300	TV (kWh)	0.317					FRG(kW)	0.499	WM(kW)	0.310
32	-	-	DEH	0.314	EF(Kw)	0.308	-	-	WM(kWh)	0.498	FRG(kW)	0.305
33	-	-	DEH (kW)	0.309	COM.LAP (kW)	0.303	-	-	FN(kWh)	0.468	-	-
34									WM(KW)	0.467	-	-
35									TV	0.429	-	-
36									FRZ(kW)	0.411	-	-
37									WM	0.386	-	-
38									TV(kWh)	0.381	-	-
39									SEF(kWh)	0.378	-	-
40									FRZ(kWh)	0.373	-	-
41									FRZ	0.359	-	-
42									SEF	0.352	-	-
43									SEF(kW)	0.347	-	-
44									FRG	0.315	-	-

Sr. No	Gujranwala Division				Faisalabad Division				Sargodha Division			
	Model Electric kWh/yr. per Household		Model Electric kWh/yr. per Capita		Model Electric kWh/yr. per Household		Model Electric kWh/yr. per Capita		Model Electric kWh/yr. per Household		Model Electric kWh/yr. per Capita	
	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)
1	APP+LTS	0.521	APP	0.570	APP	0.886	ACONC(kWh)	0.838	APP (kW)+LTS (kW)	0.475	APP (kW)+LTS (kW)	0.418
2	APP	0.497	APP+LTS	0.569	APP+LTS	0.882	CON.RM.AR	0.837	APP(kW)	0.474	APP(kW)	0.418
3	OCC	0.494	FN(kWh)	0.512	APP (kW)+LTS (kW)	0.874	ACONC(kW)	0.592	CON.RMS	0.449	CON.RMS	0.412
4	FN(kW)	0.492	FN(kW)	0.494	APP(kW)	0.866	ACONC	0.590	CON.RM.AR	0.443	APP+LTS	0.409
5	FN(kWh)	0.484	APP (kWh)+LTS(kWh)	0.493	APP (kWh)+LTS(kWh)	0.864	GIFA	0.546	APP+LTS	0.440	APP	0.408
6	APP (kWh)+LTS(kWh)	0.477	FN	0.486	APP(kWh)	0.844	MW(kWh)	0.531	APP	0.433	GIFA	0.388
7	FN	0.46	LTS(kW)	0.476	LTS(kW)	0.818	IM	0.513	APP(kWh)	0.432	APP(kWh)	0.383
8	LTS(kW)	0.449	LTS	0.449	LTS	0.815	ES(kWh)	0.502	APP (kWh)+LTS(kWh)	0.432	APP (kWh)+LTS(kWh)	0.378
9	LTS(kWh)	0.437	APP (kW)+LTS (kW)	-	ACONC(kWh)	0.811	IM(kW)	0.480	ACONC	0.425	LTS	0.344
10	LTS	0.428	APP(kWh)	0.428	ACONC	0.785	MW	0.471	ACONC(kW)	0.423	ACONC	0.326
11	APP(kWh)	0.382	FTL(kWh)	0.422	LTS(kWh)	0.782	EF(kWh)	0.467	GIFA	0.404	CON.RM.AR	0.324
12	ES(kW)	0.376	FRG(kW)	0.421	CON.RMS	0.781	ES(kW)	0.466	LTS	0.390	FN	0.323
13	ES(kWh)	0.376	TV(kWh)	0.416	ACONC(kW)	0.779	MW(kW)	0.465	FRG(kWh)	0.368	ACONC(kW)	0.322
14	CON.RM.AR	0.359	APP(kW)	0.413	CON.RM.AR	0.776	FN	0.462	ACONC(kWh)	0.361	FRG(kWh)	0.316
15	GIFA	0.347	GIFA	0.411	GIFA	0.773	EF(kW)	0.461	FN	0.339	WM(kW)	0.314
16	ES	0.344	WM(kW)	0.411	OCC	0.741	ES	0.459	FRZ	0.336	WM	0.308
17	APP (kW)+LTS (kW)	0.34	FTL(kW)	0.407	ES(kW)	0.734	FN(kWh)	0.453				
18	-	-	LTS(kWh)	0.405	ES	0.726	CON.RMS	0.440				
19	-	-	WM	0.390	IM	0.723	FTL(kWh)	0.435				
20	-	-	FTL	0.387	FN	0.716	EF	0.428				
21	-	-	TV	0.370	ES(kWh)	0.693	COM.LAP(kW)	0.407				
22	-	-	CON.RM.AR	0.313	COM.LAP	0.691	COM.LAP	0.406				
23	-	-	COM.LAP(kWh)	0.303	COM.LAP(kW)	0.691	FTL(kW)	0.401				
24					IM(kW)	0.688	FTL	0.394				
25					MW(kWh)	0.637	IM(kWh)	0.391				
26					FN(kWh)	0.633	FRG(kW)	0.362				
27					MW	0.613	FRG(kWh)	0.337				
28					FTL (kWh)	0.611	FN(kW)	0.326				
29					MW(kW)	0.606	VC(kW)	0.324				
30					FRG(kW)	0.602	VC	0.324				
31					FTL(kW)	0.6	WM	0.315				
32					FTL	0.596	DEH(kWh)	0.311				
33					EF(kW)	0.578	WM(kW)	0.308				
34					FRG(kWh)	0.556	-	-				
35					EF	0.543	-	-				
36					TV(kW)	0.539	-	-				
37					IM(kWh)	0.537	-	-				
38					WM	0.534	-	-				
39					FRG	0.533	-	-				
40					TV	0.53	-	-				
41					WM(kW)	0.523	-	-				
42					EF(kWh)	0.499	-	-				
43					TV(kWh)	0.495	-	-				
44					COM.LAP(kWh)	0.482	-	-				
45					FN(kW)	0.467	-	-				
46					FRZ(kWh)	0.443	-	-				
47					FRZ(kW)	0.441	-	-				
48					FRZ	0.44	-	-				
49					VC(kW)	0.439	-	-				
50					VC	0.437	-	-				
51					LED	0.417	-	-				
52					LED(kWh)	0.411	-	-				
53					LED(kW)	0.397	-	-				
54					SEF	0.396	-	-				
55					IB	0.334	-	-				
56					SEF(kW)	0.333	-	-				
57					IB(kW)	0.327	-	-				
58					[illegible]	[illegible]						
59					[illegible]	[illegible]	-	-				

Table 8.3 Appendix-C-2-2, Correlations of divisional models

Sr. No.	Whole Punjab				Rawalpindi Division				Sahiwal Division				Multan Division				Bahawalpur Division				Dera Ghazi Khan Division			
	Model: Electric kWh/yr. per Household		Model: Electric kWh/yr. per Capita		Model: Electric kWh/yr. per Household		Model: Electric kWh/yr. per Capita		Model: Electric kWh/yr. per Household		Model: Electric kWh/yr. per Capita		Model: Electric kWh/yr. per Household		Model: Electric kWh/yr. per Capita		Model: Electric kWh/yr. per Household		Model: Electric kWh/yr. per Capita		Model: Electric kWh/yr. per Household		Model: Electric kWh/yr. per Capita	
	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)	Acronym	Pearson coefficient(r)
1	APP+LTS	0.636	APP (kW)	0.655	CON.RMS	0.519	APP (kWh)+LTS(kWh)	0.457	APP+LTS	0.643	APP (kWh)+LTS(kWh)	0.578	APP (kW)+LTS (kW)	0.774	APP(kW)	0.764	CON.RMS	0.746	CON.RMS	0.723	APP(kW)	0.675	APP(kWh)	0.650
2	APP (kW)+LTS (kW)	0.629	APP (kW)+LTS (kW)	0.654	APP (kWh)+LTS(kWh)	0.461	APP (kW)+LTS (kW)	0.446	APP (kW)+LTS (kW)	0.641	APP(kWh)	0.563	APP(kW)	0.773	APP (kW)+LTS (kW)	0.760	CON.RM.AR	0.586	CON.RM.AR	0.550	APP (kW)+LTS (kW)	0.673	APP(kW)	0.649
3	APP	0.617	APP	0.637	APP (kW)+LTS (kW)	0.454	APP(kW)	0.434	APP(kW)	0.621	APP	0.557	APP(kWh)	0.727	ACONC	0.700	APP (kW)+LTS (kW)	0.496	APP (kW)+LTS (kW)	0.488	APP(kWh)	0.672	APP (kW)+LTS (kW)	0.647
4	APP (kW)	0.616	APP+LTS	0.626	GIFA	0.446	APP(kWh)	0.428	APP (kWh)+LTS(kWh)	0.619	APP (kW)+LTS (kW)	0.553	APP (kWh)+LTS(kWh)	0.725	APP(kWh)	0.686	ACONC	0.493	APP+LTS	0.484	APP (kWh)+LTS(kWh)	0.666	APP (kWh)+LTS(kWh)	0.647
5	CON.RMS	0.604	APP(kWh)+LTS(kWh)	0.580	APP(kW)	0.437	FN(kWh)	0.422	APP	0.617	APP(kW)	0.539	APP	0.711	APP (kWh)+LTS(kWh)	0.679	APP(kW)	0.492	APP(kW)	0.482	ACONC(kWh)	0.604	ACONC(kWh)	0.573
6	LTS	0.556	ACONC (kW)	0.569	APP(kWh)	0.426	APP	0.384	APP(kWh)	0.593	APP+LTS	0.534	APP+LTS	0.702	ACONC(kW)	0.670	ACONC(kW)	0.489	ACONC	0.467	ACONC	0.597	FRG(kWh)	0.573
7	CON.RM.AR	0.554	ACONC	0.558	ACONC(kWh)	0.412	CON.RMS	0.381	CON.RMS	0.589	CON.RM.AR	0.507	ACONC	0.691	APP	0.664	APP+LTS	0.467	ACONC(kW)	0.459	ACONC(kW)	0.594	ACONC	0.562
8	ACONC (kW)	0.553	APP (kWh)	0.566	FN(kWh)	0.407	FN	0.367	GIFA	0.559	CON.RMS	0.465	ACONC(kW)	0.664	APP+LTS	0.641	LTS	0.440	LTS	0.454	FRG(kWh)	0.581	ACONC(kW)	0.558
9	ACONC	0.543	CON.RMS	0.550	LTS(kWh)	0.392	LTS(kWh)	0.360	CON.RM.AR	0.538	ACONC(kW)	0.459	FRG(kWh)	0.645	ACONC(kWh)	0.633	GIFA	0.431	APP	0.412	APP	0.572	APP	0.530
10	APP (kWh)+LTS(kWh)	0.537	CON.RM.AR	0.538	ACONC(kW)	0.376	APP+LTS	0.355	FN	0.518	ACONC	0.445	ACONC(kWh)	0.640	CON.RMS	0.629	APP	0.393	LTS(kW)	0.404	CON.RMS	0.548	CON.RMS	0.515
11	LTS (kW)	0.525	ACONC (kWh)	0.524	ACONC	0.374	ACONC(kWh)	0.327	OCC	0.515	FN	0.442	CON.RMS	0.632	FRG(kWh)	0.606	LTS(kW)	0.373	FTL	0.391	CON.RM.AR	0.541	CON.RM.AR	0.503
12	APP (kWh)	0.514	LTS	0.504	CON.RM.AR	0.352	ACONC(kW)	0.308	ACONC(kWh)	0.511	ACONC(kWh)	0.434	LTS	0.623	COM.LAP	0.595	ACONC(kWh)	0.322	FTL(kW)	0.378	APP+LTS	0.509	FRG	0.494
13	ACONC (kWh)	0.504	LTS (kW)	0.485	OCC	0.345	ACONC	0.306	ACONC(kW)	0.505	FRG(kWh)	0.426	COM.LAP	0.600	IM	0.554	FTL	0.321	GIFA	0.372	FRG	0.500	APP+LTS	0.477
14	GIFA	0.466	FTL	0.454	APP	0.323	-	-	LTS	0.496	GIFA	0.405	IM	0.566	WM	0.548	LED(kW)	0.314	FN	0.321	LTS	0.396	LTS	0.370
15	LTS (kWh)	0.437	FTL (kW)	0.412	APP+LTS	0.315	-	-	ACONC	0.492	FN(kWh)	0.383	WM	0.552	LTS	0.541	FTL(kW)	0.309	ACONC(kWh)	0.308	LTS(kW)	0.378	LTS(kW)	0.357
16	MW	0.390	GIFA	0.401	FN	0.311	-	-	LTS(kW)	0.481	LTS	0.372	LTS(kWh)	0.543	MW	0.529					FN(kWh)	0.376	LTS(kWh)	0.352
17	MW (kW)	0.377	EF	0.400					FN(kWh)	0.442	LTS(kW)	0.351	CON.RM.AR	0.542	MW(kW)	0.528					ES(kW)	0.365	ES(kW)	0.322
18	FN	0.362	MW	0.392					LTS(kWh)	0.428	EF(kW)	0.342	LTS(kW)	0.540	CON.RM.AR	0.527					LTS(kWh)	0.365	FN(kWh)	0.319
19	COM.LAP	0.358	FTL (kWh)	0.388					FTL(kW)	0.390	FN(kW)	0.340	COM.LAP(kWh)	0.528	COM.LAP(kW)	0.526					FN	0.357	FRG(kW)	0.315
20	FTL	0.350	LTS (kWh)	0.384					FTL	0.383	LTS(kWh)	0.315	COM.LAP(kW)	0.525	GIFA	0.522					ES	0.342	ES	0.304
21	FTL (kW)	0.350	WM	0.370					MW(kW)	0.382	EF	0.302	MW(kW)	0.519	COM.LAP(kWh)	0.492					ES(kWh)	0.331	ES(kWh)	0.301
22	MW (kWh)	0.343	MW (kW)	0.355					FN(kW)	0.370	-	-	MW	0.513	LTS(kW)	0.475					TV(kW)	0.311		
23	FTL (kWh)	0.333	FRG	0.350					COM.LAP(kW)	0.367	-	-	FN(kWh)	0.510	FTL	0.462								
24	OCC	0.332	TV	0.348					MW	0.365	-	-	GIFA	0.501	LTS(kWh)	0.457								
25	FRG	0.330	EF (kW)	0.344					COM.LAP	0.361	-	-	MW(kWh)	0.489	MW(kWh)	0.453								
26	TV	0.329	FRG (kWh)	0.346					MW(kWh)	0.347	-	-	FRG	0.479	VC	0.439								
27	FN (kWh)	0.325	FN	0.326					FRG(kWh)	0.339	-	-	IM(kW)	0.476	TV	0.439								
28	LED/SMD	0.318	FRG (kW)	0.325					FTL(kWh)	0.334	-	-	ES(kWh)	0.464	TV(kW)	0.436								
29	ES	0.315	FN (kWh)	0.324					FRZ(kWh)	0.300	-	-	FTL	0.460	FN(kWh)	0.434								
30	EF	0.311	MW (kWh)	0.319									ES	0.454	FRG	0.424								
31	COM.LAP (kW)	0.300	TV (kWh)	0.317									TV(kW)	0.451	EF	0.417								
32	-	-	DEH	0.314									EF	0.448	IM(kW)	0.414								
33	-	-	DEH (kW)	0.309									VC	0.443	VC(kW)	0.413								
34													TV	0.440	TV(kWh)	0.402								
35													TV(kWh)	0.433	FTL(kW)	0.396								
36													VC(kW)	0.420	ES(kWh)	0.396								
37													FN	0.413	ES	0.383								
38													FTL(kW)	0.401	FRG(kW)	0.353								
39													ES(kW)	0.401	FN	0.346								
40													IM(kWh)	0.374	ES(kW)	0.343								
41													FRG(kW)	0.366	FTL(kWh)	0.342								
42													LED	0.361	IM(kWh)	0.336								
43													FTL(kWh)	0.356	WM(kWh)	0.323								
44													WM(kWh)	0.349	WM(kW)	0.310								
45													EF(kWh)	0.339	LED	0.310								
46													WM(kW)	0.331	DC	0.300								
47													LED(kW)	0.322										
48													EF(kW)	0.305										
49													LED(kWh)	0.301										

Table 8.4 Appendix-C-3-1 divisional energy usage intensity (EUI)

Lahore Division — Survey findings

Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	785	3036.4	1815.5	2682.5	19	11772
Gas	441	4748	5867.3	1156.4	526	30089.6
kWh/capita/a						
Electric	785	527.8	293.6	482.5	6.33	2006.8
Gas	441	727.7	921.5	194.9	49.9	5701.9
kWh/m^2.household/a						
Electric	785	31	16.4	28.1	0.91	132.73
Gas	441	33	41.9	15.3	2.26	329.5
kWh/m^2.capita/a						
Electric	785	6.14	4.5	4.9	0.23	35.1
Gas	441	5.3	6.7	2.5	0.24	45.6

Sheikhupura Division — Survey findings

Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	396	2658.6	1627.1	2342	3.27	10229
Gas	64	6474	5802.7	5139	708.5	23001.7
kWh/capita/a						
Electric	396	563	290.7	536.7	0.65	2014
Gas	64	1042.5	784.1	998.9	70.9	3066.9
kWh/m^2.household/a						
Electric	396	32	15.9	29.9	0.05	102.5
Gas	64	44	31.4	42.7	3.4	152
kWh/m^2.capita/a						
Electric	396	7.5	4.6	6.74	0.01	34.2
Gas	64	7.7	5.1	7.98	0.42	25.3

Gujranwala Division — Survey findings

Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	853	2546	1485.5	2318	17	12762
Gas	655	8633	3087.7	8527.2	698.8	22308.7
kWh/capita/a						
Electric	853	381.7	220.5	337	5.7	2973
Gas	655	1236.9	610.8	1162	82.1	8152.5
kWh/m^2.household/a						
Electric	853	35	26.7	27.7	0.81	288.2
Gas	655	117	66.3	99.6	3.34	506.9
kWh/m^2.capita/a						
Electric	853	5.49	4.1	4.4	0.24	41.2
Gas	655	16.5	11.2	13.8	0.42	117.9

Faisalabad Division — Survey findings

Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	432	2211.9	1411.2	1802	187	7256
Gas	207	5126	5490.5	1298.6	40.6	18478.9
kWh/capita/a						
Electric	432	394.5	169.2	366.7	5.8	1209.3
Gas	207	763.4	805.4	227.5	5.8	3467.2
kWh/m^2.household/a						
Electric	432	19	8.1	17.9	5.67	56.5
Gas	207	29	28.8	13.1	0.32	127.8
kWh/m^2.capita/a						
Electric	432	4.5	2.9	3.6	0.67	21.3
Gas	207	5.2	6.3	2.3	0.05	36.2

Sargodha Division — Survey findings

Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	327	1758.2	1051.9	1631	24	5940
Gas	313	1681	1989.4	1302.5	642.6	15402.5
kWh/capita/a						
Electric	327	248.8	156.9	212.3	1.85	1248.3
Gas	313	239	270.2	178.6	68.1	178.6
kWh/m^2.household/a						
Electric	327	19	11.3	16.3	0.29	16.3
Gas	313	17	11.4	13.9	2.8	13.9
kWh/m^2.capita/a						
Electric	327	2.8	2.1	2.3	0.02	19.9
Gas	313	2.6	1.2	2.1	0.35	13.1

Rawalpindi Division — Survey findings

Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	179	2317	1194.2	2169	7	7498
Gas	125	3771	4359	1196.4	506.2	172226.9
kWh/capita/a						
Electric	179	387.4	188.5	368.2	2.3	1249.7
Gas	125	629.8	692	201	78.7	2709.4
kWh/m^2.household/a						
Electric	179	32	23.7	24.5	0.17	179.4
Gas	125	67	85.9	15.2	1.12	369.9
kWh/m^2.capita/a						
Electric	179	5.5	4.6	4.2	0.06	29.9
Gas	125	11.9	15.4	2.4	0.30	54.9

Table 8.5 Appendix-C-3-2 divisional energy usage intensity (EUI)

Sahiwal Division

Survey findings						
Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	255	2588.1	1408.2	2412	121	7261
Gas	147	4964	4207.8	4255.8	360.1	14393.1
kWh/capita/a						
Electric	255	410.5	190.7	403.9	13.4	1083
Gas	147	806.1	668.2	789.6	45	2974.7
kWh/m².household/a						
Electric	255	26	13.5	23.6	1.5	81.5
Gas	147	48	41.5	39.4	2.5	196
kWh/m².capita/a						
Electric	255	4.7	3.0	4.2	0.16	24.9
Gas	147	8.4	7.6	6.9	0.31	34.8

Multan Division

Survey findings						
Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	520	1634.2	1130.9	1380	143	7768
Gas	323	5382	4161.9	5823.2	490.2	31380.5
kWh/capita/a						
Electric	520	241.5	178.9	189	20.43	1245.3
Gas	323	726.7	567.7	752.9	58.2	4482.9
kWh/m².household/a						
Electric	520	14	8.91	12.62	0.98	53.7
Gas	323	51	41.81	52.1	1.97	213.6
kWh/m².capita/a						
Electric	520	2.3	1.69	1.77	0.11	11.9
Gas	323	7.1	6.1	6.4	0.27	38.9

Bahawalpur Division

Survey findings						
Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	458	2961.3	1740.5	2359	232	10262
Gas	421	2527	3611.9	992.7	205.6	13843.7
kWh/capita/a						
Electric	458	415.4	232.3	341.5	29	1607.2
Gas	421	362.8	555.7	145.3	18.7	4254.2
kWh/m².household/a						
Electric	458	23	15.3	19.7	2.4	19.6
Gas	421	20	47.6	8.8	0.98	642.5
kWh/m².capita/a						
Electric	458	3.6	3.6	2.7	0.30	52.7
Gas	421	3.4	12.9	1.2	0.09	203.6

Dera Ghazi Khan Division

Survey findings						
Utility	N	Average	S.D.	Median	Min.	Max.
kWh/household/a						
Electric	392	1568.9	1152.4	1297	97	6599
Gas	205	7125	3513.2	6987.9	578.4	16499
kWh/capita/a						
Electric	392	232.9	164.1	197.2	16.2	1093
Gas	205	1041.5	511.8	1003	78.7	2571.4
kWh/m².household/a						
Electric	392	16	12.2	13.1	0.77	95.4
Gas	205	75	44.5	67.1	3.4	263.2
kWh/m².capita/a						
Electric	392	2.4	1.9	2.1	0.13	13.6
Gas	205	11.2	6.9	9.4	0.38	37.6

Table 8.6 Appendix-C-4-1, divisional Models summary

Lahore Division

Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model				
0.739	0.546	0.543	1227.34	1.9
Electricity use per household of Grouped model				
0.730	0.533	0.530	1244.1	1.87
Electricity use per household of Combined model				
0.740	0.548	0.545	1224.3	1.86
Electricity use per Capita of Detailed model				
0.688	0.474	0.470	213.7	1.96
Electricity use per Capita of Grouped model				
0.707	0.500	0.497	208.10	1.86
Electricity use per Capita of Combined model				
.713	.508	.505	206.61	1.93
Gas per household area model				
0.531	0.282	0.280	5062.74	0.97
Gas per capita model				
0.586	0.343	0.341	768.53	1.14

Sheikhupura Division

Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model				
0.887	0.788	0.784	771.39	1.86
Electricity use per household of Grouped model				
0.870	0.757	0.756	823.28	1.92
Electricity use per household of Combined model				
0.892	0.795	0.791	744.7	1.84
Electricity use per Capita of Detailed model				
0.801	0.641	0.635	169.68	1.85
Electricity use per Capita of Grouped model				
0.771	0.594	0.592	185.19	1.87
Electricity use per Capita of Combined model				
0.799	0.639	0.631	170.43	184
Gas per household area model				
0.756	0.572	0.565	3983.58	1.48
Gas per capita model				
0.658	0.432	0.423	611.17	1.49

Gujranwala Division

Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model				
0.639	0.409	0.405	1145.7	1.76
Electricity use per household of Grouped model				
0.627	0.393	0.390	1160.25	1.69
Electricity use per household of Combined model				
0.653	0.427	0.424	1127.23	1.81
Electricity use per Capita of Detailed model				
0.630	0.397	0.394	171.7	1.76
Electricity use per Capita of Grouped model				
0.678	0.460	0.458	174.7	1.68
Electricity use per Capita of Combined model				
0.654	0.428	0.424	167.3	1.86
Gas per household area model				
0.372	0.138	0.136	2925.4	1.66
Gas per capita model				
0.529	0.280	0.279	566.9	1.65

Faisalabad Division

Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model				
0.933	0.870	0.867	514.51	1.84
Electricity use per household of Grouped model				
0.892	0.795	0.793	641.94	1.73
Electricity use per household of Combined model				
0.932	0.868	0.865	518.63	1.85
Electricity use per Capita of Detailed model				
0.827	0.683	0.677	96.22	1.89
Electricity use per Capita of Grouped model				
0.789	0.623	0.620	106.97	1.84
Electricity use per Capita of Combined model				
0.831	0.690	0.683	95.23	1.84
Gas per household area model				
0.686	0.470	0.468	4031.44	1.1
Gas per capita model				
0.633	0.401	0.398	636.09	1.17

Sargodha Division

Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model				
0.510	0.260	0.253	908.916	1.94
Electricity use per household of Grouped model				
0.520	0.271	0.264	902.620	1.91
Electricity use per household of Combined model				
0.542	0.293	0.289	905.665	1.95
Electricity use per Capita of Detailed model				
0.516	0.266	0.259	135.112	1.81
Electricity use per Capita of Grouped model				
0.554	0.307	0.303	138.495	1.80
Electricity use per Capita of Combined model				
0.503	0.253	0.246	136.320	1.84
Gas per household area model				
0.653	0.426	0.425	1610.135	1.45
Gas per capita model				
0.730	0.532	0.531	212.512	1.63

Rawalpindi Division

Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model				
0.635	0.403	0.393	930.34	1.76
Electricity use per household of Grouped model				
0.649	0.421	0.412	961.185	1.78
Electricity use per household of Combined model				
0.651	0.423	0.410	917.317	1.73
Electricity use per Capita of Detailed model				
0.574	00.329	0.317	155.753	1.69
Electricity use per Capita of Grouped model				
0.602	0.363	0.352	160.368	1.70
Electricity use per Capita of Combined model				
0.584	0.341	0.326	154.797	1.69
Gas per household area model				
0.206	0.043	0.027	4405.609	0.89
Gas per capita model				
0.044	0.002	0-.006	708.093	0.88

Table 8.7 Appendix-C-4-2, divisional Models summary

Sahiwal Division					Multan Division				
Models Summary					Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model					Electricity use per household of Detailed model				
0.766	0.587	0.575	917.78	1.91	0.816	0.666	0.660	659.75	1.83
Electricity use per household of Grouped model					Electricity use per household of Grouped model				
0.752	0.566	0.559	952.44	1.93	0.787	0.619	0.616	700.44	1.93
Electricity use per household of Combined model					Electricity use per household of Combined model				
0.758	0.574	0.566	928.2	1.85	0.817	0.667	0.662	657.8	1.83
Electricity use per Capita of Detailed model					Electricity use per Capita of Detailed model				
0.633	0.401	0.391	148.78	1.84	0.835	0.697	0.691	99.54	1.76
Electricity use per Capita of Grouped model					Electricity use per Capita of Grouped model				
0.645	0.416	0.411	149.963	1.81	0.817	0.668	0.666	103.41	1.86
Electricity use per Capita of Combined model					Electricity use per Capita of Combined model				
0.649	0.421	0.410	146.48	1.95	0.834	0.696	0.693	99.21	1.81
Gas per household area model					Gas per household area model				
0.289	0.083	0.077	4070.74	1.57	0.248	0.062	0.056	4264.79	1.12
Gas per capita model					Gas per capita model				
0.451	0.203	0.198	611.42	1.45	0.163	0.027	0.024	594.53	1.15
Bahawalpur Division					**Dera Ghazi Khan Division**				
Models Summary					Models Summary				
R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Electricity use per household of Detailed model					Electricity use per household of Detailed model				
0.783	0.613	0.610	1087.0514	1.81	0.733	0.537	0.533	787.837	2.0
Electricity use per household of Grouped model					Electricity use per household of Grouped model				
0.620	0.385	0.382	1391.507	1.91	0.697	0.486	0.484	828.136	2.0
Electricity use per household of Combined model					Electricity use per household of Combined model				
0.799	0.639	0.635	1051.718	1.89	0.743	0.552	0.549	774.10	2.1
Electricity use per Capita of Detailed model					Electricity use per Capita of Detailed model				
0.771	0.595	0.591	148.502	1.79	0.726	0.527	0.522	113.457	2.1
Electricity use per Capita of Grouped model					Electricity use per Capita of Grouped model				
0.595	.0354	0.350	192.297	1.87	0.678	0.459	0.458	124.50	1.96
Electricity use per Capita of Combined model					Electricity use per Capita of Combined model				
0.784	0.614	0.609	145.208	1.91	0.735	0.541	0.537	111.635	2.0
Gas per household area model					Gas per household area model				
0.422	0.178	0.176	3303.070	1.19	0.292	0.085	0.081	3429.940	1.43
Gas per capita model					Gas per capita model				
0.400	0.160	0.158	535.574	1.11	0.073[a]	0.005	0.001	522.0196	1.45

Table 8.8 Appendix C-Lahore-1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	3036.43	1815.5	kWh/yr./capita	527.78	293.55
OCC	5.9	2.32	GIFA/capita	19.42	12.17
GIFA	114.36	79.45	MW/capita	.086	.094
ACONC (kW)	1.23	1.21	EF/capita	.18	.21
TV	1.31	.71	ACONC (kW) /capita	.21	.19
LED	2.35	4.5	LED/capita	.39	.83
CON.RM.AR	11.67	12.02	CON.RM.AR/capita	2.1	1.89
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	3036.42	1815.53	kWh/yr. /capita	527.78	293.55
OCC	5.96	2.32	GIFA/capita	19.42	12.18
GIFA	114.36	79.45	CON.RM.AR/capita	2.1	1.89
APP+LTS	21.48	11.55	LTS/capita	1.7	1.07
CON.RMS	2.08	1.28	kW (APP)+kW (LTS)/Capita	.58	.34
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	3036.43	1815.53	kWh/yr. /capita	527.8	293.6
OCC	5.963	2.33	GIFA/capita	19.4	12.2
GIFA	114.363	79.46	CON.RM.AR/capita	2.1	1.9
LED	2.35	4.518	LTS/capita	1.7	1.1
kW (APP)+kW (LTS)	3.373	2.093	kW (APP)+kW (LTS)/Capita	.58	.34
CON.RMS	2.08	1.281	EF/capita	.18	.21
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	4797.84	5966.64	kWh/yr./capita	736.52	946.9
GIFA	141.27	85.93	GIFA /capita	21.58	15.16

Table 8.9 Appendix C-Lahore-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	567.460		4.169	0.000				(Constant)	219.83		13.97	.000			
OCC	112.129	.144	5.341	0.000	.129	.805	1.3	GIFA/capita	3.18	.132	4.37	.000	.114	.75	1.4

GIFA	3.700	.162	5.174	0.000	.125	.596	1.7	MW/capita	185.87	.060	2.07	.000	.054	.81	1.3
ACONC (kW)	394.528	.264	8.326	0.000	.201	.582	1.7	EF/capita	233.18	.165	5.81	.000	.151	.84	1.2
TV	212.361	.084	3.224	0.000	.078	.866	1.2	ACONC (kW)/capita	421.62	.281	8.30	.000	.216	.59	1.7
LED	57.591	.143	5.439	0.000	.131	.841	1.2	LED/capita	37.75	.107	3.72	.000	.097	.82	1.2
CON.RM.AR	40.765	.270	8.623	0.000	.208	.595	1.7	CON.RM.AR/capita	42.14	.273	8.34	.000	.217	.63	1.6
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
Constant	317.51		2.47	.014				(Constant)	143.34		8.53	.000			
OCC	36.93	.047	1.67	0.000	.041	.745	1.34	GIFA/capita	1.99	.08	2.61	.009	.07	.64	1.6
GIFA	2.59	.113	3.36	0.000	.082	.526	1.90	CON.RM.AR/capita	40.61	.26	8.67	.000	.22	.69	1.4
APP+LTS	48.61	.309	8.64	0.000	.212	.468	2.14	LTS/capita	30.86	.11	3.48	.001	.09	.61	1.7
CON.RMS	557.82	.394	12.58	0.000	.308	.613	1.63	kW (APP)+kW (LTS)/Capita	365	.42	13.46	.000	.34	.66	1.5
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
Constant	414.31		3.29	0.001				(Constant)	137.2		8.20	.000			
OCC	69.45	.037	9.52	0.000	.079	.786	1.28	GIFA	1.8	.08	2.3	.020	.06	.64	1.6
GIFA	3.46	.089	3.28	0.000	.117	.593	1.69	CON.RM.AR	42.5	.28	9.1	.000	.23	.69	1.5
LED	76.84	.151	4.84	0.000	.180	.885	1.13	LTS	35.6	.13	3.9	.000	.10	.59	1.7
kW (APP)+kW (LTS)	190.04	.191	7.47	0.000	.148	.459	2.18	kW (APP)+kW (LTS)/Capita	316.9	.37	10.5	.000	.27	.52	1.9
CON.RMS	477.46	.219	6.16	0.000	.229	.464	2.16	EF	142.7	.10	3.5	.000	.09	.77	1.3
Gas use per household model								**Gas use per capita model**							
Constant	-408.15		-.88	.378				Constant	-52.87		-.84	.404			
GIFA	36.85	.531	13.18	.000	.531	1.00	1.00	GIFA/CAPITA	36.59	.586	15.22	.000	.586	1.0	1.0

Table 8.10 Appendix C-Sheikhupura -1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	2592.96	1659.1	kWh/yr.	562.59	280.74
ACONC (kW)	1.1	.87	GIFA	18.54	7.107
DEH (kW)	.23	.42	ACONC (kW)	.22	.173
FRG (kW)	.38	.17	DEH (kW)	.05	.087
FRZ (kW)	.036	.11	FRG (kW)	.089	.037
FN (kWh)	.98	.54	FN (kWh)	.22	.091
MW (kWh)	.181	.33	MW (kWh)	.035	.065
CON.RM.AR	6.94	5.74	CON.RM.AR	1.41	1.11
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2658.61	1627.1	kWh/yr.	564.090	289.989
GIFA	88.31	55.71	GIFA	18.581	7.405
kW (APP)+kW (LTS)	2.72	1.55	kW (APP)+kW (LTS)/Capita	.577	.284
kWh (APP)+kWh (LTS)	13.82	6.67	-	-	-
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2658.61	1627.1	kWh/yr.	562.598	280.736
ACONC (kW)	1.1	.8693	GIFA	18.54	7.107
FN (kWh)	.991	.53	ACONC (kW)	.223	.173
MW (kWh)	.19	.33	DEH (kW)	.0454	.0866
CON.RM.AR	7.1	5.7	FN (kWh)	.217	.0902
APP+LTS	14.843037974683543	6.44	MW (kWh)	.0351	.0647
FRG (kW)	.38886	.17	CON.RM.AR	1.410	1.018
FRZ (kW)	.0368	.11	APP	1.917	.621
DEH (kW)	.228	.423	FRG	.229	.088
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	6636.96	6038.79	kWh/yr./capita	1054.398	804.74
GIFA	144.48	85.13	GIFA/CAPITA	23.18	10.49

Table 8.11 Appendix C-Sheikupura-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	155.7		1.412	.159				(Constant)	13.99		.42	.675			
ACONC (kW)	305.6	.161	3.680	.000	.09	.28	3.6	GIFA	3.21	.081	2.2	.029	.067	.68	1.5
DEH (kW)	792.8	.200	7.551	.000	.18	.76	1.3	ACONC (kW)	314.1	.194	3.9	.000	.121	.39	2.6
FRG (kW)	1622	.164	6.168	.000	.14	.76	1.3	DEH (kW)	716.7	.221	6.7	.000	.205	.86	1.2
FRZ (kW)	1567.5	.101	3.952	.000	.09	.82	1.2	FRG (kW)	1593.5	.211	6.7	.000	.202	.92	1.1
FN (kWh)	391.8	.126	4.779	.000	.11	.76	1.3	FN (kWh)	420.9	.135	4.2	.000	.127	.88	1.1
MW (kWh)	669.9	.133	4.725	.000	.11	.68	1.5	MW (kWh)	556.5	.128	3.8	.000	.115	.81	1.2
CON.RM.AR	107.76	.373	8.006	.000	.19	.25	4.1	CON.RM.AR	96.1	.349	6.6	.000	.201	.33	3.1
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	17.63		.205	.837				(Constant)	11.74		.434	.664			
GIFA	8.39	.291	8.96	.000	.22	.58	1.73	GIFA	9.23	.236	6.69	.000	.214	.83	1.2
kW (APP)+kW (LTS)	700.45	.652	20.06	.000	.50	.58	1.73	kW (APP)+kW (LTS)/Capita	659.84	.642	18.27	.000	.584	.83	1.2
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	130.67		1.114	.266				(Constant)	-30.05		-.801	.424			
ACONC (kW)	249.95	.134	3.087	.002	.071	.29	3.5	GIFA	2.77	.070	1.89	.060	.058	.68	1.5
FN (kWh)	179.51	.059	1.774	.077	.041	.48	2.1	ACONC (kW)	254.23	.157	3.04	.003	.093	.35	2.9
MW (kWh)	571.88	.117	4.035	.000	.093	.64	1.6	DEH (kW)	560.29	.173	4.83	.000	.148	.73	1.4
CON.RM.AR	100.43	.354	7.394	.000	.170	.23	4.3	FN (kWh)	233.98	.075	1.98	.049	.061	.65	1.5
APP+LTS	38.48	.152	2.889	.004	.067	.19	5.2	MW (kWh)	431.86	.100	2.78	.006	.085	.73	1.4
FRG (kW)	1229.32	.125	4.376	.000	.101	.65	1.5	CON.RM.AR	97.10	.352	6.42	.000	.196	.31	3.2
FRZ (kW)	1382.25	.092	3.591	.000	.083	.82	1.2	APP	90.31	.200	3.64	.000	.111	.31	3.2
DEH (kW)	705.68	.183	6.554	.000	.151	.68	1.5	FRG	363.29	.114	3.18	.002	.097	.73	1.4
Gas use per household model								**Gas use per capita model**							

(Constant)	-1113.93		-1.111	.271				(Constant)	-115.48		-.62	.542			
GIFA	53.65	.756	8.96	.000	.756	1.0	1.0	GIFA/CAPITA	50.47	.658	6.82	.000	.658	1.0	1.0

Table 8.12 Appendix C-Gujranwala-1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	2545.73	1485.52	kWh/yr.	381.65	220.49
OCC	6.79	2.6	FN (kWh)	.23	.15
GIFA	82.12	39.3	COM.LAP (kWh)	.012	.045
FN (kW)	.42	.28	FTL (kW)	.006	.012
FN (kWh)	1.6	.94	CON.RM.AR	.48	.79
CON.RM.AR	3.18	5.38	TV (kWh)	.18	.16
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2545.73	1485.52	kWh/yr.	383.96	237.24
OCC	6.79	2.56	APP	1.53	.99
APP+LTS	19.51	7.80	kWh (LTS)	.34	.23
kWh (APP)+kWh (LTS)	10.67	4.83	kW (APP)+kW (LTS)/Capita	.28	.23
CON.RM.AR	3.18	5.38	-	-	-
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2545.7	1485.5	kWh/yr.	381.65	220.49
OCC	6.8	2.6	COM.LAP (kWh)	.012	.045
FN (kW)	.42	.28	FTL (kW)	.006	.012
CON.RM.AR	3.2	5.4	CON.RM.AR	.48	.79
kWh (APP)+kWh (LTS)	10.7	4.8	kW (APP)+kW (LTS)/Capita	.28	.22
-	-	-	FN (kW)	.060	.045
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	8633.30	3146.81	kWh/yr./capita	1244.6	667.41
GIFA	86.45	39.35	GIFA/CAPITA	12.1	8.78
OCC	7.64	2.25	-	-	-

Table 8.13 Appendix C-Gujranwala-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	308.279		2.56	.011				(Constant)	184.84		16.27	.000			
OCC	136.4	.235	7.11	.000	.187	.63	1.6	FN (kWh)	500.62	.358	11.17	.000	.296	.69	1.5
GIFA	3.3	.086	2.84	.005	.075	.76	1.4	COM.LAP (kWh)	555.18	.114	4.01	.000	.106	.88	1.1
FN (kW)	1092.1	.205	4.98	.000	.131	.41	2.5	FTL (kW)	2581.53	.137	4.16	.000	.110	.65	1.6
FN (kWh)	244.7	.155	3.72	.000	.098	.39	2.5	CON.RM.AR	72.15	.261	9.73	.000	.258	.98	1.1
CON.RM.AR	66.8	.242	8.53	.000	.224	.86	1.2	TV (kWh)	136.8	.101	2.91	.004	.077	.59	1.7
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	-97.25		-.75	.455				(Constant)	103.3		8.46	.000			
OCC	159.55	.275	8.19	.000	.218	.63	1.6	APP	88.6	.370	8.31	.000	.208	.32	3.2
APP+LTS	40.25	.211	5.69	.000	.152	.52	1.9	kWh (LTS)	262.8	.247	7.54	.000	.189	.58	1.7
kWh (APP)+kWh (LTS)	60.32	.196	5.48	.000	.146	.55	1.8	kW (APP)+kW (LTS)/Capita	198.9	.194	5.25	.000	.131	.46	2.2
CON.RM.AR	40.96	.148	4.67	.000	.124	.71	1.4	-	-	-	-	-	-	-	-
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	48.1		.39	.700				(Constant)	154.2		12.67	.000			
OCC	145.5	.251	8.17	.000	.211	.71	1.4	COM.LAP (kWh)	404.1	.083	2.96	.003	.076	.86	1.2
FN (kW)	1487.1	.280	9.24	.000	.239	.73	1.4	FTL (kW)	1729.8	.092	2.82	.005	.073	.63	1.6
CON.RM.AR	42.7	.154	5.01	.000	.130	.70	1.4	CON.RM.AR	42.4	.153	5.09	.000	.132	.74	1.3
kWh (APP)+kWh (LTS)	71.1	.231	7.10	.000	.184	.63	1.6	kW (APP)+kW (LTS)/Capita	257.5	.260	7.42	.000	.192	.55	1.8
-	-	-	-	-	-	-	-	FN (kW)	2006.4	.410	14.52	.000	.375	.84	1.2
Gas use per household model								**Gas use per capita model**							
(Constant)	4529.61		10.57	.000				(Constant)	759.37		20.24	.000			
GIFA	17.94	.224	5.93	.000	.215	.92	1.1	GIFA/CAPITA	40.22	.529	15.99	.000	.529	1.0	1.0
OCC	334.13	.239	6.32	.000	.229	.92	1.1	-	-	-	-	-	-	-	-

Table 8.14 Appendix C-Faisalabad-1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	2211.88	1411.17	kWh/yr.	394.517	169.169
OCC	5.49	2.81	GIFA	22.776	12.317
FRG	.98	.409	IM	.0461	.0744
IM	.33	.486	WM	.161	.112
FN (kW)	.13	.11	FN (kW)	.0247	.0177
ACONC (kWh)	4.06	3.87	FN (kWh)	.211	.121
MW (kWh)	.32	.46	ACONC (kWh)	.670	.598
EF (kWh)	.037	.051	MW (kWh)	.0491	.0724
IB	.29	.942	EF (kWh)	.006	.00858
ES	4.5	3.1	CON.RMS	.396	.173
FTL (kW)	.055	.059	-	-	-
CON.RM.AR	7.51	8.68	-	-	-
			-	-	-
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2211.88	1411.16	kWh/yr.	395.114	173.614
OCC	5.496	2.813	GIFA	22.896	12.893
CON.RM.AR	7.508	8.676	APP	1.7835	.7244
GIFA	22.776	12.317	kWh (LTS)	.271	.2254
APP+LTS	3.23	1.33	-	-	-
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2211.88	1411.16	kWh/yr.	394.517	169.169
OCC	5.49	2.81	IM	.0461	.0744
FRG	.98	.409	WM	.161	.111
IM	.33	.486	FN (kW)	.0247	.0176
FN (kW)	.13	.11	ACONC (kWh)	.670	.598
ACONC (kWh)	4.06	3.87	MW (kWh)	.0491	.0724
MW (kWh)	.32	.46	EF (kWh)	.006	.0085
EF (kWh)	.036	.051	CON.RMS	.396	.173
CON.RM.AR	7.51	8.67	APP	1.781	.703
kW (LTS)	.19	.148	kW (LTS)	.0347	.01830
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	5167.172	5526.487	kWh/yr./capita	770.26	819.758
GIFA	183.781	117.880	GIFA/CAPITA	25.650	15.266

Table 8.15 Appendix C-Faisalabad-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	217.73		2.81	.005				(Constant)	100.45		6.27	.000			
OCC	49.09	.098	3.48	.001	.061	.39	2.6	GIFA	1.96	.143	4.22	.000	.116	.66	1.5
FRG	241.21	.070	3.29	.001	.058	.69	1.5	IM	429.69	.189	5.68	.000	.156	.68	1.5
IM	450.54	.155	6.11	.000	.107	.48	2.1	WM	176.54	.116	3.96	.000	.108	.87	1.2
FN (kW)	1646.01	.127	6.37	.000	.112	.78	1.3	FN (kW)	1142.24	.119	3.66	.000	.100	.71	1.4
ACONC (kWh)	103.93	.285	9.57	.000	.168	.35	2.9	FN (kWh)	186.90	.135	3.77	.000	.103	.59	1.7
MW (kWh)	290.87	.096	4.22	.000	.074	.60	1.7	ACONC (kWh)	69.93	.247	5.95	.000	.163	.43	2.3
EF (kWh)	2788.48	.102	4.99	.000	.088	.75	1.3	MW (kWh)	315.83	.135	4.11	.000	.113	.69	1.5
IB	152.02	.102	5.42	.000	.095	.88	1.2	EF (kWh)	3405.76	.173	5.65	.000	.155	.81	1.3
ES	52.78	.114	4.33	.000	.076	.44	2.3	CON.RMS	124.79	.128	3.63	.000	.099	.61	1.7
FTL (kW)	1383.39	.058	2.54	.012	.045	.59	1.7	-	-	-	-	-	-	-	
CON.RM.AR	19.87	.122	4.01	.000	.070	.33	3.1	-	-	-	-	-	-	-	-
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	-837.25		-7.26	.000				(Constant)	70.13		4.91	.000			
OCC	259.96	.518	16.64	.000	.365	.49	2.1	GIFA	2.06	.153	3.96	.000	.117	.58	1.7
CON.RM.AR	43.44	.267	7.57	.000	.166	.39	2.6	APP	137.63	.574	13.97	.000	.413	.52	1.9
GIFA	8.87	.077	2.62	.009	.057	.55	1.8	kWh (LTS)	118.95	.154	3.73	.000	.110	.51	1.9
APP+LTS	337.94	.321	11.48	.000	.252	.62	1.6	-	-	-	-	-	-	-	-
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	232.32		2.99	.003				(Constant)	98.68		6.21	.000			
OCC	46.47	.093	3.27	.001	.058	.39	2.6	IM	383.89	.169	4.92	.000	.133	.62	1.6
FRG	224.71	.065	3.07	.002	.054	.69	1.4	WM	123.26	.081	2.43	.016	.066	.66	1.5
IM	449.98	.155	6.05	.000	.107	.48	2.1	FN (kW)	1354.66	.142	4.65	.000	.126	.79	1.3
FN (kW)	1723.98	.133	6.73	.000	.119	.81	1.3	ACONC (kWh)	67.14	.238	5.75	.000	.156	.43	2.3
ACONC (kWh)	101.31	.278	9.31	.000	.165	.36	2.9	MW (kWh)	290.39	.124	3.72	.000	.101	.66	1.5
MW (kWh)	269.35	.089	3.88	.000	.069	.61	1.7	EF (kWh)	2324.93	.118	3.55	.000	.096	.67	1.5

EF (kWh)	2643.18	.096	4.69	.000	.083	.75	1.3	CON.RMS	96.17	.098	2.84	.005	.077	.61	1.6
CON.RM.AR	20.25	.125	4.07	.000	.072	.34	2.9	APP	31.2	.130	2.15	.032	.058	.21	4.9
kW (LTS)	1910.34	.201	6.34	.000	.112	.32	3.2	kW (LTS)	1637.25	.177	4.52	.000	.123	.48	2.1
Gas use per household model								**Gas use per capita model**							
(Constant)	-742.23		-1.44	.151				(Constant)	-101.68		-1.19	.236			
GIFA	32.16	.686	13.63	.000	.686	1.0	1.0	GIFA/CAPITA	34	.633	11.85	.000	.633	1.0	1.0

Table 8.16 Appendix C-Sargodha-1 Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	1758.220	1051.981	kWh/yr.	248.820	156.976
GIFA	102.704	57.705	GIFA	14.509	8.716
FN	3.00	1.311	WM	.115	.0741
ACONC	.12	.378	CON.RMS	.169	.0810
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1758.220	1051.981	kWh/yr.	250.706	165.849
GIFA	102.704	57.705	GIFA	14.726	9.988
kW (APP)+kW (LTS)	1.1277	.944	kW (APP)+kW (LTS)/Capita	.1586	.135
CON.RM.AR	1.204	4.451	-	-	-
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1763.0972	1074.029	kWh/yr.	248.820	156.976
GIFA	103.279	59.990	GIFA	14.509	8.716
kW (APP)+kW (LTS)	1.139	.980	WM	.115	.0741
-	-	-	kW (APP)+kW (LTS)/Capita	.156	.127
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1721.831	2122.575	kWh/yr./capita	247.128	310.235
GIFA	101.703	60.012	GIFA/CAPITA	14.575	10.359

Table 8.17 Appendix C-Sargodha-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	916.09		6.55	.000				(Constant)	48.01		2.38	.018			
GIFA	4.35	.239	4.31	.000	.207	.75	1.3	GIFA	4.61	.256	4.72	.000	.226	.78	1.3
FN	100.03	.125	2.26	.025	.108	.75	1.3	WM	471.79	.223	4.55	.000	.217	.94	1.1
ACONC	797.03	.286	5.33	.000	.255	.79	1.3	CON.RMS	470.18	.243	4.40	.000	.210	.75	1.4
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	1046.51		8.77	.000				(Constant)	112.84		8.08	.000			
GIFA	3.23	.177	3.06	.002	.145	.67	1.5	GIFA	5.17	.311	5.67	.000	.261	.70	1.4
kW (APP)+kW (LTS)	295.51	.265	3.79	.000	.181	.46	2.2	kW (APP)+kW (LTS)/Capita	389.27	.319	5.81	.000	.267	.70	1.4
CON.RM.AR	38.72	.164	2.35	.019	.112	.47	2.2	-	-	-	-	-	-	-	-
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	869.77		8.71	.000				(Constant)	90.01		4.95	.000			
GIFA	4.08	.228	4.03	.000	.187	.68	1.5	GIFA	4.91	.273	5.01	.000	.241	.78	1.3
kW (APP)+kW (LTS)	414.62	.378	6.69	.000	.311	.68	1.5	WM	396.42	.187	3.52	.000	.169	.82	1.2
-	-	-	-	-	-	-	-	kW (APP)+kW (LTS)/Capita	267.39	.218	3.65	.000	.176	.66	1.5
Gas use per household model								**Gas use per capita model**							
(Constant)	-627.04		-3.52	.000				(Constant)	-71.31		-3.46	.001			
GIFA	23.1	.653	15.30	.000	.653	1.0	1.0	GIFA/CAPITA	21.85	.730	18.96	.000	.730	1.0	1.0

Table 8.18 Appendix C-Rawalpindi-1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	2316.612	1194.173	kWh/yr.	387.372	188.528
GIFA	100.625	76.362	GIFA	16.109	9.896
CON.RMS	1.51	.811	FN	.8315	.577
FN	4.90	3.178	CON.RMS	.258	.1281
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2325.365	1253.258	kWh/yr.	388.788	199.208
GIFA	101.698	79.139	GIFA	16.28	10.496
kWh (LTS)	1.279	.881	APP	1.119	.789
kW (APP)+kW (LTS)	1.0942	.877	kWh (APP)+kWh (LTS)/Capita	1.056	.782
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2316.612	1194.173	kWh/yr.	387.372	188.528
GIFA	100.625	76.362	GIFA	16.109	9.896
CON.RMS	1.51	.811	FN	.8315	.577
FN	4.90	3.178	CON.RMS	.258	.128
kWh (LTS)	1.279	.87635	kWh (APP)+kWh (LTS)/Capita	1.051	.771
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	3857.977	4465.685	kWh/yr./capita	639.113	705.929
GIFA	102.105	87.266	GIFA/CAPITA	16.032	12.047
OCC	6.166	1.617	-	-	-

Table 8.19 Appendix C-Rawalpindi-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	498.59		2.69	.008				(Constant)	90.1		2.59	.010			
GIFA	3.58	.229	3.07	.003	.180	.62	1.6	GIFA	3.5	.184	2.51	.013	.156	.72	1.4
CON.RMS	562.51	.382	5.12	.000	.300	.62	1.6	FN	141.5	.433	6.81	.000	.423	.95	1.1
FN	124.52	.331	5.65	.000	.331	.99	1.1	CON.RMS	476.5	.324	4.51	.000	.280	.75	1.4
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	872.15		5.89	.000				(Constant)	142.76		5.07	.000			
GIFA	5.44	.344	5.59	.000	.318	.85	1.2	GIFA	5.85	.308	4.79	.000	.286	.86	1.2
kWh (LTS)	361.86	.255	4.15	.000	.236	.86	1.2	APP	83.94	.333	4.19	.000	.250	.57	1.8
kW (APP)+kW (LTS)	399.19	.280	4.33	.000	.246	.77	1.3	kWh (APP)+kWh (LTS)/Capita	53.71	.211	2.57	.011	.153	.53	1.9
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	449.3		2.45	.015				(Constant)	100.91		2.88	.004			
GIFA	2.99	.191	2.54	.012	.147	.59	1.7	GIFA	3.31	.174	2.37	.019	.146	.71	1.4
CON.RMS	563.66	.383	5.21	.000	.301	.62	1.6	FN	117.74	.361	4.79	.000	.296	.67	1.5
FN	80.04	.213	2.82	.005	.163	.59	1.7	CON.RMS	377.49	.257	3.17	.002	.196	.58	1.7
kWh (LTS)	254.17	.187	2.45	.015	.141	.57	1.8	kWh (APP)+kWh (LTS)/Capita	35.87	.147	1.78	.077	.110	.56	1.8
Gas use per household model								**Gas use per capita model**							
(Constant)	1136.58		.71	.48				(Constant)	597.38		5.65	.000			
GIFA	5.83	.114	1.12	.27	.099	.76	1.3	GIFA/CAPITA	2.61	.044	.493	.623	.044	1.0	1.0
OCC	344.75	.125	1.22	.23	.109	.76	1.3	-	-	-	-	-	-	-	-

Table 8.20 Appendix C- Sahiwal -1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	2588.09	1408.16	kWh/yr.	410.472	190.66
OCC	6.39	2.45	GIFA	17.51402	9.567
GIFA	108.943	65.99	FN (kW)	.0349	.0281
FN	3.95	1.990	CON.RMS	.328	.1519
ACONC (kWh)	3.32	4.140	CON.RM.AR	.837	1.031
MW (kWh)	.291	.507	-	-	-
FTL (kW)	.064	.092	-	-	-
CON.RMS	1.98	1.144	-	-	-
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2591.37	1434.65	kWh/yr.	410.664	195.458
OCC	6.38	2.488	GIFA	17.7631	10.950
GIFA	109.613	68.394	kWh (APP)+kWh (LTS)/Capita	2.543	1.540
APP+LTS	18.4508	9.467	-	-	-
kW (APP)+kW (LTS)	2.707	1.855	-	-	-
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2588.093	1408.161	kWh/yr.	410.47	190.668
GIFA	108.94	65.993	GIFA	17.514	9.567
FN	3.95	1.990	FN (kW)	.0349	.0281
MW (kWh)	.29114	.507440	CON.RMS	.328	.151
CON.RMS	1.98	1.144	CON.RM.AR	.837	1.031
APP+LTS	18.42	9.27	kW (APP)+kW (LTS)	2.701	1.833
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	4990.31	4238.14	kWh/yr./capita	814.088	682.66
GIFA	116.76	67.55	GIFA/CAPITA	18.23	12.097

Table 8.21 Appendix C- Sahiwal -2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	53.37		.29	.77				(Constant)	160.65		5.88	.000			
OCC	71.05	.124	2.43	.016	.09	.65	1.6	GIFA	4.19	.210	3.97	.000	.195	.86	1.2
GIFA	4.83	.226	4.47	.000	.18	.66	1.6	FN (kW)	1499.19	.221	4.35	.000	.214	.93	1.1
FN	171.01	.242	5.21	.000	.21	.78	1.3	CON.RMS	235.64	.188	3.01	.003	.148	.62	1.6
ACONC (kWh)	35.39	.104	1.97	.050	.08	.61	1.7	CON.RM.AR	55.68	.301	4.79	.000	.235	.61	1.7
MW (kWh)	305.91	.110	2.52	.012	.10	.88	1.1	-	-	-	-	-	-	-	-
FTL (kW)	1806.52	.118	2.59	.010	.11	.81	1.3	-	-	-	-	-	-	-	-
CON.RMS	280.57	.228	4.11	.000	.17	.55	1.8	-	-	-	-	-	-	-	-
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	292.50		1.75	.082				(Constant)	171.79		8.45	.000			
OCC	67.07	.116	2.17	.031	.090	.59	1.7	GIFA	4.29	.241	4.55	.000	.217	.82	1.3
GIFA	5.03	.240	4.55	.000	.188	.62	1.7	kWh (APP)+kWh (LTS)/Capita	63.91	.504	9.53	.000	.455	.82	1.2
APP+LTS	36.51	.241	3.67	.000	.152	.39	2.5	-	-	-	-	-	-	-	-
kW (APP)+kW (LTS)	238.31	.308	5.08	.000	.210	.46	2.2	-	-	-	-	-	-	-	-
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	138.58		.910	.364				(Constant)	132.31		4.64	.000			
GIFA	5.41	.253	5.101	.000	.211	.69	1.5	GIFA	4.21	.211	4.05	.000	.196	.86	1.2
FN	123.29	.174	3.171	.002	.131	.57	1.8	FN (kW)	1431.03	.211	4.21	.000	.203	.93	1.1
MW (kWh)	311.32	.112	2.534	.012	.105	.88	1.2	CON.RMS	221.08	.176	2.87	.005	.138	.62	1.6
CON.RMS	360.26	.293	5.899	.000	.244	.69	1.4	CON.RM.AR	40.64	.220	3.26	.001	.157	.51	1.9
APP+LTS	30.92	.204	3.101	.002	.128	.39	2.5	kW (APP)+kW (LTS)	17.69	.170	2.98	.003	.144	.72	1.4
Gas use per household model								**Gas use per capita model**							
(Constant)	2874.91		4.41	.000				(Constant)	350.52		3.96	.000			
GIFA	18.12	.289	3.74	.000	.289	1.0	1.0	GIFA/CAPITA	25.43	.451	6.28	.000	.451	1.0	1.0

Table 8.22 Appendix C-Multan-1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	1634.22	1130.94	kWh/yr.	241.15	178.96
GIFA	120.53	64.074	GIFA	17.72	9.99
ACONC	.30	.652	ACONC	.043	.10
WM	.54	.581	TV	.11	.095
VC	.04	.188	EF	.063	.13
FRG (kW)	.194	.244	WM	.075	.085
TV (kW)	.134	.14	FRG (kW)	.027	.035
COM.LAP (kW)	.043	.0801	COM.LAP (kW)	.006	.011
EF (kWh)	.032	.0721	VC (kW)	.003	.016
CON.RMS	1.2	1.1	MW (kWh)	.022	.064
			CON.RMS	.19	.19
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1634.22	1130.94	kWh/yr.	241.15	178.96
GIFA	120.53	64.08	GIFA	17.71	9.99
kW (APP)+kW (LTS)	1.45	1.67	kW (APP)	.179	.246
CON.RMS	1.19	1.074	CON.RMS	.191	.196
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1634.22	1130.94	kWh/yr.	241.15	178.955
GIFA	120.53	64.08	GIFA	17.715	9.995
WM	.54	.581	WM	.075	.0855
FRG (kW)	.19	.24	FRG (kW)	.0265	.035
TV (kW)	.130	.107	VC (kW)	.003	.0159
COM.LAP (kW)	.043	.080	CON.RMS	.190	.196
EF (kWh)	.032	.072	kW (APP)+kW (LTS)/Capita	.202	.258
CON.RMS	1.19	1.07	-	-	-
kW (APP)+kW (LTS)	1.44	1.67	-	-	-
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	5443.39	4388.98	kWh/yr./capita	736.01	601.67
GIFA	124.08	74.026	GIFA/CAPITA	17.19	11.01
OCC	7.52	1.98	-	-	-

Table 8.23 Appendix C-Multan-2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	358		4.67	.000				(Constant)	45.7		4.14	.000			
GIFA	1.7	.098	3.14	.002	.080	.67	1.5	GIFA	2.5	.136	4.37	.000	.107	.62	1.6
ACONC	271.2	.156	3.87	.000	.099	.40	2.5	ACONC	258.9	.145	3.74	.000	.092	.39	2.5
WM	399.1	.205	6.61	.000	.169	.68	1.5	TV	130.2	.069	2.23	.026	.055	.62	1.6
VC	506.6	.084	2.74	.006	.070	.69	1.4	EF	109.5	.081	2.84	.005	.069	.73	1.4
FRG (kW)	686.8	.146	5.29	.000	.136	.86	1.2	WM	423.1	.201	6.22	.000	.152	.57	1.8
TV (kW)	1328.8	.126	4.13	.000	.106	.71	1.4	FRG (kW)	711.9	.138	5.17	.000	.126	.84	1.2
COM.LAP (kW)	1505.1	.107	3.37	.001	.086	.65	1.5	COM.LAP (kW)	923.9	.060	1.89	.060	.046	.58	1.7
EF (kWh)	1229.4	.078	2.78	.006	.071	.83	1.2	VC (kW)	977.71	.087	3.10	.002	.076	.77	1.3
CON.RMS	285.8	.271	7.41	.000	.190	.49	2.1	MW (kWh)	219.5	.078	2.71	.007	.066	.72	1.4
-	-	-	-	-	-	-	-	CON.RMS	292.66	.321	9.75	.000	.238	.55	1.8
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	584.9		8.7	.000				(Constant)	76.4		8.25	.000			
GIFA	2.1	.120	3.74	.000	.102	.72	1.4	GIFA	2.7	.148	4.75	.000	.121	.66	1.5
kW (APP)+kW (LTS)	397.5	.588	15.24	.000	.415	.49	2.1	kW (APP)	417.9	.575	19.25	.000	.489	.72	1.4
CON.RMS	185.1	.176	4.73	.000	.129	.54	1.9	CON.RMS	224.5	.246	7.41	.000	.188	.58	1.7
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	313.4		4.35	.000				(Constant)	48.3		4.86	.000			
GIFA	1.85	.105	3.43	.001	.088	.70	1.4	GIFA	2.6	.144	4.72	.000	.115	.64	1.6
WM	299.7	.154	4.59	.000	.117	.58	1.7	WM	349.3	.166	4.92	.000	.120	.52	1.9
FRG (kW)	605.4	.129	4.68	.000	.120	.86	1.2	FRG (kW)	634.9	.123	4.59	.000	.112	.83	1.2
TV (kW)	1071.41	.102	3.26	.001	.083	.67	1.5	VC (kW)	811.8	.072	2.61	.009	.063	.78	1.3
COM.LAP (kW)	1155.2	.082	2.46	.014	.063	.59	1.7	CON.RMS	264.9	.291	9.03	.000	.220	.57	1.8
EF (kWh)	983.8	.063	2.19	.029	.056	.80	1.3	kW (APP)+kW (LTS)/Capita	253.4	.365	8.8	.000	.214	.34	2.9
CON.RMS	279.027	.265	7.258	.000	.185	.490	2.1	-	-	-	-	-	-	-	
kW (APP)+kW (LTS)	183.894	.272	5.01	.000	.128	.222	4.5	-	-	-	-	-	-	-	-
Gas use per household model								**Gas use per capita model**							
(Constant)	1241.9		1.32	.189				(Constant)	582.9		9.55	.000			
GIFA	3.9	.067	1.21	.227	.065	.94	1.1	GIFA/CAPITA	8.9	.163	2.98	.003	.163	1.0	1.0
OCC	492.9	.223	4.03	.000	.217	.94	1.1	-	-	-	-	-	-	-	-

Table 8.24 Appendix C- Bahawalpur -1, Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	2961.245	1740.499	kWh/yr.	415.345	232.322
OCC	7.420	2.085	GIFA	20.692	10.869
GIFA	151.056	81.736	FN	.592	.324
FTL (kW)	.0472	.0753	FTL (kW)	.0068	.0109
CON.RMS	1.75	1.216	CON.RMS	.2485	.166
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2967.1942	1769.815	kWh/yr.	416.533	238.487
GIFA	151.146	82.532	GIFA	20.766	11.233
kW (APP)+kW (LTS)	2.450	2.105	LTS	1.43163	1.0116
			kW (APP)+kW (LTS)/Capita	.34731	.3138
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2961.245	1740.499	kWh/yr.	415.345	232.322
GIFA	151.056	81.736	GIFA	20.692	10.869
FTL (kW)	.0472	.0753	FN	.592	.324
CON.RMS	1.75	1.216	FTL (kW)	.0068	.0109
APP	10.105	5.255	CON.RMS	.248	.166
kWh (APP)	6.685	8.4588	kW (APP)	.309	.280
			kWh (APP)	.969	1.225
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	2550.213	3638.250	kWh/yr./capita	370.969	583.712
GIFA	152.618	84.402	GIFA/CAPITA	20.914	11.348

Table 8.25 Appendix C- Bahawalpur -2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	169.97		.88	.378				(Constant)	53.50		2.83	.005			
OCC	68.11	.082	2.47	.014	.072	.78	1.3	GIFA	3.62	.169	5.28	.000	.158	.87	1.2
GIFA	3.65	.172	4.98	.000	.146	.72	1.4	FN	92.57	.129	4.00	.000	.120	.86	1.2
FTL (kW)	2375.25	.103	3.36	.001	.098	.92	1.1	FTL (kW)	1957.91	.092	2.79	.005	.084	.83	1.2
CON.RMS	928.76	.649	20.49	.000	.600	.85	1.2	CON.RMS	879.87	.630	19.53	.000	.584	.86	1.2
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	925.48		6.42	.000				(Constant)	166.31		8.25	.000			
GIFA	7.55	.352	9.37	.000	.343	.95	1.1	GIFA	5.16	.243	5.99	.000	.225	.86	1.2
kW (APP)+kW (LTS)	367.30	.437	11.62	.000	.426	.95	1.1	LTS	39.82	.169	3.17	.002	.119	.49	2.1
								kW (APP)+kW (LTS)/Capita	247.76	.326	6.16	.000	.231	.51	1.9
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	248.07		1.86	.063				(Constant)	46.85		2.49	.013			
GIFA	4.66	.219	7.25	.000	.205	.88	1.2	GIFA	4.08	.191	6.00	.000	.176	.85	1.2
FTL (kW)	2219.88	.096	3.11	.002	.088	.84	1.2	FN	86.46	.121	3.46	.001	.101	.70	1.4
CON.RMS	957.75	.669	20.39	.000	.577	.74	1.3	FTL (kW)	2017.98	.095	2.88	.004	.084	.79	1.3
APP	47.14	.142	4.34	.000	.123	.74	1.3	CON.RMS	888.78	.636	18.25	.000	.534	.70	1.4
kWh (APP)	-36.45	-.177	-5.39	.000	-.153	.74	1.4	kW (APP)	95.55	.115	2.73	.007	.080	.48	2.1
								kWh (APP)	-32.38	-.171	-4.64	.000	-.136	.63	1.6
Gas use per household model								**Gas use per capita model**							
(Constant)	-222.89		-.68	.499				(Constant)	-59.45		-1.09	.272			
GIFA	18.17	.422	9.63	.000	.422	1.0	1.0	GIFA/CAPITA	20.58	.400	9.05	.000	.400	1.0	1.0

Table 8.26 Appendix C- Dera Ghazi Khan -1. Calculated values from the physical survey for selected predictive variables

Descriptive Statistics					
PER HOUSEHOLD			**PER CAPITA**		
Electricity use per household of Detailed model			**Electricity use per capita of Detailed model**		
Variable	**Mean-unit**	**Std. Deviation**	**Variable**	**Mean-unit**	**Std. Deviation**
kWh/yr.	1568.843	1152.351	kWh/yr.	232.946	164.107
FRG	.71	.579	FRG	.103	.0861
TV (kW)	.111	.0911	FN (kWh)	.197	.123
ACONC (kWh)	.668	2.0251	ACONC (kWh)	.0911	.280
CON.RM.AR	3.131	4.673	CON.RMS	.211	.100
Electricity use per household of Grouped model			**Electricity use per capita of Grouped model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1568.843	1152.351	kWh/yr.	234.306	169.101
kWh (APP)	4.198	4.475	kWh (APP)	.6217	.684
CON.RM.AR	3.131	4.6736			
Electricity use per household Combined model			**Electricity use per capita Combined model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	1568.843	1152.351	kWh/yr.	232.946	164.107
FRG	.71	.579	FRG	.103	.0861
CON.RM.AR	3.131	4.673	CON.RMS	.211	.100
kW (APP)	.755	.866	kW (APP)	.109	.122
Gas use per household model			**Gas use per capita model**		
Variable	**Mean**	**Std. Deviation**	**Variable**	**Mean**	**Std. Deviation**
kWh/yr.	7120.863	3577.455	kWh/yr./capita	1041.441	522.164
OCC	6.909	1.413	GIFA/CAPITA	15.424	6.129

Table 8.27 Appendix C- Dera Ghazi Khan -2, Predictive Coefficients for final annual electric and gas use per household and capita models

Coefficients															
Electricity use per household of Detailed model								**Electricity use per Capita of Detailed model**							
Variables	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**	**Variables**	**B**	**Beta**	**t**	**Sig.**	**Correlations part**	**Tolerance**	**VIF**
(Constant)	616.12		7.49	.000				(Constant)	40.35		2.52	.012			
FRG	728.59	.366	10.24	.000	.355	.94	1.1	FRG	675.67	.355	9.68	.000	.339	.91	1.1
TV (kW)	1248.93	.099	2.62	.009	.091	.84	1.2	FN (kWh)	103.31	.078	2.05	.041	.072	.85	1.2
ACONC (kWh)	194.27	.341	7.02	.000	.243	.51	1.9	ACONC (kWh)	206.78	.353	8.54	.000	.299	.72	1.4
CON.RM.AR	53.43	.217	4.74	.000	.164	.57	1.8	CON.RMS	393.09	.242	5.66	.000	.198	.67	1.5
Electricity use per household of Grouped model								**Electricity use per Capita of Grouped model**							
(Constant)	809.42		14.00	.000				(Constant)	130.28		15.41	.000			
kWh (APP)	139.08	.540	12.08	.000	.439	.66	1.5	kWh (APP)	167.33	.678	18.29	.000	.678	1.0	1.0
CON.RM.AR	56.04	.227	5.08	.000	.185	.66	1.5								
Electricity use per household of Combined model								**Electricity use per Capita of Combined model**							
(Constant)	561.47		8.68	.000				(Constant)	29.48		2.06	.040			
FRG	576.69	.290	7.90	.000	.269	.86	1.2	FRG	574.27	.301	8.15	.000	.281	.87	1.2
CON.RM.AR	49.90	.202	4.66	.000	.158	.61	1.6	CON.RMS	396.41	.244	6.01	.000	.207	.72	1.4
kW (APP)	586.14	.441	9.65	.000	.328	.55	1.8	kW (APP)	549.02	.411	9.57	.000	.330	.65	1.6
Gas use per household model								**Gas use per capita model**							
(Constant)	2016.69		1.69	.091				(Constant)	945.24		9.65	.000			
OCC	738.69	.292	4.38	.000	.292	1.0	1.0	GIFA/CAPITA	6.24	.073	1.06	.292	.073	1.0	1.0

8.10 Appendix-C-Timings-1 (monthly demand timings)

January: **Wednesdays** are the days of the highest electricity demand whose average value (17.3%) is 1.25 times more than average demand for the rest of the week (13.8%). The average values of weekdays and weekends are 14.9% & 12.7% respectively.

February: Wednesdays are the days of the highest electricity demand whose average value (15.3%) is 1.09 times more than the average demand for the rest of the week (14.1%). The average values of weekdays and weekends are 14.4% & 14.1% respectively.

March: Wednesdays are the days of the highest electricity demand whose average value (17.6%) is 1.28 times more than the average demand for the rest of the week (13.8%). The average values of weekdays and weekends are 14.6% & 13.6% respectively.

April: Sundays are the days of the highest electricity demand whose average value (16.6%) is 1.20 times more than average demand for the rest of the week (13.8%). The average values of weekdays and weekends are 13.8% & 15.4% respectively.

May: Thursdays are the days of the highest electricity demand whose average value (16.1%) is 1.16 times more than the average demand for the rest of the week (13.9%). The average values of weekdays and weekends are 14.6% & 13.4% respectively.

June: Saturdays are the days of the highest electricity demand whose average value (17.3%) is 1.06 times more than the average demand for the rest of the week (16.4%). The average values of weekdays and weekends are 13.6% & 16.1% respectively.

July: Tuesdays are the days of the highest electricity demand whose average value (16.6%) is 1.21 times more than the average demand for the rest of the week (13.7%). The average values of weekdays and weekends are 14.4% & 14.0% respectively.

August: Wednesdays are the days of the highest electricity demand whose average value (17.7%) is 1.29 times more than the average demand for the rest of the week (13.7%). The average values of weekdays and weekends are 14.8% & 12.9% respectively.

September: Fridays are the days of the highest electricity demand whose average value (16.8%) is 1.21 times more than the average demand for the rest of the week (13.9%). The average values of weekdays and weekends are 14.2% & 14.5% respectively.

October: Sundays is the day of the highest electricity demand whose average value (17.4%) is 1.26 times more than average demand for the rest of the week (13.8%). The average values of weekdays and weekends are 14.1% & 14.6% respectively.

November: Wednesdays are the days of the highest electricity demand whose average value (16.9%) is 1.22 times more than average need for the rest of the week (13.9%). The average values of weekdays and weekends are 14.8% & 13.1% respectively.

December: Fridays are the days of the highest electricity demand whose average value (16.3%) is 1.17 times more than average need for the rest of the week (13.9%). The average values of weekdays and weekends are 13.7% & 15.8% respectively.

8.11 Appendix-C-Timings-2

Winter Season:

January: Wednesday, precisely the night-time hourly demand is between 4-4.5% of total day's need and daytime demand is around 4-5.%. However, daytime demand falls to 3% in early night hours and goes to 4.5% from 19:00 to 22:00hrs and drops again after 22:00hrs. During the day the demand drops to 4% between 14:00-16:00hrs and then increases in the afternoon Figure 5.24. Weekdays and weekends follow the similar patterns of daily demands that high demand during the day and lower during nights. Though weekend demands are higher during early night times at 18:00hrs Figure 5.25. It implies, as most of the demand occurs during day time, the green energy produced during the day can be used straight away without storage. Still, we do need 4-4.5%/hr of daily electrical energy during the night (for around 13:45 hrs), there is need to have storage capability for about 14hrs for 4-4.5%/hr demand to meet the night demands by green energy, i.e. by solar PV.

February: (Wednesday) precisely the night demand is between 4-5% of total day's demand except around 18:00-19:00hrs it goes to 4.5%, and daytime demand is around 3-3.5% where peak demand starts to increase about 14:00hrs till 15:00 hrs Figure 5.24. Further, we found that weekdays and weekends follow similar demand patterns except weekdays have slightly more demand during early night hours (18:00-22:00) while weekends have more needs during early morning hours(07:00-12:00hrs) Figure 5.25. It implies, as most of the demand occurs during night-time, the green energy produced during the day can be used straight away without storage. Still, we do need 4-5% of daily electrical energy during the night (for around 13:15hrs), there is a need for storage to meet the night demands by green energy.

November: (Wednesdays) Precisely the night demand is between 3.5-4% of total day's demand except around 19:00hrs it goes to 5%, and daytime demand is around 4.0 -5.5% where peak demand occurs about 11:00hrs, rest of the day the demand fluctuates between 4.0-4.5% Figure 5.24. We found the almost similar demand profiles on average weekdays and weekends values with little variations, i.e. during weekends demand becomes highest around 9:00hrs & 17:00hrs and at night it falls about 20:00hrs Figure 5.25. It implies, as most of the demand occurs during day time, the green energy produced during the day can be used straight away without storage. Still, we do need 3.5-4% of daily electrical energy during the night, and we need to store electricity for the night for around 13:10hrs.

December: (Fridays) Precisely, the night demand is between 3.5-4.5% of total day's demand, and daytime demand is around 4-4.5 % and remains the same throughout the day Figure 5.24. We found almost similar demand profiles on average weekdays and weekends values with little variations, i.e. the average demand stays between 3-4.5%, and its high during the late-night weekends hours, i.e.

01:00-05:00hrs Figure 5.25. It indicates, as most of the demand stays the same during the day, the green energy produced during the day should be able to meet the night-time demand for around 13:48hrs.

We found that overall, during the winter season, the percentage of electrical energy demand is higher during the daytime. However, the night demands are lower; we have longer night hours than a day; we need to have the solar storage capacity to meet night demand.

Spring Season:

March: (Wednesdays) Precisely the night demand is highest 5.0% at 19:00hrs, after this the demand starts decreasing and reaches 3.5% for the rest of the night. The day demand is usually high throughout the day around 4.5%, with a little spike between 8:00-11:00hrs and 14:00hrs, where it reaches 5% Figure 5.24. We found the almost similar demand profiles on average weekdays and weekends values with little variations, i.e. the average demand stays high during the day around 4.5% at 8:00hrs than night demand, however, the weekdays night demand is a bit higher after midnight Figure 5.25. It shows as the demand occurs mostly during the daytime, this demand can be met by the Solar PV and we do need back-up storage to meet the average night demand of 3.5% for 12:23hrs.

April: (Sundays) the average demand value has more or less equal demand during day and night, i.e. between 4-4.5% Figure 5.24. We noticed the almost similar demand profiles on average weekdays and weekends values with little variations, i.e. the average demand stays constant throughout the day and night for the whole week, however, for weekdays there is a slight increase in demand between 14:00-17:00hrs Figure 5.25. As the length of day and night are approximately the same, we need to have a storage capability for the night-time energy demand of 4-4.5% for 11:23hrs.

We found that for spring season the electrical energy demand is little higher during the night in march but almost similar demand during April, further, the length of days and nights are same, and we need to have a solar PV system which should not provide the need for daytime energy but equally should have the capacity to store energy for night time for approximately 12 hours.

Autumn Season:

October: (Sundays): the day demand is between 3.5-4.0% of total day's demand except around 8:00hrs it goes to 4.5%. Night-time demand is around 4.0-4.5.0% where it increases to 5.5% around 20:00hrs; it is essential to note that early during night hours the demand stays high above 4.5% and after midnight it decreases to 4% or less Figure 5.24. We noticed similar demand profiles on average weekdays and weekends values with little variations, i.e. the average demand stays high during the early night hours and lowers after midnight. However, weekends' demands are slightly higher than weekdays, especially during the late-night between 20:00-24:00hrs, while weekdays demands are a little higher between 13:00-17:00hrs Figure 5.25. It indicates, as most of the demand occurs during the night, we need to store energy to meet 4.0-5.5% night demand for the period of around 12:15hrs.

To meet the electrical energy demand by solar PV during the autumn season we need to know if the solar PV's designed to meet the day and night demands of other seasons can fulfil the demand of the autumn season. This will be discussed in the next objective.

Summer Season:

May: (Thursdays) the night demand is between 4.0-5.2% of total day's need and daytime demand is around 3.5-4.0% (and fluctuates throughout the daytime), it becomes maximum during 16:00-17:00hrs and touches 4.5%. however, the night-time demand starts increasing after 19:00hrs and becomes highest around 22:00(around 5.2%), the night demand starts decreasing after 01:00hrs.(5.2%) till 05:00hrs(4.0%) and becomes equal to daytime requirements, the difference of day and night electrical energy demand is only 0.75% (higher during the night) Figure 5.24. We noticed that weekdays and weekends follow the same pattern as of peak demand days, i.e. Thursdays, throughout the month Figure 5.25. However, weekdays' demands are higher during the night from 18:00hrs till 24:00hrs and weekends demands are higher during the day between 07:00-17:00hrs. It means, as higher demand occurs during the night, we need to have larger storage capacities to store green energy. Fortunately, we have longer days (13:30 hrs) than nights, so there is a higher potential to generate and store more energy during the day.

June: (Fridays) the night demand is between 3.5-4.5% of the total day's demand, and daytime demand is around 4.0-5.0%. However, the night-time demand is higher during the earlier night hours (19:00) and drops down during late night at 22:00hrs, the difference of day and night electrical energy demand is only 0.5% (higher during the day) Figure 5.24. We found that the average weekdays and weekends demand follows a similar demand with little variations, i.e. during weekends demand drops around 14:00hrs till 17:00hrs after that it starts increasing and stays high 22:00hrs, as compared to weekdays Figure 5.25. It implies, as higher demand occurs during night-time (weekends), we need larger storage capacities to store green energy, and fortunately, we have longer days (14:07 hrs) than nights, so there is higher potential to store more energy.

July: (Saturdays) the night demand is between 3.5-4.5% of total day's demand, and daytime demand is around 3.5-5.0% (and stays constant throughout the daytime). However, the night-time demand is highest at 19:00hrs till 23:00hrs, the difference of day and night electrical energy demand is about 1.0% (higher during the day) Figure 5.24. We noticed that weekdays and weekends follow the same demand pattern, where weekend's needs are a little higher during late evenings and weekday's demands are slightly more during mid-day Figure 5.25. It implies, as higher demand occurs during day-time, we need to have sufficient storage capacities to store green energy. Fortunately, we have longer days (14:08 hrs) than nights, so there is a higher potential to generate and save more energy.

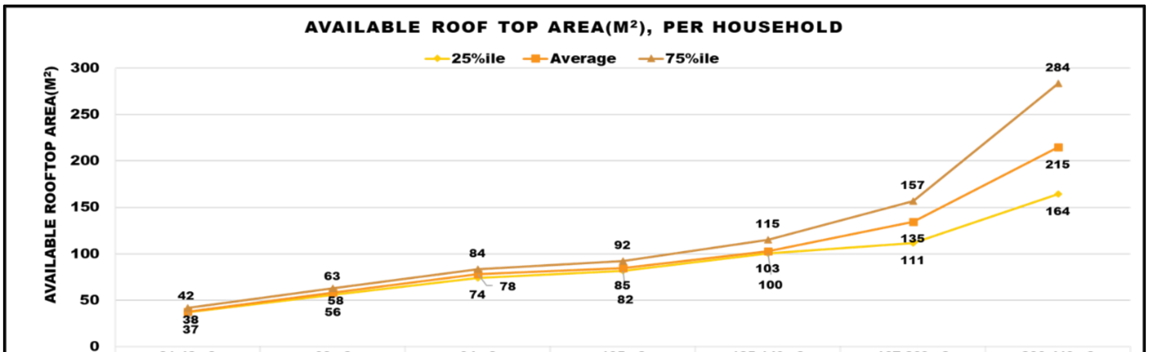
August: (Wednesdays) Precisely the night demand is between 4.0-6.0% of total day's need and daytime demand is around 3.0-4.5% (and fluctuates throughout the daytime). however, the night-time demand starts increasing after 21:00hrs and becomes highest around midnight (about 6%), the night demand starts decreasing after 02:00hrs. (5.5%) till 05:00hrs (4.0%) the difference of day and night electrical energy demand is only 1.5% (higher during the night) Figure 5.24. We noticed that weekdays and weekends follow the same pattern as of peak demand days, i.e. Wednesdays, throughout the month Figure 5.25. However, weekends' demands are higher during the day and weekdays' requirements are higher during the night. It means, as higher demand occurs during night-time, we need to have larger storage capacities to store green energy. Fortunately, we have longer days (13:35 hrs) than nights, so there is a higher potential to generate and store more energy during the day.

September: (Fridays) the night demand is between 4.0-5.0% of total day's demand and daytime demand is around 3.0-4.5% (and fluctuates throughout the daytime). However, the night-time demand starts increasing after 19:00hrs and becomes highest around 21:00(about 5.2%), after that demand starts decreasing till 24:00hr (4.5%), the difference of day and night electrical energy demand is only 0.5% (higher during the night) Figure 5.24. We noticed that weekdays and weekends follow the same pattern of demand throughout the day, where night demand is slighter higher than day demands Figure 5.25. It means, as higher demand occurs during nighttime, we need to have larger storage capacities to store green energy. Fortunately, we have longer days (12:40 hrs) than nights, so there is a higher potential to generate and store more energy during the day.

We conclude that summer electrical energy demands follow a dual pattern, i.e. higher day and night in different months. However, the length of the summer nights is smaller, and the days are approximately 2 hours longer. This longer day times of sunshine availability would enable us to generate and store more of green energy by solar PV's. It was understood that maybe the weekends would be the days of higher energy demand, but we found that each month has different days of peak electrical energy demand.

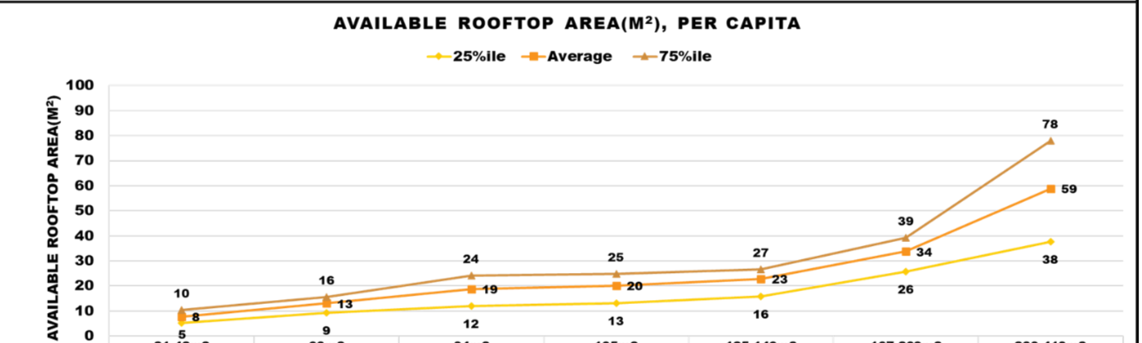
Appendix D

Table 8.28 Appendix-D-1



	21-42m2	63m2	84m2	105m2	125-146m2	167-209m2	230-418m2
25%ile	37	56	74	82	100	111	164
Average	38	58	78	85	103	135	215
75%ile	42	63	84	92	115	157	284

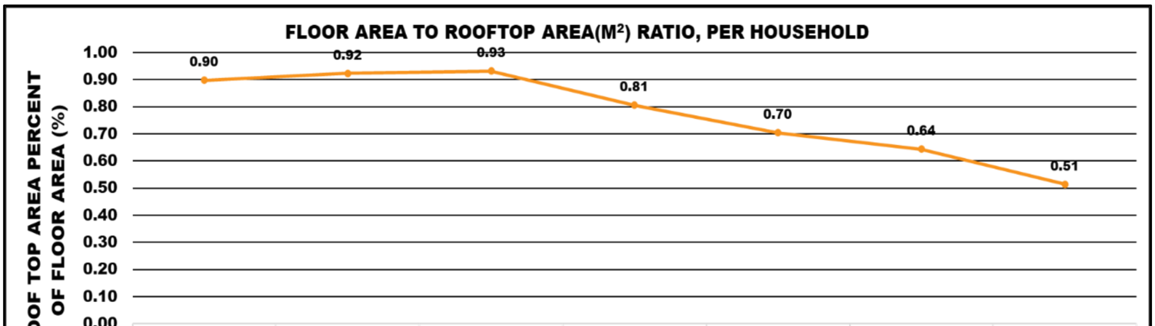
HOUSE SIZES(M²)



	21-42m2	63m2	84m2	105m2	125-146m2	167-209m2	230-418m2
25%ile	5	9	12	13	16	26	38
Average	8	13	19	20	23	34	59
75%ile	10	16	24	25	27	39	78

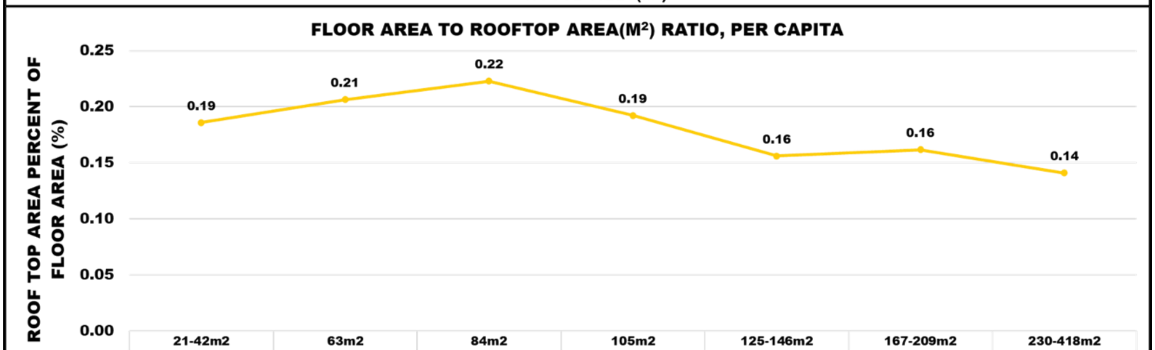
HOUSE SIZES(M²)

Table 8.29 Appendix-D-2



	21-42m2	63m2	84m2	105m2	125-146m2	167-209m2	230-418m2
Ratio	0.90	0.92	0.93	0.81	0.70	0.64	0.51

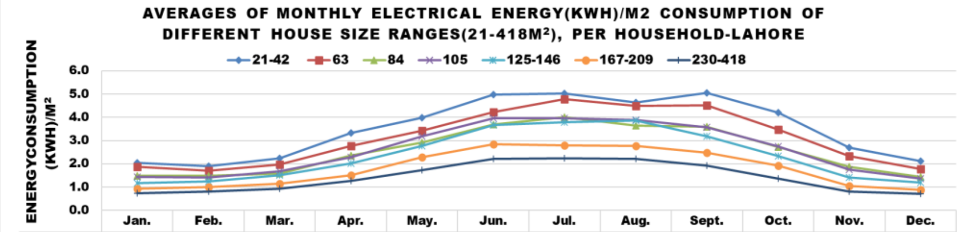
HOUSE SIZES(M²)



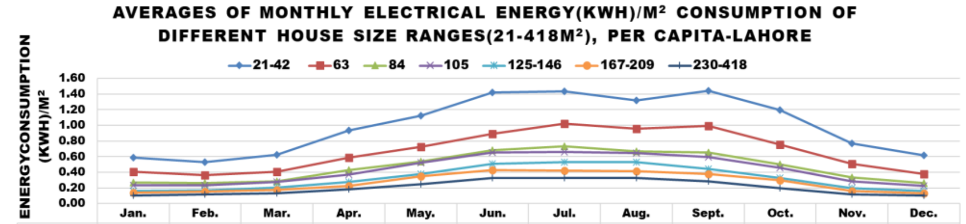
	21-42m2	63m2	84m2	105m2	125-146m2	167-209m2	230-418m2
Ratio	0.19	0.21	0.22	0.19	0.16	0.16	0.14

HOUSE SIZES(m²)

Table 8.30 Appendix -D-Lahore -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	2.0	1.9	2.2	3.3	4.0	5.0	5.0	4.6	5.1	4.2	2.7	2.1
63	1.9	1.7	2.0	2.8	3.4	4.2	4.8	4.5	4.5	3.5	2.3	1.8
84	1.5	1.5	1.6	2.4	2.9	3.7	4.0	3.6	3.6	2.7	1.9	1.4
105	1.4	1.4	1.7	2.3	3.2	4.0	4.0	3.9	3.6	2.8	1.7	1.4
125-146	1.2	1.2	1.5	2.0	2.8	3.7	3.8	3.9	3.2	2.3	1.4	1.2
167-209	0.9	1.0	1.2	1.5	2.3	2.9	2.8	2.8	2.5	1.9	1.1	0.9
230-418	0.7	0.8	0.9	1.3	1.7	2.2	2.3	2.2	1.9	1.4	0.8	0.7

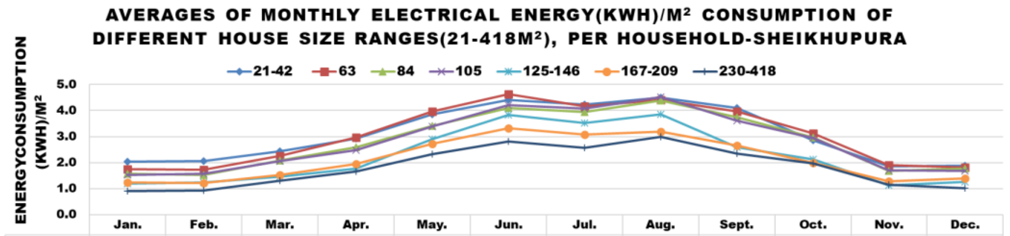


	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.59	0.53	0.62	0.94	1.12	1.42	1.44	1.32	1.44	1.20	0.77	0.61
63	0.41	0.36	0.41	0.59	0.73	0.89	1.02	0.96	0.99	0.76	0.50	0.38
84	0.27	0.26	0.28	0.43	0.54	0.68	0.73	0.67	0.65	0.50	0.34	0.26
105	0.23	0.23	0.27	0.37	0.52	0.65	0.66	0.64	0.59	0.46	0.29	0.23
125-146	0.16	0.17	0.20	0.27	0.37	0.51	0.53	0.53	0.44	0.32	0.19	0.16
167-209	0.14	0.15	0.17	0.23	0.35	0.43	0.42	0.42	0.38	0.30	0.16	0.13
230-418	0.11	0.12	0.13	0.18	0.25	0.33	0.33	0.33	0.28	0.20	0.12	0.10

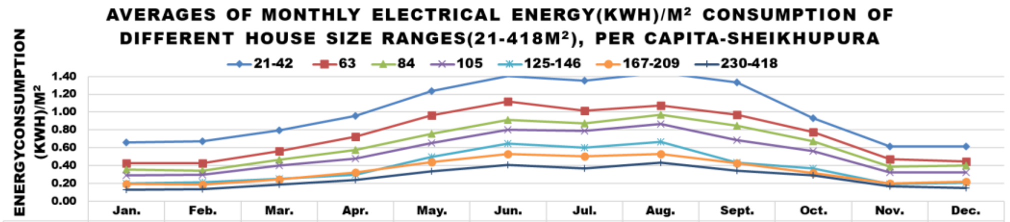
Table 8.31 Appendix -D-Lahore -2

LAHORE DIVISION														
PER HOUSEHOLD														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
21-42m²	25% ile	1.2	1.2	1.5	1.8	2.5	2.9	2.9	2.7	3.2	2.6	1.6	1.3	**2.1**
	Median	1.9	1.7	2.1	3.2	3.7	4.9	4.8	4.4	4.9	4.0	2.5	2.1	**3.3**
	75% ile	2.7	2.5	2.9	4.4	5.2	6.5	6.8	6.1	6.6	5.3	3.5	2.6	**4.6**
63m²	25% ile	1.2	1.1	1.4	2.0	2.3	2.7	3.0	2.9	3.1	2.3	1.6	1.3	**2.1**
	Median	1.7	1.5	1.9	2.7	3.1	3.9	4.3	3.9	4.3	3.4	2.1	1.6	**2.9**
	75% ile	2.3	2.2	2.3	3.4	4.2	5.1	5.8	5.4	5.8	4.4	2.8	2.2	**3.8**
84m²	25% ile	1.1	1.1	1.1	1.6	2.0	2.2	2.4	2.1	2.1	1.8	1.3	1.1	**1.7**
	Median	1.3	1.4	1.5	2.2	2.7	3.1	3.3	3.2	3.3	2.4	1.6	1.3	**2.3**
	75% ile	1.8	1.8	2.1	2.9	3.7	4.7	5.1	4.4	4.6	3.5	2.4	1.8	**3.2**
105m²	25% ile	0.9	0.9	1.1	1.5	1.9	2.4	2.6	2.4	2.1	1.7	1.1	0.9	**1.6**
	Median	1.3	1.3	1.6	2.2	2.7	3.4	3.8	3.5	3.2	2.4	1.5	1.3	**2.3**
	75% ile	1.7	1.8	2.2	2.8	4.1	4.8	5.0	5.0	4.7	3.5	2.1	1.6	**3.3**
125-146m²	25% ile	0.8	0.9	1.0	1.4	1.6	2.4	2.5	2.6	2.1	1.5	1.0	0.8	**1.5**
	Median	1.0	1.2	1.4	2.0	2.4	3.3	3.4	3.6	2.9	2.1	1.3	1.1	**2.1**
	75% ile	1.3	1.4	2.0	2.3	3.4	4.7	4.5	4.7	3.9	3.0	1.7	1.4	**2.9**
167-209m²	25% ile	0.6	0.7	0.8	1.1	1.7	1.9	2.0	1.7	1.4	1.1	0.7	0.6	**1.2**
	Median	0.7	0.9	1.2	1.3	2.1	2.8	2.7	2.9	2.2	1.3	0.9	0.8	**1.6**
	75% ile	1.2	1.2	1.4	1.8	2.8	3.6	3.5	3.4	3.4	2.6	1.2	1.1	**2.3**
230-418m²	25% ile	0.4	0.5	0.6	0.9	1.2	1.5	1.5	1.4	1.2	0.8	0.5	0.4	**0.9**
	Median	0.6	0.7	0.8	1.1	1.5	1.9	2.0	2.2	1.6	1.1	0.7	0.6	**1.2**
	75% ile	1.0	1.0	1.1	1.5	2.0	2.6	2.6	2.7	2.4	1.7	1.1	0.8	**1.7**
PER CAPITA														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
21-42m²	25% ile	0.34	0.35	0.40	0.59	0.71	0.85	0.83	0.74	0.87	0.72	0.47	0.36	**0.60**
	Median	0.49	0.48	0.57	0.85	1.08	1.24	1.25	1.15	1.29	1.03	0.68	0.54	**0.89**
	75% ile	0.72	0.64	0.80	1.18	1.38	1.74	1.74	1.60	1.93	1.60	0.94	0.78	**1.25**
63m²	25% ile	0.23	0.23	0.28	0.39	0.47	0.62	0.65	0.60	0.60	0.46	0.29	0.24	**0.42**
	Median	0.33	0.32	0.35	0.53	0.67	0.82	0.92	0.86	0.89	0.70	0.44	0.33	**0.60**
	75% ile	0.46	0.45	0.51	0.69	0.91	1.07	1.17	1.08	1.23	0.94	0.62	0.48	**0.80**
84m²	25% ile	0.17	0.17	0.19	0.26	0.30	0.38	0.42	0.37	0.39	0.27	0.20	0.16	**0.27**
	Median	0.22	0.22	0.26	0.38	0.50	0.60	0.63	0.60	0.55	0.43	0.30	0.23	**0.41**
	75% ile	0.31	0.33	0.36	0.54	0.75	0.89	0.96	0.89	0.86	0.68	0.41	0.34	**0.61**
105m²	25% ile	0.14	0.14	0.17	0.23	0.30	0.36	0.36	0.35	0.32	0.25	0.17	0.13	**0.24**
	Median	0.20	0.21	0.24	0.33	0.43	0.54	0.57	0.56	0.49	0.37	0.23	0.20	**0.37**
	75% ile	0.28	0.27	0.36	0.45	0.71	0.88	0.81	0.80	0.80	0.58	0.38	0.28	**0.55**
125-146m²	25% ile	0.10	0.11	0.14	0.17	0.23	0.29	0.30	0.31	0.26	0.18	0.12	0.10	**0.19**
	Median	0.13	0.16	0.18	0.25	0.33	0.48	0.48	0.49	0.37	0.29	0.17	0.14	**0.29**
	75% ile	0.18	0.20	0.27	0.33	0.44	0.65	0.66	0.67	0.57	0.40	0.23	0.19	**0.40**
167-209m²	25% ile	0.08	0.09	0.11	0.15	0.22	0.27	0.24	0.24	0.20	0.14	0.09	0.08	**0.16**
	Median	0.11	0.13	0.16	0.22	0.32	0.38	0.36	0.35	0.33	0.21	0.13	0.11	**0.23**
	75% ile	0.19	0.18	0.22	0.30	0.44	0.59	0.56	0.58	0.51	0.37	0.19	0.17	**0.36**
230-418m²	25% ile	0.06	0.07	0.09	0.11	0.15	0.18	0.19	0.17	0.15	0.11	0.07	0.06	**0.12**
	Median	0.08	0.10	0.11	0.15	0.22	0.27	0.30	0.30	0.24	0.16	0.10	0.08	**0.18**
	75% ile	0.12	0.14	0.15	0.22	0.32	0.42	0.39	0.40	0.36	0.24	0.16	0.13	**0.25**

Table 8.32 Appendix -D-Sheikhupura -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	2.0	2.1	2.4	2.9	3.9	4.4	4.2	4.5	4.1	2.9	1.9	1.9
63	1.7	1.7	2.3	3.0	4.0	4.6	4.2	4.4	4.0	3.1	1.9	1.8
84	1.6	1.5	2.1	2.6	3.4	4.1	4.0	4.4	3.7	3.0	1.7	1.8
105	1.5	1.6	2.0	2.5	3.4	4.2	4.1	4.5	3.6	3.0	1.7	1.7
125-146	1.2	1.2	1.5	1.8	2.9	3.8	3.5	3.9	2.6	2.1	1.1	1.3
167-209	1.2	1.2	1.5	2.0	2.7	3.3	3.1	3.2	2.7	2.0	1.3	1.4
230-418	0.9	0.9	1.3	1.7	2.3	2.8	2.6	3.0	2.4	2.0	1.1	1.0



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.66	0.67	0.79	0.96	1.23	1.41	1.35	1.44	1.33	0.93	0.61	0.62
63	0.43	0.43	0.56	0.72	0.97	1.12	1.02	1.07	0.97	0.78	0.47	0.45
84	0.36	0.34	0.47	0.58	0.76	0.91	0.87	0.97	0.84	0.67	0.39	0.40
105	0.29	0.30	0.40	0.48	0.65	0.81	0.79	0.87	0.69	0.56	0.32	0.32
125-146	0.20	0.21	0.25	0.30	0.50	0.65	0.60	0.66	0.43	0.37	0.19	0.21
167-209	0.20	0.19	0.25	0.32	0.44	0.53	0.50	0.53	0.43	0.32	0.20	0.22
230-418	0.13	0.13	0.19	0.24	0.33	0.41	0.37	0.43	0.34	0.29	0.17	0.15

Table 8.33 Appendix -D-Sheikhupura -2

SHEIKHUPURA DIVISION

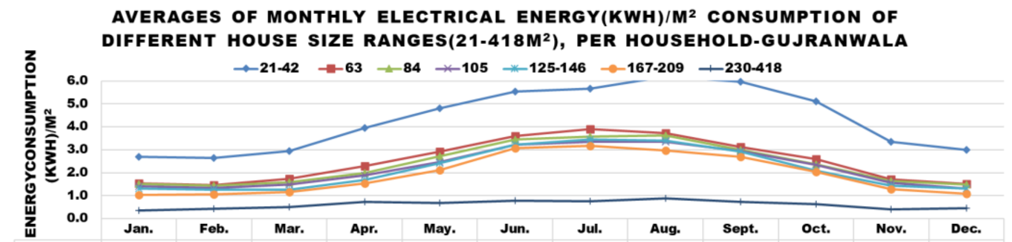
PER HOUSEHOLD

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	1.0	1.1	1.4	1.9	2.0	2.6	2.5	2.4	2.5	1.8	1.3	0.9	**1.8**
	Median	1.8	1.7	2.2	2.8	3.6	3.7	3.8	3.8	3.9	2.9	1.6	1.8	**2.8**
	75% ile	2.7	2.6	3.0	3.8	5.0	5.2	5.2	5.4	5.0	3.7	2.4	2.4	**3.9**
63m²	25% ile	1.1	1.1	1.6	1.9	2.6	2.6	2.2	2.7	2.6	2.0	1.2	1.1	**1.9**
	Median	1.5	1.6	2.0	2.9	3.7	4.2	3.8	4.2	3.6	3.0	1.6	1.7	**2.8**
	75% ile	2.2	2.0	2.7	3.7	5.0	6.0	5.6	5.6	5.0	3.9	2.4	2.2	**3.8**
84m²	25% ile	1.0	0.9	1.5	1.8	2.2	2.5	2.5	2.9	2.8	2.1	1.2	1.0	**1.9**
	Median	1.4	1.3	1.8	2.3	2.9	3.7	3.5	3.8	3.4	2.6	1.5	1.5	**2.5**
	75% ile	1.9	1.8	2.7	3.2	4.3	5.4	5.2	5.1	4.3	3.2	2.0	2.2	**3.5**
105m²	25% ile	0.9	0.9	1.2	1.6	2.3	3.3	3.1	3.3	2.2	1.6	1.2	1.1	**1.9**
	Median	1.4	1.4	1.8	2.4	3.3	4.2	4.0	4.6	3.1	2.6	1.5	1.5	**2.7**
	75% ile	2.0	2.1	2.8	3.1	4.1	5.0	4.9	5.7	4.4	3.5	2.0	2.2	**3.5**
125-146m²	25% ile	0.8	0.8	0.9	1.0	2.1	2.5	2.5	2.6	1.8	1.5	0.7	0.8	**1.5**
	Median	1.0	1.0	1.4	1.7	2.9	3.8	3.6	4.0	2.4	1.9	1.0	1.0	**2.1**
	75% ile	1.2	1.5	1.9	2.4	3.6	4.8	4.7	4.8	3.3	2.4	1.3	1.6	**2.8**
167-209m²	25% ile	0.7	0.7	1.0	1.4	2.0	2.3	1.9	2.3	2.1	1.6	0.8	0.8	**1.5**
	Median	0.9	1.1	1.3	1.7	2.4	2.9	3.3	3.2	2.6	1.9	1.1	1.3	**2.0**
	75% ile	1.3	1.5	2.1	2.5	3.5	4.2	4.2	4.4	3.1	2.3	1.7	1.5	**2.7**
230-418m²	25% ile	0.7	0.6	0.9	1.3	2.0	2.2	1.9	2.2	2.0	1.5	0.8	0.7	**1.4**
	Median	0.7	0.8	1.3	1.6	2.1	3.0	2.4	2.9	2.2	1.9	1.0	0.9	**1.7**
	75% ile	1.2	1.3	1.5	1.8	3.0	3.3	3.3	4.0	2.5	2.4	1.4	1.1	**2.2**

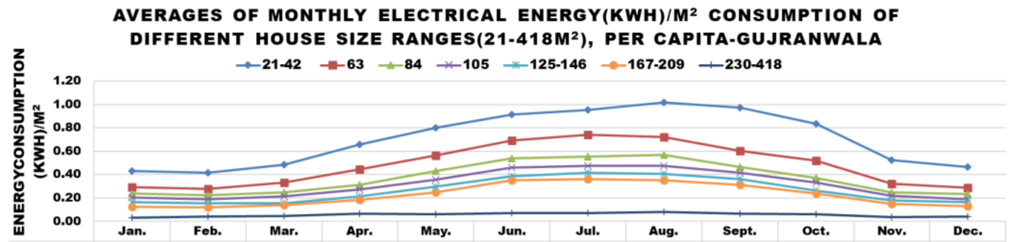
PER CAPITA

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.31	0.33	0.42	0.58	0.66	0.82	0.80	0.81	0.85	0.58	0.38	0.33	**0.57**
	Median	0.60	0.57	0.74	0.91	1.16	1.24	1.20	1.20	1.22	0.91	0.52	0.55	**0.90**
	75% ile	0.85	0.83	0.95	1.27	1.66	1.71	1.66	1.71	1.59	1.22	0.75	0.83	**1.25**
63m²	25% ile	0.26	0.28	0.38	0.46	0.68	0.70	0.57	0.75	0.68	0.55	0.28	0.29	**0.49**
	Median	0.37	0.39	0.54	0.68	0.96	1.08	1.00	1.05	0.89	0.69	0.40	0.39	**0.70**
	75% ile	0.54	0.54	0.69	0.92	1.19	1.39	1.29	1.36	1.23	0.96	0.60	0.60	**0.94**
84m²	25% ile	0.20	0.20	0.31	0.40	0.51	0.56	0.55	0.64	0.57	0.45	0.25	0.22	**0.41**
	Median	0.30	0.28	0.39	0.51	0.65	0.77	0.75	0.88	0.82	0.63	0.32	0.33	**0.55**
	75% ile	0.47	0.42	0.59	0.71	0.96	1.17	1.10	1.22	1.02	0.79	0.50	0.52	**0.79**
105m²	25% ile	0.17	0.18	0.24	0.33	0.45	0.62	0.62	0.65	0.40	0.34	0.22	0.21	**0.37**
	Median	0.27	0.26	0.35	0.43	0.62	0.79	0.74	0.83	0.57	0.48	0.29	0.29	**0.49**
	75% ile	0.38	0.40	0.58	0.55	0.79	0.90	0.87	1.06	0.82	0.67	0.41	0.39	**0.65**
125-146m²	25% ile	0.12	0.11	0.14	0.16	0.29	0.37	0.44	0.41	0.31	0.25	0.12	0.13	**0.24**
	Median	0.17	0.18	0.23	0.27	0.50	0.61	0.55	0.62	0.40	0.34	0.17	0.17	**0.35**
	75% ile	0.24	0.25	0.34	0.39	0.69	0.77	0.77	0.88	0.56	0.39	0.24	0.27	**0.48**
167-209m²	25% ile	0.11	0.12	0.15	0.21	0.29	0.36	0.32	0.35	0.36	0.24	0.13	0.14	**0.23**
	Median	0.17	0.19	0.21	0.27	0.38	0.54	0.48	0.47	0.41	0.31	0.19	0.20	**0.32**
	75% ile	0.26	0.25	0.34	0.36	0.59	0.67	0.63	0.66	0.48	0.39	0.28	0.25	**0.43**
230-418m²	25% ile	0.09	0.09	0.11	0.16	0.26	0.31	0.30	0.29	0.26	0.21	0.10	0.11	**0.19**
	Median	0.11	0.12	0.22	0.25	0.29	0.37	0.33	0.41	0.29	0.24	0.16	0.12	**0.24**
	75% ile	0.15	0.16	0.24	0.28	0.44	0.45	0.44	0.50	0.39	0.34	0.18	0.15	**0.31**

Table 8.34 Appendix -D-Gujranwala -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	2.7	2.6	2.9	3.9	4.8	5.5	5.7	6.2	6.0	5.1	3.3	3.0
63	1.5	1.5	1.7	2.3	2.9	3.6	3.9	3.7	3.1	2.6	1.7	1.5
84	1.5	1.4	1.6	2.0	2.7	3.4	3.6	3.6	3.0	2.4	1.6	1.5
105	1.4	1.3	1.5	1.9	2.5	3.2	3.3	3.3	2.9	2.3	1.6	1.3
125-146	1.3	1.2	1.3	1.7	2.4	3.2	3.4	3.4	2.9	2.1	1.4	1.3
167-209	1.0	1.0	1.2	1.5	2.1	3.1	3.2	3.0	2.7	2.0	1.3	1.1
230-418	0.3	0.4	0.5	0.7	0.7	0.8	0.8	0.9	0.7	0.6	0.4	0.4

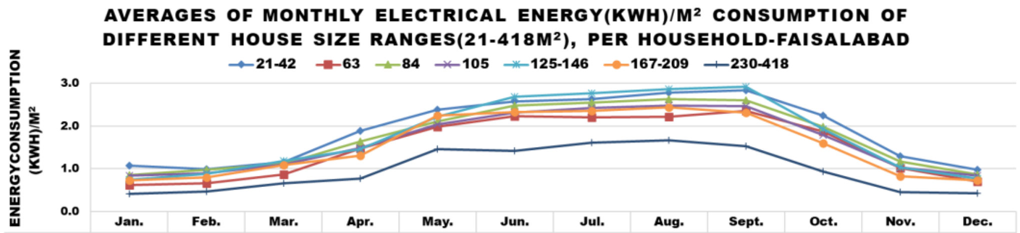


	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.43	0.42	0.49	0.66	0.80	0.91	0.95	1.02	0.97	0.83	0.53	0.47
63	0.29	0.28	0.33	0.45	0.56	0.69	0.74	0.72	0.61	0.52	0.32	0.29
84	0.24	0.23	0.25	0.31	0.43	0.54	0.55	0.57	0.47	0.37	0.25	0.23
105	0.20	0.19	0.22	0.27	0.36	0.46	0.48	0.47	0.42	0.33	0.22	0.19
125-146	0.17	0.16	0.15	0.21	0.30	0.39	0.41	0.41	0.36	0.26	0.18	0.16
167-209	0.12	0.12	0.14	0.19	0.25	0.35	0.36	0.35	0.31	0.24	0.15	0.13
230-418	0.03	0.04	0.05	0.07	0.06	0.07	0.07	0.08	0.06	0.06	0.04	0.04

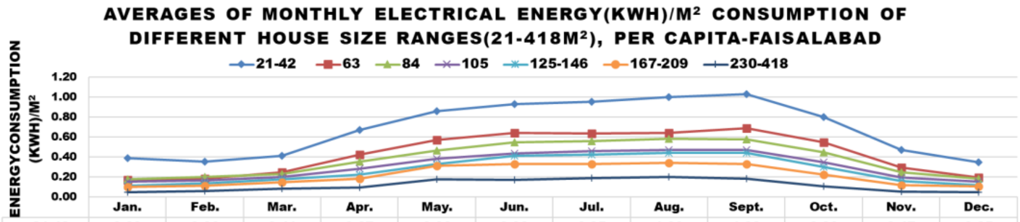
Table 8.35 Appendix -D-Gujranwala -2

GUJRANWALA DIVISION														
PER HOUSEHOLD														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
$21\text{-}42m^2$	25% ile	1.2	1.1	1.3	1.9	2.4	2.7	2.7	2.8	3.1	2.8	1.3	1.2	**2.0**
	Median	2.3	2.2	2.7	3.6	4.3	5.0	5.1	5.6	5.7	4.8	2.9	2.5	**3.9**
	75% ile	3.5	3.6	4.1	5.7	6.7	7.7	7.8	8.5	8.1	7.0	4.5	4.0	**5.9**
$63m^2$	25% ile	1.0	0.9	1.0	1.5	1.9	2.3	2.5	2.5	2.1	1.6	1.1	1.1	**1.6**
	Median	1.4	1.4	1.6	2.2	2.9	3.7	3.9	3.6	2.7	2.4	1.6	1.5	**2.4**
	75% ile	1.8	1.8	2.2	2.8	3.7	4.4	4.6	4.5	3.7	3.2	2.2	1.8	**3.1**
$84m^2$	25% ile	1.1	1.1	1.2	1.5	2.0	2.8	2.8	2.7	2.0	1.6	1.2	1.2	**1.8**
	Median	1.4	1.4	1.5	2.0	2.6	3.2	3.4	3.4	2.6	2.1	1.5	1.4	**2.2**
	75% ile	1.8	1.8	1.9	2.4	3.3	3.9	4.0	4.1	3.7	2.9	1.9	1.7	**2.8**
$105m^2$	25% ile	1.0	0.9	1.0	1.4	1.8	2.3	2.4	2.3	1.9	1.5	1.1	1.0	**1.6**
	Median	1.2	1.2	1.4	1.8	2.4	2.8	2.9	2.9	2.6	1.9	1.4	1.2	**2.0**
	75% ile	1.7	1.6	1.7	2.2	2.8	3.7	4.0	4.1	3.6	2.9	1.8	1.6	**2.7**
$125\text{-}146m^2$	25% ile	0.9	0.9	0.8	1.2	1.8	2.1	2.2	2.3	1.7	1.3	1.0	0.9	**1.4**
	Median	1.2	1.2	1.2	1.5	2.2	3.0	3.1	2.9	2.6	1.8	1.3	1.1	**1.9**
	75% ile	1.6	1.5	1.6	2.0	2.9	4.1	4.5	4.6	3.4	2.5	1.7	1.5	**2.7**
$167\text{-}209m^2$	25% ile	0.6	0.7	0.8	1.1	1.5	2.4	2.5	1.9	1.6	1.3	0.9	0.7	**1.3**
	Median	0.9	1.0	1.0	1.3	2.2	3.2	3.2	3.1	2.9	1.9	1.1	0.9	**1.9**
	75% ile	1.3	1.3	1.4	1.7	2.3	3.7	4.2	4.0	3.3	2.5	1.6	1.2	**2.4**
$230\text{-}418m^2$	25% ile	0.3	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.6	0.5	0.4	0.3	**0.5**
	Median	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	0.8	0.6	0.4	0.3	**0.6**
	75% ile	0.4	0.4	0.5	0.8	0.8	0.9	0.8	1.0	0.9	0.7	0.5	0.5	**0.7**
PER CAPITA														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
$21\text{-}42m^2$	25% ile	0.23	0.23	0.27	0.39	0.48	0.54	0.56	0.61	0.56	0.50	0.29	0.26	**0.41**
	Median	0.37	0.35	0.43	0.61	0.73	0.84	0.84	0.89	0.87	0.76	0.45	0.39	**0.63**
	75% ile	0.55	0.56	0.65	0.85	1.01	1.17	1.22	1.30	1.26	1.07	0.70	0.61	**0.91**
$63m^2$	25% ile	0.20	0.19	0.21	0.30	0.41	0.49	0.49	0.49	0.39	0.34	0.23	0.21	**0.33**
	Median	0.25	0.25	0.30	0.39	0.55	0.65	0.68	0.65	0.55	0.44	0.32	0.28	**0.44**
	75% ile	0.34	0.33	0.42	0.53	0.64	0.83	0.84	0.86	0.72	0.63	0.39	0.34	**0.57**
$84m^2$	25% ile	0.17	0.16	0.18	0.22	0.30	0.40	0.41	0.41	0.32	0.24	0.19	0.17	**0.26**
	Median	0.22	0.21	0.23	0.30	0.40	0.48	0.51	0.51	0.40	0.31	0.23	0.21	**0.33**
	75% ile	0.26	0.27	0.30	0.37	0.51	0.64	0.67	0.66	0.58	0.46	0.28	0.27	**0.44**
$105m^2$	25% ile	0.13	0.13	0.15	0.18	0.25	0.32	0.33	0.32	0.26	0.21	0.15	0.14	**0.21**
	Median	0.18	0.17	0.19	0.25	0.33	0.39	0.41	0.40	0.37	0.29	0.20	0.17	**0.28**
	75% ile	0.24	0.22	0.25	0.33	0.42	0.53	0.55	0.55	0.51	0.42	0.26	0.22	**0.37**
$125\text{-}146m^2$	25% ile	0.11	0.10	0.09	0.13	0.21	0.26	0.27	0.26	0.19	0.14	0.12	0.10	**0.16**
	Median	0.13	0.13	0.14	0.17	0.25	0.32	0.35	0.36	0.29	0.20	0.14	0.13	**0.22**
	75% ile	0.18	0.17	0.18	0.26	0.34	0.47	0.48	0.47	0.43	0.32	0.20	0.17	**0.31**
$167\text{-}209m^2$	25% ile	0.07	0.07	0.07	0.10	0.15	0.22	0.21	0.19	0.20	0.15	0.08	0.07	**0.13**
	Median	0.09	0.10	0.12	0.13	0.18	0.34	0.36	0.31	0.28	0.19	0.13	0.09	**0.19**
	75% ile	0.14	0.14	0.16	0.21	0.30	0.44	0.48	0.49	0.41	0.33	0.18	0.15	**0.29**
$230\text{-}418m^2$	25% ile	0.03	0.04	0.04	0.06	0.06	0.07	0.06	0.08	0.05	0.04	0.04	0.03	**0.05**
	Median	0.03	0.04	0.05	0.06	0.06	0.07	0.07	0.09	0.07	0.04	0.04	0.03	**0.05**
	75% ile	0.04	0.04	0.05	0.07	0.06	0.07	0.07	0.09	0.08	0.07	0.04	0.05	**0.06**

Table 8.36 Appendix -D-Faisalabad -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	1.1	1.0	1.2	1.9	2.4	2.6	2.6	2.8	2.8	2.2	1.3	1.0
63	0.6	0.7	0.9	1.5	2.0	2.2	2.2	2.2	2.4	1.9	1.0	0.7
84	0.9	1.0	1.1	1.6	2.1	2.5	2.5	2.6	2.6	2.0	1.2	0.9
105	0.8	0.9	1.1	1.5	2.0	2.3	2.4	2.5	2.5	1.8	1.0	0.8
125-146	0.7	0.9	1.2	1.5	2.2	2.7	2.8	2.9	2.9	1.9	1.0	0.8
167-209	0.7	0.8	1.1	1.3	2.2	2.3	2.4	2.4	2.3	1.6	0.8	0.7
230-418	0.4	0.5	0.7	0.8	1.5	1.4	1.6	1.7	1.5	0.9	0.5	0.4

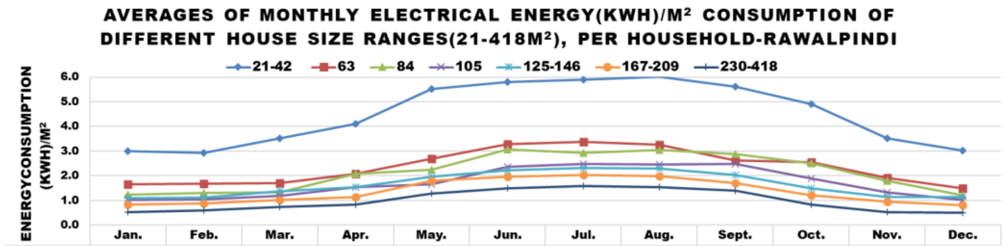


	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.39	0.36	0.41	0.67	0.86	0.93	0.95	1.00	1.03	0.80	0.47	0.35
63	0.17	0.18	0.25	0.42	0.57	0.64	0.63	0.64	0.69	0.55	0.30	0.20
84	0.18	0.20	0.23	0.35	0.46	0.55	0.56	0.58	0.58	0.45	0.25	0.18
105	0.15	0.16	0.20	0.28	0.38	0.44	0.46	0.47	0.47	0.35	0.19	0.16
125-146	0.12	0.14	0.18	0.22	0.33	0.41	0.42	0.44	0.44	0.30	0.16	0.12
167-209	0.10	0.11	0.15	0.19	0.31	0.33	0.33	0.34	0.33	0.23	0.12	0.10
230-418	0.05	0.06	0.08	0.09	0.18	0.17	0.19	0.20	0.18	0.11	0.06	0.05

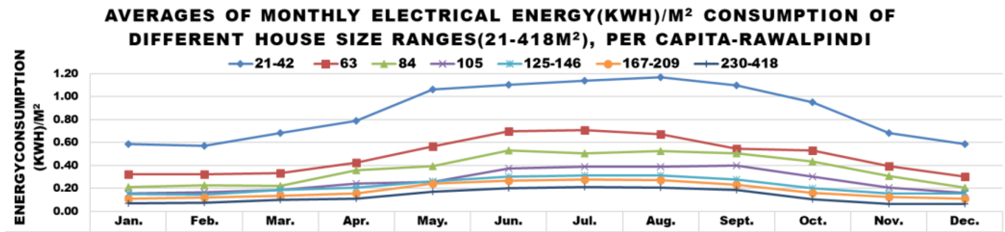
Table 8.37 Appendix -D-Faisalabad -2

FAISALABAD DIVISION														
PER HOUSEHOLD														
House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.6	0.6	0.7	1.1	1.3	1.5	1.7	1.7	1.7	1.2	0.7	0.5	**1.1**
	Median	0.9	0.9	1.0	1.6	2.3	2.4	2.5	2.8	2.7	2.3	1.1	0.9	**1.8**
	75% ile	1.4	1.3	1.4	2.7	3.4	3.5	3.4	3.5	3.5	2.9	1.7	1.4	**2.5**
63m²	25% ile	0.3	0.3	0.5	0.8	1.4	1.7	1.7	1.7	1.8	1.5	0.6	0.3	**1.1**
	Median	0.5	0.5	0.8	1.3	2.1	2.3	2.3	2.3	2.3	1.8	1.0	0.5	**1.5**
	75% ile	0.8	0.9	1.0	2.0	2.5	2.7	2.7	2.7	2.7	2.2	1.3	1.0	**1.9**
84m²	25% ile	0.4	0.5	0.5	0.9	1.5	1.7	1.7	1.8	1.8	1.5	0.6	0.5	**1.1**
	Median	0.8	0.8	1.1	1.6	2.0	2.3	2.2	2.3	2.5	1.9	1.2	0.8	**1.6**
	75% ile	1.2	1.5	1.4	2.2	2.6	3.1	3.2	3.2	3.2	2.3	1.5	1.2	**2.2**
105m²	25% ile	0.5	0.5	0.6	1.0	1.5	1.5	1.6	1.6	1.7	1.4	0.7	0.4	**1.1**
	Median	0.8	0.8	1.1	1.4	1.9	2.2	2.2	2.3	2.3	1.7	1.0	0.7	**1.5**
	75% ile	1.2	1.2	1.5	1.9	2.3	2.6	2.6	2.6	2.6	2.2	1.3	1.2	**1.9**
125-146m²	25% ile	0.5	0.6	0.7	1.0	1.5	1.7	1.7	1.9	1.7	1.2	0.7	0.4	**1.1**
	Median	0.7	0.8	1.1	1.4	2.0	2.5	2.7	2.6	2.6	1.6	0.9	0.8	**1.7**
	75% ile	1.0	1.2	1.6	1.8	3.2	3.6	3.4	3.4	3.5	2.4	1.2	1.0	**2.3**
167-209m²	25% ile	0.6	0.6	0.8	1.1	1.7	1.7	1.9	2.0	1.8	1.2	0.6	0.6	**1.2**
	Median	0.7	0.8	1.2	1.2	2.3	2.4	2.5	2.6	2.4	1.5	0.7	0.7	**1.6**
	75% ile	0.8	0.9	1.3	1.4	3.0	2.7	2.7	2.7	2.8	1.8	0.9	0.8	**1.8**
230-418m²	25% ile	0.3	0.4	0.6	0.6	1.3	1.2	1.4	1.5	1.4	0.6	0.4	0.4	**0.8**
	Median	0.4	0.4	0.6	0.7	1.4	1.4	1.7	1.7	1.5	0.9	0.4	0.4	**1.0**
	75% ile	0.5	0.5	0.7	0.9	1.5	1.7	1.8	1.8	1.8	1.1	0.5	0.5	**1.1**
PER CAPITA														
House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.20	0.20	0.27	0.42	0.51	0.57	0.61	0.65	0.65	0.47	0.28	0.19	**0.42**
	Median	0.31	0.31	0.36	0.55	0.76	0.82	0.89	0.99	0.94	0.78	0.40	0.30	**0.62**
	75% ile	0.45	0.42	0.48	0.86	1.15	1.18	1.16	1.20	1.29	1.08	0.57	0.48	**0.86**
63m²	25% ile	0.08	0.10	0.15	0.25	0.36	0.44	0.48	0.50	0.52	0.39	0.18	0.11	**0.30**
	Median	0.15	0.16	0.20	0.36	0.54	0.62	0.64	0.62	0.66	0.55	0.26	0.16	**0.41**
	75% ile	0.22	0.23	0.32	0.55	0.76	0.78	0.78	0.79	0.83	0.70	0.42	0.24	**0.55**
84m²	25% ile	0.10	0.11	0.14	0.22	0.30	0.37	0.39	0.40	0.44	0.30	0.15	0.11	**0.25**
	Median	0.16	0.17	0.21	0.36	0.45	0.54	0.56	0.56	0.58	0.45	0.21	0.17	**0.37**
	75% ile	0.21	0.25	0.29	0.46	0.57	0.65	0.65	0.67	0.67	0.57	0.32	0.23	**0.46**
105m²	25% ile	0.09	0.09	0.13	0.18	0.29	0.30	0.30	0.31	0.30	0.23	0.13	0.09	**0.20**
	Median	0.13	0.16	0.19	0.25	0.34	0.39	0.41	0.42	0.46	0.33	0.17	0.13	**0.28**
	75% ile	0.20	0.20	0.25	0.35	0.48	0.54	0.56	0.57	0.58	0.44	0.24	0.21	**0.38**
125-146m²	25% ile	0.08	0.09	0.12	0.17	0.23	0.29	0.28	0.28	0.29	0.20	0.10	0.08	**0.18**
	Median	0.10	0.12	0.15	0.20	0.30	0.38	0.41	0.41	0.40	0.22	0.14	0.11	**0.25**
	75% ile	0.15	0.17	0.22	0.26	0.43	0.46	0.48	0.49	0.50	0.35	0.18	0.14	**0.32**
167-209m²	25% ile	0.07	0.08	0.11	0.12	0.23	0.24	0.25	0.26	0.21	0.16	0.07	0.07	**0.16**
	Median	0.09	0.10	0.14	0.16	0.29	0.30	0.33	0.34	0.33	0.20	0.10	0.09	**0.21**
	75% ile	0.13	0.14	0.18	0.22	0.38	0.41	0.40	0.43	0.41	0.25	0.12	0.12	**0.27**
230-418m²	25% ile	0.04	0.04	0.06	0.06	0.12	0.13	0.15	0.15	0.14	0.08	0.04	0.04	**0.09**
	Median	0.04	0.05	0.07	0.08	0.17	0.15	0.18	0.18	0.16	0.10	0.05	0.05	**0.11**
	75% ile	0.06	0.06	0.09	0.11	0.20	0.19	0.22	0.22	0.22	0.12	0.06	0.06	**0.13**

Table 8.38 Appendix -D-Rawalpindi -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	3.0	2.9	3.5	4.1	5.5	5.8	5.9	6.0	5.6	4.9	3.5	3.0
63	1.7	1.7	1.7	2.1	2.7	3.3	3.4	3.2	2.6	2.6	1.9	1.5
84	1.2	1.3	1.3	2.1	2.2	3.1	2.9	3.0	2.9	2.5	1.8	1.2
105	1.0	1.0	1.2	1.5	1.6	2.4	2.5	2.4	2.5	1.9	1.3	1.0
125-146	1.1	1.1	1.4	1.5	2.0	2.2	2.3	2.3	2.0	1.5	1.1	1.1
167-209	0.8	0.9	1.0	1.1	1.8	1.9	2.0	2.0	1.7	1.2	0.9	0.8
230-418	0.5	0.6	0.7	0.8	1.3	1.5	1.6	1.5	1.4	0.8	0.5	0.5



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.58	0.57	0.68	0.79	1.06	1.10	1.14	1.17	1.10	0.95	0.68	0.59
63	0.32	0.32	0.33	0.42	0.57	0.70	0.71	0.67	0.55	0.53	0.39	0.30
84	0.21	0.22	0.22	0.36	0.39	0.53	0.51	0.52	0.50	0.43	0.31	0.21
105	0.16	0.16	0.19	0.24	0.26	0.38	0.39	0.39	0.40	0.30	0.21	0.16
125-146	0.15	0.15	0.18	0.21	0.26	0.30	0.31	0.31	0.28	0.20	0.15	0.16
167-209	0.11	0.12	0.14	0.16	0.24	0.27	0.28	0.27	0.23	0.16	0.13	0.11
230-418	0.07	0.08	0.10	0.11	0.17	0.20	0.21	0.21	0.19	0.11	0.07	0.07

Table 8.39 Appendix -D-Rawalpindi -2

RAWALPINDI DIVISION

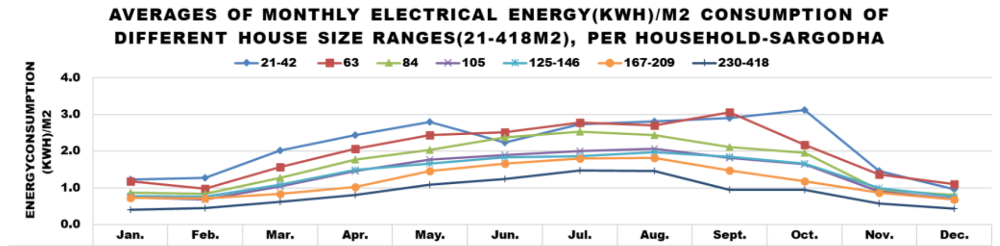
PER HOUSEHOLD

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	1.6	1.4	2.1	2.7	3.0	3.1	3.1	3.5	3.5	3.5	2.2	2.0	**2.6**
	Median	2.2	2.1	2.5	3.3	4.3	4.4	4.8	4.7	5.0	4.2	2.9	2.4	**3.6**
	75% ile	3.7	3.0	4.2	5.1	6.4	7.5	6.8	7.3	6.4	6.2	5.0	3.4	**5.4**
63m²	25% ile	1.1	0.9	1.2	1.7	2.1	2.2	2.3	2.4	1.7	1.9	1.5	1.2	**1.7**
	Median	1.5	1.4	1.6	2.1	2.7	3.4	3.5	3.1	2.2	2.5	1.8	1.5	**2.3**
	75% ile	1.8	1.9	2.2	2.8	3.5	4.2	4.2	4.3	3.4	3.2	2.3	1.8	**3.0**
84m²	25% ile	0.8	0.8	0.8	1.5	1.5	1.8	1.7	1.7	1.9	1.7	1.2	0.7	**1.4**
	Median	1.1	1.2	1.2	2.0	2.2	3.0	2.9	2.8	2.8	2.1	1.6	1.1	**2.0**
	75% ile	1.6	1.8	1.6	2.4	2.7	3.9	3.8	3.4	3.7	3.0	2.0	1.7	**2.6**
105m²	25% ile	0.7	0.6	0.6	0.7	1.1	1.4	1.4	1.3	1.5	1.1	0.8	0.7	**1.0**
	Median	1.0	1.1	1.2	1.4	1.5	2.3	2.5	2.5	2.4	2.0	1.4	1.0	**1.7**
	75% ile	1.4	1.4	1.5	2.4	2.4	3.2	3.2	3.2	2.9	2.4	1.8	1.3	**2.3**
125-146m²	25% ile	0.8	0.9	1.0	1.2	1.6	1.7	1.8	1.8	1.4	1.2	0.9	0.9	**1.3**
	Median	0.9	1.1	1.3	1.4	2.0	2.2	2.2	2.1	1.9	1.4	1.1	1.0	**1.6**
	75% ile	1.2	1.2	1.7	1.8	2.4	2.5	2.8	2.9	2.1	1.7	1.2	1.2	**1.9**
167-209m²	25% ile	0.7	0.7	0.9	1.1	1.1	1.3	1.3	1.3	1.1	1.1	0.7	0.6	**1.0**
	Median	0.7	0.8	0.9	1.2	1.6	1.7	1.8	1.6	1.3	1.2	0.8	0.7	**1.2**
	75% ile	0.8	0.9	1.2	1.3	2.7	2.9	2.9	2.9	2.3	1.3	1.0	0.9	**1.8**
230-418m²	25% ile	0.4	0.5	0.6	0.7	1.0	1.2	1.2	1.2	1.1	0.6	0.4	0.4	**0.8**
	Median	0.5	0.6	0.7	0.8	1.3	1.6	1.6	1.6	1.4	0.7	0.5	0.5	**1.0**
	75% ile	0.6	0.7	0.9	1.1	1.5	1.8	1.9	1.8	1.8	1.0	0.6	0.6	**1.2**

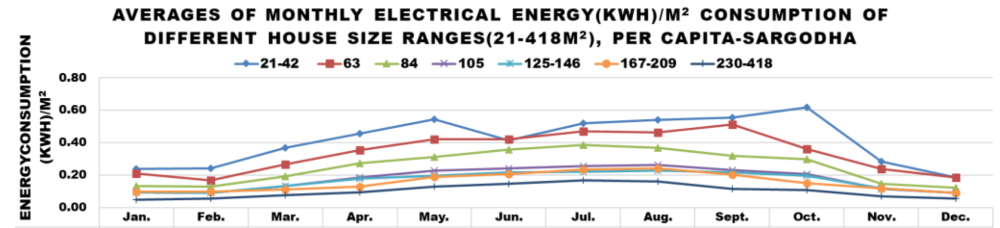
PER CAPITA

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.31	0.27	0.36	0.55	0.66	0.68	0.70	0.80	0.79	0.68	0.41	0.34	**0.55**
	Median	0.41	0.41	0.52	0.66	0.89	0.96	1.03	0.96	0.97	0.86	0.58	0.49	**0.73**
	75% ile	0.71	0.70	0.78	0.97	1.08	1.24	1.29	1.35	1.30	1.20	1.00	0.71	**1.03**
63m²	25% ile	0.20	0.18	0.23	0.27	0.30	0.45	0.53	0.52	0.39	0.41	0.26	0.20	**0.33**
	Median	0.27	0.29	0.32	0.41	0.54	0.68	0.73	0.71	0.55	0.54	0.40	0.27	**0.47**
	75% ile	0.40	0.41	0.43	0.53	0.75	0.86	0.83	0.76	0.68	0.62	0.48	0.36	**0.59**
84m²	25% ile	0.13	0.14	0.17	0.25	0.23	0.32	0.28	0.30	0.35	0.29	0.20	0.12	**0.23**
	Median	0.20	0.24	0.22	0.34	0.37	0.56	0.51	0.45	0.47	0.34	0.29	0.21	**0.35**
	75% ile	0.28	0.31	0.29	0.46	0.51	0.71	0.73	0.70	0.68	0.61	0.34	0.30	**0.49**
105m²	25% ile	0.08	0.09	0.10	0.12	0.15	0.21	0.20	0.22	0.23	0.18	0.12	0.10	**0.15**
	Median	0.16	0.17	0.19	0.24	0.23	0.38	0.38	0.33	0.37	0.31	0.21	0.17	**0.26**
	75% ile	0.22	0.22	0.25	0.33	0.37	0.49	0.53	0.52	0.48	0.41	0.31	0.22	**0.36**
125-146m²	25% ile	0.11	0.13	0.14	0.18	0.22	0.23	0.23	0.23	0.21	0.17	0.13	0.12	**0.17**
	Median	0.12	0.16	0.16	0.19	0.25	0.29	0.31	0.30	0.25	0.19	0.15	0.14	**0.21**
	75% ile	0.15	0.16	0.20	0.23	0.31	0.35	0.36	0.37	0.30	0.25	0.18	0.16	**0.25**
167-209m²	25% ile	0.08	0.10	0.12	0.14	0.16	0.19	0.20	0.18	0.16	0.13	0.10	0.09	**0.14**
	Median	0.09	0.11	0.13	0.15	0.19	0.21	0.23	0.22	0.19	0.16	0.12	0.09	**0.16**
	75% ile	0.12	0.12	0.15	0.16	0.32	0.32	0.32	0.32	0.32	0.18	0.15	0.12	**0.22**
230-418m²	25% ile	0.06	0.07	0.07	0.09	0.12	0.15	0.15	0.15	0.15	0.08	0.05	0.05	**0.10**
	Median	0.07	0.08	0.11	0.12	0.18	0.22	0.23	0.23	0.21	0.11	0.07	0.07	**0.14**
	75% ile	0.08	0.09	0.12	0.14	0.21	0.27	0.28	0.27	0.24	0.13	0.08	0.08	**0.17**

Table 8.40 Appendix -D-Sargodha -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	1.2	1.3	2.0	2.4	2.8	2.2	2.7	2.8	2.9	3.1	1.5	1.0
63	1.2	1.0	1.6	2.1	2.4	2.5	2.8	2.7	3.1	2.2	1.4	1.1
84	0.9	0.8	1.3	1.8	2.0	2.4	2.5	2.4	2.1	2.0	0.9	0.8
105	0.7	0.7	1.0	1.5	1.8	1.9	2.0	2.1	1.8	1.6	0.9	0.7
125-146	0.8	0.8	1.1	1.5	1.7	1.8	1.9	2.0	1.8	1.7	1.0	0.8
167-209	0.7	0.7	0.8	1.0	1.5	1.7	1.8	1.8	1.5	1.2	0.9	0.7
230-418	0.4	0.4	0.6	0.8	1.1	1.2	1.5	1.5	0.9	0.9	0.6	0.4

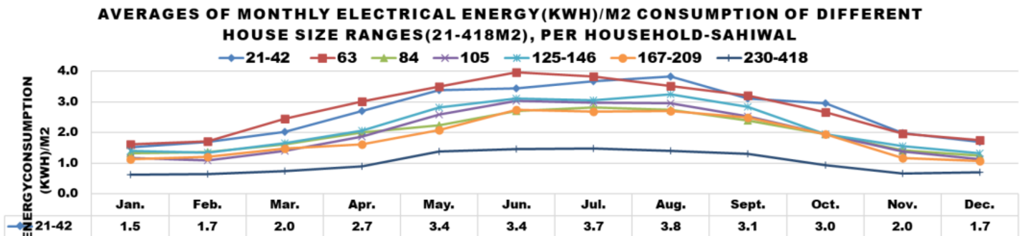


	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.24	0.24	0.37	0.46	0.54	0.41	0.52	0.54	0.55	0.62	0.28	0.18
63	0.21	0.17	0.27	0.35	0.42	0.42	0.47	0.46	0.51	0.36	0.24	0.19
84	0.13	0.13	0.19	0.27	0.31	0.36	0.39	0.37	0.32	0.30	0.15	0.12
105	0.10	0.09	0.13	0.19	0.23	0.24	0.26	0.26	0.23	0.21	0.12	0.09
125-146	0.09	0.09	0.13	0.18	0.20	0.22	0.22	0.23	0.22	0.20	0.12	0.09
167-209	0.10	0.10	0.11	0.13	0.19	0.21	0.24	0.24	0.20	0.15	0.12	0.09
230-418	0.05	0.06	0.08	0.10	0.13	0.15	0.17	0.16	0.11	0.11	0.07	0.06

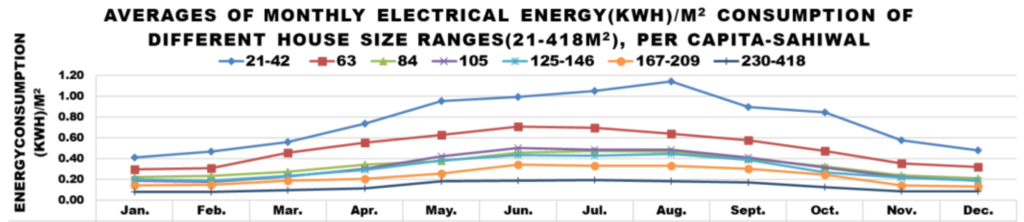
Table 8.41 Appendix -D-Sargodha -2

SARGODHA DIVISION														
PER HOUSEHOLD														
House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.6	0.5	1.1	1.2	1.3	1.0	1.2	1.3	1.4	1.7	0.9	0.5	**1.0**
	Median	0.8	0.9	1.2	2.2	2.5	2.2	3.0	3.2	2.3	2.3	1.2	0.9	**1.9**
	75% ile	1.3	1.7	2.5	3.4	3.6	3.5	3.8	4.0	4.1	3.8	2.3	1.3	**2.9**
63m²	25% ile	0.4	0.3	0.7	1.1	1.2	1.0	1.5	1.4	1.1	1.2	0.5	0.5	**0.9**
	Median	0.7	0.7	1.3	1.8	2.2	2.1	2.5	2.1	2.6	1.8	1.0	0.7	**1.6**
	75% ile	1.6	1.3	1.9	2.6	3.0	3.5	3.4	3.6	3.8	2.9	1.8	1.4	**2.6**
84m²	25% ile	0.5	0.4	0.7	1.0	1.3	1.4	1.6	1.4	1.2	1.1	0.5	0.5	**1.0**
	Median	0.8	0.7	1.1	1.7	2.0	2.2	2.3	2.3	2.1	1.8	0.8	0.6	**1.5**
	75% ile	1.2	1.1	1.6	2.2	2.7	3.1	3.4	3.3	2.8	2.7	1.3	1.1	**2.2**
105m²	25% ile	0.4	0.4	0.5	0.9	1.1	1.2	1.2	1.4	1.1	1.1	0.5	0.3	**0.8**
	Median	0.6	0.7	0.9	1.4	1.7	1.8	1.9	1.9	1.7	1.5	0.9	0.6	**1.3**
	75% ile	1.0	0.9	1.4	1.8	2.2	2.3	2.6	2.7	2.4	2.0	1.2	0.9	**1.8**
125-146m²	25% ile	0.4	0.4	0.6	0.8	0.9	0.9	0.9	1.2	1.2	1.0	0.5	0.3	**0.8**
	Median	0.8	0.6	1.0	1.3	1.4	1.7	1.7	1.6	1.5	1.4	0.8	0.6	**1.2**
	75% ile	0.9	1.1	1.4	2.0	2.0	2.2	2.2	2.2	2.2	2.3	1.2	1.1	**1.7**
167-209m²	25% ile	0.5	0.5	0.5	0.8	1.1	1.4	1.5	1.4	1.1	0.9	0.6	0.5	**0.9**
	Median	0.6	0.6	0.9	1.0	1.5	1.7	2.0	1.7	1.5	1.2	0.8	0.6	**1.2**
	75% ile	0.7	0.9	1.0	1.2	1.8	1.8	2.2	2.3	2.0	1.4	1.1	0.8	**1.4**
230-418m²	25% ile	0.3	0.3	0.4	0.5	0.7	1.0	1.2	1.0	0.4	0.6	0.3	0.3	**0.6**
	Median	0.4	0.5	0.6	0.8	1.1	1.1	1.4	1.3	0.8	0.9	0.7	0.5	**0.8**
	75% ile	0.6	0.6	0.9	1.0	1.3	1.7	1.6	1.6	1.5	1.3	0.8	0.6	**1.1**
PER CAPITA														
House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.12	0.10	0.21	0.27	0.29	0.24	0.27	0.31	0.33	0.36	0.14	0.11	**0.23**
	Median	0.16	0.15	0.29	0.38	0.44	0.33	0.48	0.55	0.48	0.44	0.24	0.17	**0.34**
	75% ile	0.25	0.24	0.36	0.54	0.65	0.55	0.68	0.68	0.65	0.67	0.40	0.25	**0.49**
63m²	25% ile	0.06	0.04	0.12	0.17	0.20	0.20	0.26	0.25	0.21	0.19	0.09	0.08	**0.16**
	Median	0.12	0.12	0.19	0.28	0.31	0.30	0.38	0.33	0.36	0.27	0.16	0.11	**0.24**
	75% ile	0.29	0.23	0.31	0.41	0.44	0.48	0.57	0.55	0.55	0.45	0.28	0.26	**0.40**
84m²	25% ile	0.07	0.06	0.11	0.16	0.19	0.21	0.21	0.21	0.17	0.16	0.08	0.07	**0.14**
	Median	0.11	0.10	0.16	0.24	0.28	0.31	0.33	0.31	0.28	0.27	0.12	0.10	**0.22**
	75% ile	0.17	0.17	0.24	0.34	0.41	0.45	0.54	0.51	0.43	0.39	0.18	0.15	**0.33**
105m²	25% ile	0.05	0.05	0.07	0.12	0.15	0.14	0.16	0.16	0.14	0.12	0.06	0.04	**0.10**
	Median	0.07	0.08	0.11	0.17	0.20	0.22	0.24	0.25	0.21	0.18	0.11	0.07	**0.16**
	75% ile	0.13	0.12	0.18	0.25	0.31	0.32	0.34	0.35	0.30	0.27	0.15	0.12	**0.24**
125-146m²	25% ile	0.05	0.04	0.08	0.09	0.09	0.10	0.12	0.14	0.14	0.10	0.06	0.04	**0.09**
	Median	0.08	0.07	0.12	0.16	0.18	0.20	0.21	0.21	0.20	0.18	0.09	0.07	**0.15**
	75% ile	0.12	0.13	0.18	0.25	0.28	0.30	0.30	0.31	0.28	0.24	0.16	0.13	**0.22**
167-209m²	25% ile	0.06	0.07	0.07	0.09	0.16	0.18	0.15	0.15	0.11	0.10	0.08	0.06	**0.11**
	Median	0.09	0.10	0.13	0.14	0.18	0.19	0.25	0.21	0.15	0.13	0.09	0.08	**0.14**
	75% ile	0.11	0.13	0.14	0.16	0.23	0.23	0.31	0.35	0.23	0.18	0.14	0.10	**0.19**
230-418m²	25% ile	0.04	0.04	0.05	0.06	0.09	0.11	0.13	0.13	0.05	0.08	0.04	0.04	**0.07**
	Median	0.05	0.04	0.07	0.09	0.13	0.16	0.17	0.18	0.12	0.12	0.07	0.05	**0.10**
	75% ile	0.07	0.08	0.10	0.12	0.15	0.17	0.22	0.21	0.14	0.13	0.08	0.07	**0.13**

Table 8.42 Appendix -D-Sahiwal -1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	1.5	1.7	2.0	2.7	3.4	3.4	3.7	3.8	3.1	3.0	2.0	1.7
63	1.6	1.7	2.4	3.0	3.5	4.0	3.8	3.5	3.2	2.7	2.0	1.8
84	1.3	1.4	1.6	2.0	2.2	2.7	2.8	2.7	2.4	1.9	1.4	1.2
105	1.2	1.1	1.4	1.9	2.6	3.0	3.0	3.0	2.5	1.9	1.4	1.1
125-146	1.4	1.3	1.7	2.1	2.8	3.1	3.1	3.2	2.8	1.9	1.6	1.3
167-209	1.1	1.2	1.5	1.6	2.1	2.7	2.7	2.7	2.5	1.9	1.2	1.1
230-418	0.6	0.6	0.7	0.9	1.4	1.5	1.5	1.4	1.3	0.9	0.7	0.7



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.41	0.47	0.56	0.74	0.96	1.00	1.05	1.14	0.90	0.85	0.58	0.48
63	0.30	0.31	0.46	0.55	0.63	0.71	0.70	0.64	0.58	0.47	0.35	0.32
84	0.22	0.23	0.27	0.34	0.38	0.46	0.47	0.47	0.40	0.33	0.24	0.21
105	0.19	0.18	0.23	0.30	0.42	0.50	0.48	0.49	0.41	0.31	0.23	0.19
125-146	0.20	0.19	0.23	0.29	0.38	0.43	0.43	0.45	0.39	0.27	0.22	0.19
167-209	0.14	0.15	0.19	0.20	0.26	0.34	0.33	0.33	0.30	0.25	0.14	0.13
230-418	0.08	0.08	0.10	0.12	0.18	0.19	0.19	0.18	0.17	0.13	0.08	0.09

Table 8.43 Appendix -D-Sahiwal -2

SAHIWAL DIVISION

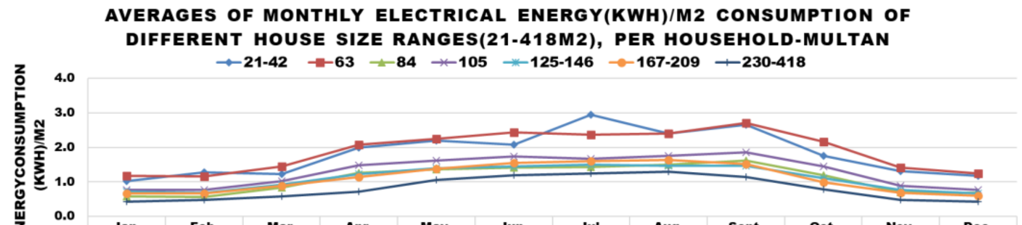
PER HOUSEHOLD

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.7	1.0	1.0	1.4	1.7	2.4	2.2	2.3	1.7	1.8	0.7	0.7	**1.5**
	Median	1.7	1.7	2.1	2.4	2.9	3.0	3.3	3.4	2.9	2.4	1.8	1.8	**2.5**
	75% ile	2.0	2.2	2.6	3.1	3.8	4.4	4.0	5.2	4.0	3.9	2.5	2.2	**3.3**
63m²	25% ile	0.9	1.0	1.7	2.0	2.2	2.2	2.5	2.0	1.9	1.6	1.2	1.2	**1.7**
	Median	1.5	1.7	2.4	2.8	3.1	4.0	3.5	3.1	3.4	2.4	1.9	1.6	**2.6**
	75% ile	2.1	2.5	3.3	4.2	5.1	5.2	5.0	4.9	4.2	3.3	2.7	2.4	**3.7**
84m²	25% ile	0.8	0.8	0.9	1.3	1.5	1.5	1.7	1.6	1.5	1.2	0.8	0.7	**1.2**
	Median	1.0	1.0	1.3	1.7	1.8	2.0	2.1	1.9	1.7	1.5	0.9	1.0	**1.5**
	75% ile	1.5	1.7	2.2	2.9	2.7	3.2	3.2	3.0	2.6	2.2	1.8	1.7	**2.4**
105m²	25% ile	0.7	0.7	0.9	1.3	1.6	2.0	2.0	1.9	1.6	1.3	0.9	0.7	**1.3**
	Median	1.1	1.0	1.3	1.7	2.5	3.1	2.6	2.5	2.3	1.8	1.4	1.1	**1.9**
	75% ile	1.5	1.5	1.9	2.5	3.2	4.0	3.9	4.2	3.2	2.2	1.8	1.5	**2.6**
125-146m²	25% ile	0.9	0.9	1.3	1.7	2.1	2.4	2.5	2.5	2.0	1.2	1.0	1.0	**1.6**
	Median	1.1	1.3	1.5	1.9	2.7	2.9	2.9	2.8	2.6	1.7	1.3	1.3	**2.0**
	75% ile	1.6	1.4	1.9	2.4	3.3	3.8	3.8	4.2	3.7	2.4	2.1	1.5	**2.7**
167-209m²	25% ile	0.7	0.8	1.1	1.2	1.6	2.1	2.6	2.2	1.8	1.2	0.7	0.7	**1.4**
	Median	0.9	0.9	1.2	1.3	2.2	2.9	2.9	2.9	2.5	1.6	0.9	0.9	**1.8**
	75% ile	1.5	1.3	1.7	2.1	2.7	3.4	3.0	3.3	3.2	2.5	1.4	1.2	**2.3**
230-418m²	25% ile	0.4	0.4	0.6	0.7	1.0	1.0	1.0	1.0	0.9	0.7	0.5	0.4	**0.7**
	Median	0.5	0.6	0.7	0.9	1.3	1.4	1.3	1.3	1.3	0.8	0.6	0.5	**0.9**
	75% ile	0.7	0.7	0.9	1.1	1.9	1.7	1.7	1.6	1.4	1.0	0.8	0.7	**1.2**

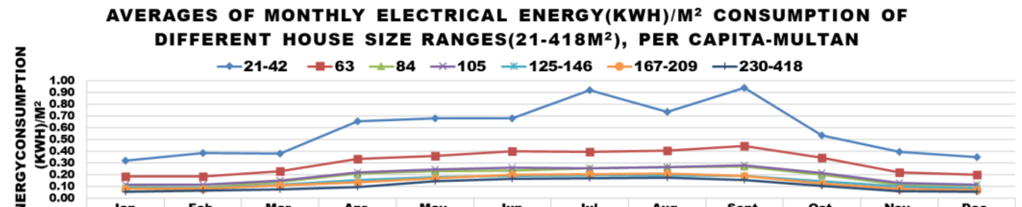
PER CAPITA

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.31	0.32	0.42	0.52	0.59	0.71	0.71	0.74	0.60	0.63	0.31	0.31	**0.51**
	Median	0.38	0.44	0.51	0.61	0.86	0.88	0.93	1.04	0.88	0.82	0.47	0.40	**0.69**
	75% ile	0.55	0.61	0.64	0.89	1.08	1.22	1.25	1.36	1.04	0.98	0.75	0.62	**0.92**
63m²	25% ile	0.16	0.21	0.30	0.41	0.40	0.49	0.49	0.39	0.40	0.31	0.23	0.22	**0.33**
	Median	0.27	0.28	0.44	0.54	0.64	0.69	0.69	0.63	0.57	0.49	0.36	0.32	**0.49**
	75% ile	0.34	0.38	0.57	0.65	0.78	1.00	0.87	0.82	0.72	0.60	0.48	0.38	**0.63**
84m²	25% ile	0.10	0.10	0.13	0.19	0.21	0.25	0.25	0.23	0.22	0.17	0.12	0.12	**0.17**
	Median	0.17	0.20	0.23	0.26	0.30	0.37	0.36	0.38	0.32	0.28	0.20	0.16	**0.27**
	75% ile	0.31	0.29	0.37	0.51	0.51	0.64	0.63	0.64	0.57	0.46	0.30	0.31	**0.46**
105m²	25% ile	0.12	0.11	0.14	0.21	0.28	0.34	0.31	0.29	0.30	0.21	0.13	0.11	**0.21**
	Median	0.18	0.17	0.22	0.31	0.39	0.52	0.44	0.47	0.38	0.30	0.22	0.19	**0.32**
	75% ile	0.23	0.23	0.29	0.39	0.53	0.65	0.62	0.65	0.54	0.39	0.31	0.24	**0.42**
125-146m²	25% ile	0.13	0.12	0.15	0.17	0.26	0.29	0.27	0.26	0.25	0.14	0.12	0.12	**0.19**
	Median	0.15	0.16	0.21	0.26	0.35	0.42	0.44	0.42	0.38	0.24	0.18	0.17	**0.28**
	75% ile	0.24	0.23	0.28	0.33	0.49	0.56	0.54	0.61	0.53	0.34	0.30	0.23	**0.39**
167-209m²	25% ile	0.07	0.08	0.11	0.12	0.18	0.20	0.24	0.24	0.20	0.11	0.07	0.06	**0.14**
	Median	0.10	0.11	0.14	0.15	0.24	0.34	0.29	0.31	0.27	0.19	0.09	0.10	**0.19**
	75% ile	0.19	0.21	0.22	0.26	0.30	0.39	0.38	0.38	0.38	0.29	0.21	0.18	**0.28**
230-418m²	25% ile	0.06	0.05	0.06	0.08	0.10	0.12	0.11	0.12	0.11	0.07	0.07	0.06	**0.08**
	Median	0.06	0.08	0.10	0.10	0.16	0.14	0.14	0.15	0.14	0.11	0.07	0.07	**0.11**
	75% ile	0.10	0.09	0.12	0.15	0.26	0.24	0.27	0.25	0.18	0.18	0.09	0.09	**0.17**

Table 8.44 Appendix -D-Multan-1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	1.0	1.3	1.2	2.0	2.2	2.1	2.9	2.4	2.7	1.8	1.3	1.2
63	1.2	1.2	1.4	2.1	2.3	2.4	2.4	2.4	2.7	2.2	1.4	1.2
84	0.6	0.6	0.8	1.3	1.4	1.4	1.4	1.5	1.6	1.2	0.7	0.7
105	0.8	0.8	1.0	1.5	1.6	1.7	1.7	1.7	1.9	1.4	0.9	0.8
125-146	0.7	0.7	0.9	1.2	1.4	1.5	1.5	1.5	1.5	1.1	0.8	0.7
167-209	0.7	0.7	0.9	1.1	1.4	1.5	1.6	1.6	1.5	1.0	0.7	0.6
230-418	0.4	0.5	0.6	0.7	1.1	1.2	1.2	1.3	1.1	0.8	0.5	0.4

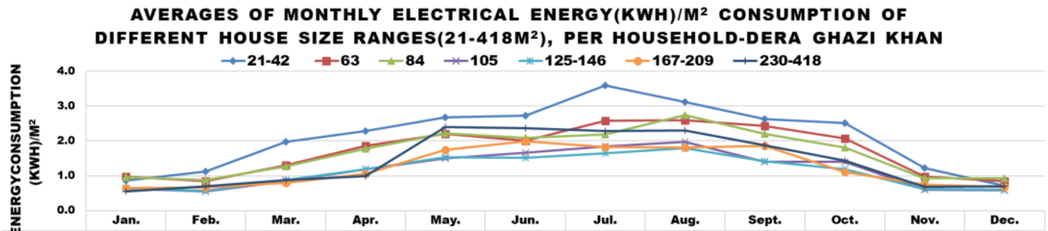


	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.32	0.39	0.38	0.66	0.68	0.68	0.92	0.74	0.94	0.54	0.40	0.35
63	0.19	0.19	0.23	0.34	0.36	0.40	0.39	0.41	0.45	0.35	0.22	0.20
84	0.10	0.09	0.14	0.21	0.23	0.24	0.26	0.27	0.27	0.20	0.12	0.11
105	0.12	0.12	0.15	0.22	0.24	0.26	0.25	0.27	0.28	0.22	0.13	0.12
125-146	0.09	0.09	0.12	0.16	0.18	0.19	0.20	0.20	0.19	0.15	0.10	0.09
167-209	0.08	0.08	0.11	0.14	0.17	0.20	0.21	0.21	0.19	0.13	0.08	0.07
230-418	0.06	0.06	0.08	0.10	0.15	0.16	0.17	0.18	0.16	0.11	0.06	0.06

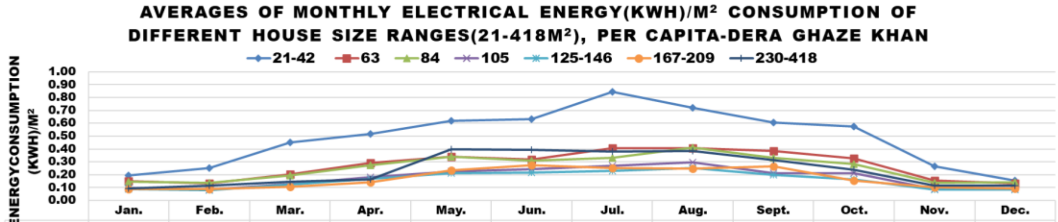
Table 8.45 Appendix -D-Multan-2

MULTAN DIVISION														
PER HOUSEHOLD														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
$21\text{-}42m^2$	25% ile	0.4	0.5	0.8	1.4	1.3	1.1	1.5	2.0	2.0	0.7	0.7	0.6	**1.1**
	Median	0.9	1.5	1.2	2.3	2.2	2.4	2.5	2.3	2.2	1.7	1.4	1.2	**1.8**
	75% ile	1.7	2.0	1.4	2.6	3.5	2.8	3.1	3.1	3.4	2.4	2.2	1.7	**2.5**
$63m^2$	25% ile	0.5	0.4	0.7	1.4	1.5	1.6	1.3	1.4	1.7	1.3	0.8	0.8	**1.1**
	Median	1.3	1.2	1.5	2.0	2.2	2.3	2.3	2.2	2.5	1.8	1.4	1.3	**1.8**
	75% ile	1.5	1.6	1.7	2.5	2.6	2.7	3.0	3.0	3.8	3.1	1.7	1.5	**2.4**
$84m^2$	25% ile	0.2	0.2	0.4	0.7	0.8	0.7	0.7	0.8	0.8	0.7	0.3	0.2	**0.5**
	Median	0.5	0.5	0.7	1.2	1.2	1.2	1.1	1.1	1.4	1.1	0.6	0.4	**0.9**
	75% ile	0.8	0.8	1.1	1.6	1.8	1.9	1.8	1.9	2.0	1.5	1.0	0.8	**1.4**
$105m^2$	25% ile	0.3	0.3	0.5	0.8	0.8	0.9	0.8	0.8	0.9	0.7	0.4	0.3	**0.6**
	Median	0.6	0.6	0.8	1.3	1.3	1.4	1.3	1.4	1.6	1.2	0.8	0.6	**1.1**
	75% ile	1.0	1.1	1.5	2.0	2.4	2.3	2.3	2.4	2.4	2.0	1.2	1.0	**1.8**
$125\text{-}146m^2$	25% ile	0.3	0.2	0.4	0.7	0.7	0.7	0.6	0.7	0.7	0.5	0.4	0.3	**0.5**
	Median	0.6	0.6	0.8	1.0	1.1	1.2	1.2	1.2	1.2	1.0	0.7	0.5	**0.9**
	75% ile	0.9	0.9	1.2	1.6	1.8	1.9	2.0	2.0	2.0	1.6	1.0	0.9	**1.5**
$167\text{-}209m^2$	25% ile	0.4	0.4	0.4	0.6	0.7	0.7	0.8	0.8	0.8	0.6	0.5	0.3	**0.6**
	Median	0.7	0.7	0.8	1.0	1.2	1.2	1.2	1.2	1.1	0.9	0.7	0.6	**0.9**
	75% ile	0.9	0.9	1.2	1.5	2.0	2.2	2.3	2.6	2.1	1.3	0.8	0.8	**1.5**
$230\text{-}418m^2$	25% ile	0.3	0.4	0.4	0.5	0.6	0.8	0.7	0.9	0.6	0.5	0.4	0.3	**0.5**
	Median	0.4	0.4	0.6	0.7	1.1	1.2	1.3	1.3	1.1	0.7	0.4	0.4	**0.8**
	75% ile	0.5	0.7	0.8	0.9	1.4	1.6	1.6	1.6	1.5	1.1	0.6	0.6	**1.1**
PER CAPITA														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
$21\text{-}42m^2$	25% ile	0.15	0.25	0.26	0.51	0.56	0.45	0.57	0.70	0.69	0.31	0.26	0.20	**0.41**
	Median	0.26	0.40	0.43	0.68	0.70	0.71	0.66	0.75	0.72	0.58	0.45	0.40	**0.56**
	75% ile	0.47	0.50	0.49	0.79	0.89	0.85	0.94	0.83	0.89	0.72	0.47	0.45	**0.69**
$63m^2$	25% ile	0.09	0.08	0.12	0.23	0.25	0.26	0.21	0.22	0.26	0.18	0.12	0.11	**0.18**
	Median	0.16	0.17	0.22	0.29	0.35	0.33	0.35	0.36	0.40	0.26	0.20	0.17	**0.27**
	75% ile	0.23	0.23	0.27	0.41	0.43	0.44	0.48	0.48	0.50	0.46	0.28	0.25	**0.37**
$84m^2$	25% ile	0.04	0.03	0.07	0.12	0.13	0.13	0.12	0.12	0.14	0.12	0.06	0.04	**0.09**
	Median	0.08	0.07	0.11	0.18	0.19	0.19	0.19	0.20	0.23	0.18	0.09	0.07	**0.15**
	75% ile	0.13	0.13	0.19	0.29	0.29	0.30	0.32	0.33	0.36	0.26	0.15	0.13	**0.24**
$105m^2$	25% ile	0.05	0.04	0.07	0.12	0.12	0.12	0.11	0.12	0.13	0.10	0.06	0.04	**0.09**
	Median	0.09	0.09	0.13	0.18	0.19	0.20	0.18	0.19	0.22	0.19	0.11	0.10	**0.16**
	75% ile	0.16	0.16	0.19	0.29	0.32	0.34	0.30	0.33	0.37	0.27	0.17	0.14	**0.25**
$125\text{-}146m^2$	25% ile	0.03	0.03	0.05	0.09	0.09	0.09	0.09	0.09	0.10	0.07	0.04	0.03	**0.07**
	Median	0.08	0.07	0.09	0.14	0.14	0.14	0.14	0.15	0.16	0.12	0.08	0.07	**0.12**
	75% ile	0.12	0.11	0.14	0.22	0.25	0.24	0.25	0.24	0.27	0.19	0.13	0.10	**0.19**
$167\text{-}209m^2$	25% ile	0.04	0.04	0.04	0.07	0.07	0.07	0.08	0.09	0.08	0.06	0.04	0.03	**0.06**
	Median	0.08	0.07	0.08	0.12	0.13	0.14	0.12	0.12	0.13	0.10	0.08	0.07	**0.10**
	75% ile	0.11	0.12	0.16	0.18	0.24	0.28	0.26	0.29	0.27	0.17	0.12	0.10	**0.19**
$230\text{-}418m^2$	25% ile	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.07	0.05	0.04	0.04	0.04	**0.05**
	Median	0.05	0.06	0.08	0.09	0.15	0.14	0.19	0.19	0.18	0.09	0.06	0.05	**0.11**
	75% ile	0.08	0.09	0.11	0.14	0.19	0.22	0.25	0.26	0.21	0.16	0.08	0.08	**0.16**

Table 8.46 Appendix -D-Dera Ghazi Khan-1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.9	1.1	2.0	2.3	2.7	2.7	3.6	3.1	2.6	2.5	1.2	0.7
63	1.0	0.9	1.3	1.9	2.2	2.0	2.6	2.6	2.4	2.1	1.0	0.9
84	1.0	0.9	1.3	1.8	2.2	2.1	2.2	2.7	2.2	1.8	0.9	0.9
105	0.6	0.5	0.8	1.2	1.5	1.7	1.8	2.0	1.4	1.4	0.6	0.6
125-146	0.6	0.6	0.9	1.2	1.5	1.5	1.6	1.8	1.4	1.2	0.6	0.6
167-209	0.7	0.7	0.8	1.1	1.7	2.0	1.8	1.8	1.9	1.1	0.8	0.7
230-418	0.6	0.7	0.9	1.0	2.4	2.4	2.3	2.3	1.9	1.4	0.7	0.7

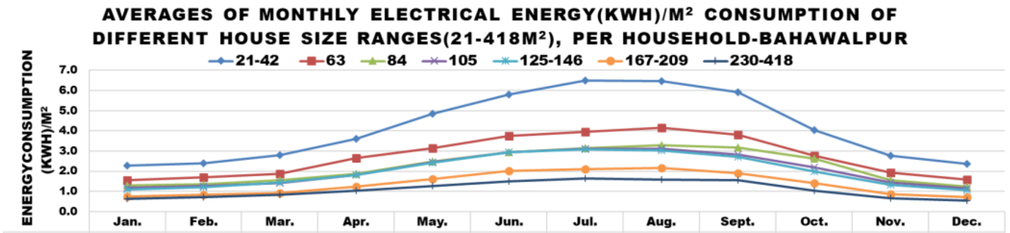


	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.19	0.25	0.45	0.52	0.62	0.63	0.84	0.72	0.61	0.57	0.27	0.16
63	0.15	0.13	0.20	0.29	0.34	0.32	0.40	0.41	0.38	0.33	0.16	0.13
84	0.15	0.14	0.19	0.27	0.34	0.31	0.33	0.41	0.33	0.28	0.14	0.14
105	0.10	0.08	0.13	0.18	0.23	0.24	0.27	0.29	0.21	0.21	0.09	0.09
125-146	0.09	0.08	0.13	0.17	0.21	0.22	0.23	0.25	0.20	0.16	0.08	0.08
167-209	0.09	0.09	0.10	0.14	0.23	0.28	0.25	0.25	0.27	0.16	0.10	0.09
230-418	0.09	0.12	0.15	0.17	0.40	0.39	0.38	0.39	0.31	0.24	0.11	0.12

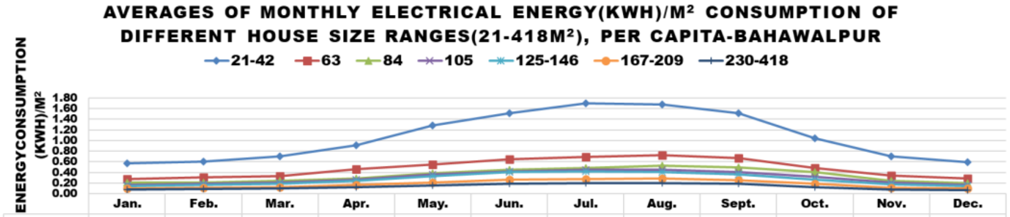
Table 8.47 Appendix -D-Dera Ghazi Khan-2

DERA GHAZI KHAN DIVISION														
PER HOUSEHOLD														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
21-42m²	25% ile	0.4	0.5	1.4	1.5	1.4	1.9	2.0	2.0	1.7	1.7	0.4	0.3	**1.3**
	Median	0.7	0.8	2.3	2.3	2.3	2.4	3.0	2.9	2.6	2.7	0.8	0.7	**2.0**
	75% ile	1.2	1.3	2.5	2.8	3.3	3.1	4.8	3.9	3.5	3.1	1.6	0.9	**2.7**
63m²	25% ile	0.4	0.3	0.5	0.7	0.7	0.8	1.1	1.0	0.8	1.0	0.3	0.3	**0.7**
	Median	0.6	0.6	1.0	1.2	1.3	1.7	2.3	1.9	1.7	1.5	0.7	0.6	**1.3**
	75% ile	1.0	1.0	1.6	2.2	2.7	2.8	3.4	3.2	3.3	2.7	1.2	1.1	**2.2**
84m²	25% ile	0.3	0.3	0.5	0.7	0.8	0.7	1.0	1.1	0.9	0.8	0.3	0.3	**0.6**
	Median	0.6	0.6	1.0	1.4	1.7	1.6	1.9	2.0	1.6	1.5	0.7	0.6	**1.3**
	75% ile	1.3	1.3	1.7	2.5	3.0	2.6	2.7	3.5	2.8	2.3	1.2	1.2	**2.2**
105m²	25% ile	0.3	0.3	0.5	0.7	0.9	0.8	0.9	1.0	0.7	0.7	0.3	0.3	**0.6**
	Median	0.6	0.5	0.8	1.2	1.4	1.4	1.4	1.5	1.2	1.0	0.5	0.4	**1.0**
	75% ile	0.8	0.7	1.1	1.6	2.0	2.0	2.1	2.5	1.8	1.7	0.8	0.7	**1.5**
125-146m²	25% ile	0.3	0.2	0.5	0.6	0.7	0.6	0.8	0.8	0.7	0.5	0.2	0.2	**0.5**
	Median	0.5	0.4	0.8	1.1	1.3	1.2	1.3	1.4	1.2	1.0	0.5	0.5	**0.9**
	75% ile	0.8	0.8	1.1	1.5	2.2	2.0	2.3	2.5	2.0	1.6	0.8	0.8	**1.5**
167-209m²	25% ile	0.3	0.4	0.5	0.7	1.1	1.6	0.9	1.2	1.2	0.9	0.4	0.5	**0.8**
	Median	0.7	0.7	0.7	1.2	1.8	2.1	1.9	2.1	2.0	1.2	0.6	0.7	**1.3**
	75% ile	0.8	0.9	1.2	1.3	2.4	2.7	2.8	2.5	2.5	1.5	1.1	1.0	**1.7**
230-418m²	25% ile	0.5	0.7	0.8	1.0	2.3	2.3	2.2	2.2	1.8	1.2	0.6	0.7	**1.3**
	Median	0.6	0.7	0.9	1.0	2.4	2.4	2.3	2.3	1.9	1.4	0.7	0.7	**1.4**
	75% ile	0.6	0.7	1.0	1.0	2.5	2.5	2.4	2.4	2.0	1.7	0.8	0.7	**1.5**
PER CAPITA														
House Sizes	**Ranges**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Average**
21-42m²	25% ile	0.10	0.12	0.35	0.38	0.31	0.48	0.51	0.48	0.43	0.42	0.09	0.07	**0.31**
	Median	0.17	0.18	0.46	0.49	0.51	0.53	0.61	0.62	0.51	0.60	0.20	0.14	**0.42**
	75% ile	0.24	0.27	0.54	0.62	0.74	0.64	1.11	0.84	0.76	0.62	0.37	0.22	**0.58**
63m²	25% ile	0.06	0.05	0.09	0.12	0.11	0.13	0.18	0.18	0.14	0.16	0.05	0.06	**0.11**
	Median	0.09	0.10	0.16	0.21	0.23	0.28	0.34	0.30	0.28	0.25	0.11	0.10	**0.20**
	75% ile	0.19	0.16	0.26	0.38	0.42	0.47	0.51	0.48	0.52	0.43	0.20	0.18	**0.35**
84m²	25% ile	0.05	0.05	0.08	0.11	0.13	0.13	0.17	0.17	0.15	0.11	0.04	0.05	**0.10**
	Median	0.10	0.09	0.17	0.23	0.28	0.26	0.28	0.29	0.24	0.23	0.10	0.10	**0.20**
	75% ile	0.18	0.19	0.26	0.37	0.43	0.38	0.41	0.53	0.44	0.36	0.17	0.18	**0.33**
105m²	25% ile	0.05	0.05	0.07	0.10	0.13	0.11	0.13	0.14	0.11	0.10	0.04	0.04	**0.09**
	Median	0.09	0.08	0.12	0.17	0.21	0.20	0.23	0.26	0.18	0.17	0.07	0.07	**0.15**
	75% ile	0.13	0.11	0.17	0.25	0.32	0.32	0.35	0.39	0.27	0.26	0.12	0.11	**0.23**
125-146m²	25% ile	0.04	0.03	0.07	0.09	0.11	0.09	0.11	0.10	0.09	0.08	0.03	0.03	**0.07**
	Median	0.07	0.06	0.10	0.14	0.18	0.17	0.17	0.18	0.15	0.13	0.06	0.06	**0.12**
	75% ile	0.12	0.11	0.16	0.23	0.30	0.31	0.33	0.33	0.28	0.21	0.10	0.11	**0.22**
167-209m²	25% ile	0.06	0.06	0.06	0.08	0.16	0.22	0.11	0.15	0.13	0.11	0.05	0.07	**0.11**
	Median	0.09	0.09	0.13	0.15	0.27	0.28	0.29	0.28	0.27	0.14	0.08	0.08	**0.18**
	75% ile	0.11	0.12	0.14	0.17	0.30	0.33	0.33	0.32	0.33	0.23	0.15	0.13	**0.22**
230-418m²	25% ile	0.08	0.11	0.13	0.16	0.39	0.38	0.37	0.37	0.30	0.19	0.10	0.11	**0.22**
	Median	0.09	0.12	0.15	0.17	0.40	0.39	0.38	0.39	0.31	0.24	0.11	0.12	**0.24**
	75% ile	0.10	0.12	0.16	0.17	0.41	0.41	0.39	0.40	0.33	0.29	0.13	0.12	**0.25**

Table 8.48 Appendix -D-Bahawalpur-1



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	2.3	2.4	2.8	3.6	4.9	5.8	6.5	6.5	5.9	4.0	2.8	2.4
63	1.5	1.7	1.9	2.7	3.1	3.8	3.9	4.2	3.8	2.8	1.9	1.6
84	1.3	1.4	1.6	1.9	2.5	2.9	3.1	3.3	3.2	2.6	1.6	1.2
105	1.2	1.3	1.4	1.8	2.5	2.9	3.1	3.1	2.8	2.2	1.4	1.2
125-146	1.1	1.2	1.4	1.8	2.4	2.9	3.1	3.0	2.7	2.0	1.3	1.1
167-209	0.7	0.8	0.9	1.2	1.6	2.0	2.1	2.1	1.9	1.4	0.9	0.7
230-418	0.6	0.7	0.8	1.0	1.3	1.5	1.6	1.6	1.6	1.0	0.7	0.5



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
21-42	0.58	0.60	0.70	0.91	1.28	1.51	1.70	1.67	1.51	1.04	0.70	0.60
63	0.27	0.30	0.33	0.47	0.55	0.65	0.69	0.72	0.67	0.48	0.34	0.28
84	0.21	0.21	0.24	0.29	0.39	0.46	0.49	0.53	0.50	0.41	0.24	0.20
105	0.17	0.18	0.20	0.26	0.36	0.42	0.45	0.45	0.41	0.32	0.21	0.17
125-146	0.15	0.16	0.19	0.25	0.33	0.40	0.41	0.41	0.37	0.27	0.18	0.15
167-209	0.10	0.11	0.12	0.17	0.21	0.27	0.28	0.29	0.26	0.19	0.11	0.09
230-418	0.07	0.09	0.10	0.13	0.16	0.18	0.20	0.20	0.19	0.12	0.08	0.07

Table 8.49 Appendix -D-Bahawalpur-2

BAHAWALPUR DIVISION

PER HOUSEHOLD

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	1.9	2.0	2.1	2.8	3.0	3.0	3.4	3.3	2.9	2.4	2.1	1.9	**2.6**
	Median	2.1	2.2	2.5	2.9	3.5	3.7	3.7	3.6	3.4	2.9	2.5	2.2	**2.9**
	75% ile	2.3	2.6	3.0	3.8	3.9	4.5	4.8	5.5	6.7	4.4	3.2	2.8	**4.0**
63m²	25% ile	1.3	1.3	1.5	2.0	2.3	2.5	2.5	2.4	2.2	1.8	1.6	1.3	**1.9**
	Median	1.4	1.6	1.7	2.2	2.7	3.0	3.3	3.5	3.2	2.5	1.8	1.5	**2.3**
	75% ile	1.6	1.8	1.9	3.0	3.2	4.0	4.1	5.4	4.5	3.5	2.1	1.7	**3.1**
84m²	25% ile	1.1	1.0	1.0	1.4	1.9	2.2	2.4	2.1	2.2	1.7	1.2	1.0	**1.6**
	Median	1.2	1.3	1.4	1.6	2.3	2.5	2.6	2.6	2.6	2.1	1.4	1.2	**1.9**
	75% ile	1.4	1.5	1.9	2.2	3.0	3.6	4.0	4.5	3.4	3.1	1.9	1.4	**2.7**
105m²	25% ile	0.8	0.8	0.9	1.3	1.8	1.8	2.1	2.1	1.9	1.5	1.0	0.8	**1.4**
	Median	1.0	1.0	1.3	1.8	2.1	2.3	2.6	2.6	2.5	1.8	1.3	1.0	**1.8**
	75% ile	1.2	1.4	1.6	2.1	2.9	3.2	3.6	3.7	3.6	2.8	1.7	1.4	**2.4**
125-146m²	25% ile	0.7	0.7	0.8	1.1	1.4	1.6	1.7	1.7	1.6	1.2	0.9	0.7	**1.2**
	Median	0.8	0.9	1.2	1.5	1.7	2.4	2.7	2.4	2.4	1.7	1.2	0.9	**1.6**
	75% ile	1.2	1.3	1.7	2.2	3.2	3.7	3.8	4.0	3.8	2.4	1.5	1.1	**2.5**
167-209m²	25% ile	0.5	0.5	0.6	0.8	1.0	1.2	1.2	1.3	1.2	0.9	0.6	0.5	**0.9**
	Median	0.6	0.7	0.8	1.1	1.3	1.5	1.8	1.8	1.5	1.2	0.8	0.6	**1.1**
	75% ile	0.9	1.0	1.1	1.5	1.9	2.4	2.7	2.7	2.3	1.7	1.0	0.8	**1.7**
230-418m²	25% ile	0.3	0.4	0.5	0.7	0.8	0.9	1.0	1.1	1.0	0.6	0.4	0.4	**0.7**
	Median	0.5	0.6	0.7	0.8	1.1	1.2	1.3	1.3	1.3	0.9	0.6	0.4	**0.9**
	75% ile	0.8	0.9	1.0	1.2	1.4	1.8	1.8	1.9	1.6	1.2	0.7	0.6	**1.2**

PER CAPITA

House Sizes	Ranges	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
21-42m²	25% ile	0.43	0.44	0.52	0.59	0.73	0.75	0.76	0.75	0.74	0.59	0.49	0.45	**0.60**
	Median	0.52	0.56	0.63	0.72	0.87	0.89	0.99	1.09	0.88	0.74	0.71	0.56	**0.76**
	75% ile	0.66	0.74	0.89	1.03	1.06	1.23	1.36	1.17	1.34	0.89	0.82	0.68	**0.99**
63m²	25% ile	0.21	0.22	0.25	0.31	0.40	0.42	0.46	0.46	0.37	0.32	0.27	0.22	**0.33**
	Median	0.26	0.27	0.29	0.40	0.44	0.52	0.55	0.56	0.59	0.44	0.32	0.26	**0.41**
	75% ile	0.30	0.36	0.39	0.61	0.65	0.80	0.86	0.94	0.87	0.65	0.38	0.32	**0.59**
84m²	25% ile	0.17	0.17	0.18	0.22	0.31	0.34	0.36	0.35	0.33	0.26	0.20	0.15	**0.25**
	Median	0.19	0.20	0.25	0.28	0.37	0.43	0.43	0.43	0.39	0.32	0.22	0.17	**0.31**
	75% ile	0.23	0.25	0.29	0.37	0.44	0.56	0.60	0.60	0.53	0.46	0.27	0.23	**0.40**
105m²	25% ile	0.11	0.11	0.12	0.18	0.22	0.24	0.26	0.26	0.25	0.18	0.14	0.11	**0.18**
	Median	0.14	0.15	0.17	0.23	0.29	0.31	0.36	0.37	0.34	0.25	0.18	0.14	**0.24**
	75% ile	0.20	0.20	0.23	0.33	0.44	0.54	0.59	0.58	0.53	0.42	0.26	0.20	**0.38**
125-146m²	25% ile	0.08	0.08	0.11	0.15	0.17	0.19	0.21	0.20	0.18	0.14	0.12	0.09	**0.14**
	Median	0.10	0.13	0.14	0.19	0.25	0.32	0.34	0.34	0.32	0.22	0.15	0.11	**0.22**
	75% ile	0.17	0.19	0.23	0.29	0.40	0.53	0.55	0.52	0.44	0.32	0.22	0.16	**0.34**
167-209m²	25% ile	0.06	0.06	0.07	0.09	0.13	0.15	0.16	0.15	0.13	0.11	0.08	0.06	**0.10**
	Median	0.08	0.09	0.11	0.13	0.18	0.20	0.23	0.23	0.20	0.16	0.10	0.09	**0.15**
	75% ile	0.11	0.14	0.15	0.20	0.27	0.32	0.34	0.35	0.34	0.23	0.13	0.11	**0.22**
230-418m²	25% ile	0.04	0.05	0.06	0.07	0.09	0.11	0.12	0.11	0.11	0.07	0.06	0.04	**0.08**
	Median	0.06	0.07	0.09	0.10	0.12	0.13	0.15	0.16	0.14	0.10	0.07	0.06	**0.10**
	75% ile	0.09	0.10	0.12	0.15	0.18	0.23	0.25	0.24	0.24	0.16	0.09	0.08	**0.16**

Appendix E

Table 8.50 Appendix E Occupancy, IQR ranges

Occupancy, Inter Quartile Ranges (IQR)											
House Sizes(m^2)	**IQR**	**Lahore**	**Sheikhupura**	**Gujranwala**	**Faisalabad**	**Sargodha**	**Rawalpindi**	**Sahiwal**	**Multan**	**Bahawalpur**	**D.G.Khan**
21-42m^2	**25%ile**	3	3	3	2	4	4	2	2	3	3
	Median	3	3	6	3	5	5.5	3	3	4	4
	75%ile	4	3.5	8	3	6.6	6	5	3	5	5.7
63m^2	**25%ile**	4	3	4	3	5	4	4	6	5	4
	Median	5	4	5	3	6	5	5	6	6	5
	75%ile	6	5	6	4	7	6.5	8	7	7	6
84m^2	**25%ile**	4	4	6	3	6	5	5	5	6	5
	Median	6	4	7	4	7	6	6	6	7	6
	75%ile	7	5	7	5	8	6	8	8	8	7
105m^2	**25%ile**	5	5	6	4	7	6	6	6	6	6
	Median	6	5	7	5	8	6	6	7	7	7
	75%ile	7	6	8	7	9	7	7	8	8	8
125-146m^2	**25%ile**	6	5	7.5	6	7.3	7	6	6	7	6
	Median	7	6	9	6	8	7.5	8	8	8	8
	75%ile	8	7	10	8	10	8	8	10	9	9
167-209m^2	**25%ile**	6	6	7	6	6	6	7.5	7	7	6
	Median	7	6	8	7	7	7	9	9	8	7
	75%ile	8	7	13	9.3	9.5	8	10	11	9	9
230-418m^2	**25%ile**	6	6	9.8	7	6	7	7	6	7	6
	Median	7	7	12	9	8	8	8	9	9	8
	75%ile	9	8	14	11	9	8	10.6	10.5	11	10

Table 8.51 Appendix-E-DHW-Capita

Solar Thermal generation potential summary per Capita (DHW) by FTC											
Flat Tube Collectors(FTC)		**1**		**2**		**3**		**4**		**5**	
Collectors unit area and energy saved		**Area(m^2) 0.9**	**Energy saved**	**Area(m^2) 1.9**	**Energy saved**	**Area(m^2) 2.8**	**Energy saved**	**Area(m^2) 3.7**	**Energy saved**	**Area(m^2) 4.7**	**Energy saved**
Occupancy	**Divisions**	**%age demand met**	**(kWh)**	**%age demand met**	**(kWh)**	**%age demand met**	**(kWh)**	**%age demand met**	**(kWh)**	**%age demand met**	**(kWh)**
1	**Lahore**	53.6	178	77.8	259	90.3	300	99.3	330		
1	**Sheikhupura**	53.8	179	78	260	90.5	301	99.3	330		
1	**Gujranwalah**	63.4	207	86	281	95.5	312	100	326		
1	**Faislabad**	61.7	195	84.9	268	96.2	304	100	316		
1	**Sargodha**	60.6	197	84.4	274	95.1	309	100	325		
1	**Rawalpindi**	44.2	158	67.6	242	81.1	290	92	329	99.7	357
1	**Sahiwal**	64.2	201	86.9	272	97.4	305	100	313		
1	**Multan**	62.6	204	85.9	280	95.8	313	100	326		
1	**Bahawalpure**	66.7	203	88.7	270	99.2	302	100	305		
1	**D.G.Khan**	65.8	206	88.2	276	98.1	307	100	313		

Table 8.52 Appendix-E-DHW-Household-21-105m²

Solar Thermal generation potential summary for per Household (DHW) by FTC

Households (21-42 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
4	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	78.5	1014	84.6	1113	90.5	1189
3	Sheikhupura	22.3	223	40.1	400	53.8	537	64.3	642	72.1	720	78	779	82.6	824	87.6	921	94.6	1013	99.4	1147
6	Gujranwala	14.7	287	27.5	539	38.7	757	48.3	945	56.5	1105	63.4	1241	69.2	1354	75.4	1399	81.5	1468	87.5	1534
3	Faisalabad	26.6	252	46.8	444	61.7	585	72.3	686	79.7	756	84.9	805	88.9	843	95.8	912	99.8	1045	-	-
5	Sargodha	16.3	265	30.3	493	42.2	687	52.2	850	60.6	986	67.4	1097	73	1188	76.9	1232	83.2	1299	90.2	1387
5	Rawalpindi	11	198	20.9	374	29.6	531	37.4	669	44.2	792	50.2	899	55.5	993	61.5	1024	68.9	1124	75.6	1248
4	Sahiwal	21.6	271	39.2	491	53.2	666	64.2	803	72.5	908	78.8	986	83.4	1044	89.5	1047	94.6	1169	100	1267
3	Multan	26.9	263	47.4	464	62.6	613	73.4	718	80.8	791	85.9	840	89.6	877	94.8	947	99.6	1048	-	-
4	Bahawalpur	22.8	278	41.1	501	55.6	677	66.7	812	75	913	81	987	85.4	1040	92.8	1089	99.8	1135	-	-
4	D.G.Khan	22.4	280	40.5	506	54.8	685	65.8	823	74.2	928	80.3	1005	84.8	1061	91.6	1134	97.8	1289	-	-

Households (63 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
5	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	79..5	1036	86.3	1149	92.3	1239
4	Sheikhupura	17.2	229	31.7	422	43.8	583	53.8	716	61.9	824	68.5	912	73.8	982	78.4	1011	85.3	1131	92.8	1197
5	Gujranwala	17.4	284	32.2	525	44.6	728	54.9	896	63.4	1034	70.2	1145	75.6	1234	82.9	1298	88.5	1384	94.9	1461
4	Faisalabad	20.6	260	37.4	473	51	645	61.7	781	70	886	76.4	966	81.2	1027	87.4	1136	94.2	1197	99.8	1267
6	Sargodha	13.7	268	25.9	505	36.5	713	45.8	893	53.7	1049	60.6	1183	66.4	1296	71.2	1364	76.9	1431	83.6	1532
5	Rawalpindi	11	198	20.9	374	29.6	531	37.4	669	44.2	792	50.2	899	55.5	993	60.2	1043	67.9	1134	73.1	1257
6	Sahiwal	14.9	280	27.9	524	39.2	736	48.9	918	57.2	1074	64.2	1205	70	1314	76.4	1410	82.6	1538	89.9	1634
6	Multan	14.3	280	26.9	527	37.9	742	47.4	928	55.6	1089	62.6	1225	68.4	1340	74.6	1423	81.5	1541	89.7	1637
6	Bahawalpur	15.7	287	29.4	537	41.1	752	51.2	935	59.6	1089	66.7	1218	72.5	1324	77.8	1431	84.6	1421	92.5	1527
5	D.G.Khan	18.3	285	33.7	527	46.6	728	57.2	894	65.8	1029	72.7	1136	78.1	1221	84.9	1298	92.8	1348	98.7	1438

Households (84 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
6	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	79.5	1035	86.7	1134	92.7	1197
5	Sheikhupura	14	233	26.2	436	36.8	613	46	765	53.8	895	60.5	1006	66	1099	73.6	1168	80.4	1264	89.8	1431
7	Gujranwala	12.7	290	24	549	34.1	779	43	981	50.7	1159	57.5	1314	63.4	1448	69.5	1497	76.4	1568	83.7	1634
5	Faisalabad	16.8	265	31.1	492	43.2	683	53.4	843	61.7	976	68.5	1083	74	1171	81.5	1248	88.7	1342	95.4	1430
7	Sargodha	11.9	271	22.6	514	32.1	732	40.6	925	48.2	1097	54.8	1248	60.6	1380	67.2	1468	74.6	1532	82.7	1622
6	Rawalpindi	9.3	199	17.7	381	25.4	546	32.3	695	38.6	829	44.2	950	49.3	1058	56.2	1121	63.1	1210	69.8	1347
6	Sahiwal	14.9	280	27.9	524	39.2	736	48.9	918	57.2	1074	64.2	1205	70	1314	76.8	1410	83.4	1497	89.8	1549
6	Multan	14.3	280	26.9	527	37.9	742	47.4	928	55.6	1089	62.6	1225	68.4	1340	76.8	1425	82.7	1537	88.7	1637
7	Bahawalpur	13.6	290	25.7	547	36.3	774	45.6	973	53.7	1145	60.7	1294	66.7	1421	73.8	1510	80.4	1587	87.6	1647
6	D.G.Khan	15.4	289	28.9	541	40.5	759	50.4	945	58.8	1103	65.8	1235	71.7	1349	79.8	1437	85.9	1574	92.4	1612

Households (105 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
7	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	78.9	1034	84.9	1130	91.2	1246
5	Sheikhupura	14	233	26.2	436	36.8	613	46	765	53.8	895	60.5	1006	66	1099	72.4	1168	79.4	1264	84.6	1341
7	Gujranwala	12.7	290	24	549	34.1	779	43	981	50.7	1159	57.5	1314	63.4	1448	70.1	1511	77.6	1587	83.6	1681
6	Faisalabad	14.2	268	26.6	504	37.4	710	46.8	888	54.9	1041	61.7	1171	67.5	1280	74.6	1374	81.2	1469	87.5	1534
8	Sargodha	10.5	272	20	521	28.7	746	36.5	950	43.6	1134	49.9	1299	55.6	1446	61.8	1567	69.8	1624	76.9	1711
7	Rawalpindi	8	201	15.4	386	22.2	556	28.3	713	34.2	857	39.4	988	44.2	1108	50.5	1224	58.4	1348	65.8	1437
7	Sahiwal	12.9	282	24.4	534	34.6	757	43.5	954	51.4	1126	58.2	1276	64.2	1405	69.8	1504	76.5	1597	82.9	1637
7	Multan	12.4	283	23.5	536	33.4	762	42.1	963	49.9	1140	56.7	1294	62.6	1429	68.9	1531	74.9	1637	83.4	1716
7	Bahawalpur	13.6	290	25.7	547	36.3	774	45.6	973	53.7	1145	60.7	1294	66.7	1421	73.9	1499	79.2	1568	86.1	1684
7	D.G.Khan	13.3	292	25.2	552	35.7	781	44.9	983	52.9	1158	59.9	1310	65.8	1441	72.8	1499	77.9	1597	83.9	1697

Table 8.53 Appendix-E-DHW-Household-125-418m²

Solar Thermal generation potential summary for per Household (DHW) by FTC

Households (125-146 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
8	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	78.6	1035	84.9	1138	92.4	1249
6	Sheikhupura	11.8	235	22.3	446	31.7	633	40.1	799	47.4	946	53.8	1074	75.4	1186	82.7	1267	88.7	1364	94.8	1436
9	Gujranwala	10	293	19.2	562	27.5	808	35.1	1032	42	1234	48.3	1418	53.9	1582	60.4	1635	66.8	1724	74.9	1811
7	Faisalabad	12.2	271	23.2	513	33	730	41.6	921	49.1	1090	55.9	1237	61.7	1366	68.4	1431	75.9	1522	82.1	1637
9	Sargodha	9.3	274	18	526	25.9	758	33.1	970	39.7	1164	45.8	1340	51.2	1500	57.5	1568	64.8	1652	72.8	1734
8	Rawalpindi	7	202	13.6	390	19.7	365	25.4	727	30.7	878	35.5	1018	40.1	1147	47.5	1278	54.7	1342	62.5	1410
8	Sahiwal	11.3	284	21.6	541	30.9	773	39.2	981	46.6	1167	53.2	1332	59	1478	66.5	1574	72.9	1657	80.4	1730
8	Multan	10.9	285	20.8	543	29.8	778	37.9	989	45.2	1179	51.6	1349	57.5	1500	64.9	1582	72.4	1637	78.9	1734
8	Bahawalpur	12	292	22.8	556	32.5	792	41.1	1002	48.8	1189	55.6	1354	61.5	1498	67.5	1537	73.9	1631	80.1	1724
8	D.G.Khan	11.8	294	22.4	560	31.9	798	40.5	1012	48.1	1202	54.8	1370	60.7	1517	67.5	1600	73.9	1679	81.8	1715

Households (167-209 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
7	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	79.8	1034	86.5	1142	92.6	1278
6	Sheikhupura	11.8	235	22.3	446	31.7	633	40.1	799	47.4	946	53.8	1074	75.4	1186	82.9	1257	88.9	1324	94.6	1464
9	Gujranwala	10	293	19.2	562	27.5	808	35.1	1032	42	1234	48.3	1418	53.9	1582	60.4	1684	68.9	1754	75.9	1810
8	Faisalabad	10.8	273	20.6	520	29.4	745	37.4	947	44.6	1128	51	1290	56.7	1434	62.8	1499	70.2	1569	78.2	1658
8	Sargodha	10.5	272	20	521	28.7	746	36.5	950	43.6	1134	49.9	1299	55.6	1446	63.5	1534	69.7	1620	76.9	1712
7	Rawalpindi	8	201	15.4	386	22.2	556	28.3	713	34.2	857	39.4	988	44.2	1108	49.8	1167	57.0	1267	64.5	1342
9	Sahiwal	10.1	286	19.4	547	27.9	786	35.6	1003	42.6	1200	48.9	1378	54.6	1537	62.5	1599	69.8	1674	76.8	1769
9	Multan	9.7	286	18.7	549	26.9	790	34.4	1010	41.2	1211	47.4	1393	53	1557	59.8	1650	68.9	1749	74.9	1821
8	Bahawalpur	12	292	22.8	556	32.5	792	41.1	1002	48.8	1189	55.6	1354	61.5	1498	68.5	1567	76.8	1687	80.9	1764
8	D.G.Khan	11.8	294	22.4	560	31.9	798	40.5	1012	48.1	1202	54.8	1370	60.7	1517	67.5	1599	75.9	1687	82.7	1769

Households (230-418 m²)

Flat Tube Collectors(FTC)		1		2		3		4		5		6		7		8		9		10	
Collectors unit area and energy saved		Area(m²) 0.9	Energy saved	Area(m²) 1.9	Energy saved	Area(m²) 2.8	Energy saved	Area(m²) 3.7	Energy saved	Area(m²) 4.7	Energy saved	Area(m²) 5.6	Energy saved	Area(m²) 6.5	Energy saved	Area(m²) 7.2	Energy saved	Area(m²) 8.2	Energy saved	Area(m²) 9.0	Energy saved
Avg. Occupancy	Divisions	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)	%age demand met	(kWh)
8	Lahore	17.1	228	31.6	420	43.7	581	53.6	713	61.7	821	68.3	909	73.6	979	79.8	1059	86.9	1169	93.9	1287
7	Sheikhupura	10.2	237	19.4	453	27.8	648	35.4	825	42.2	984	48.4	1126	53.8	1253	60.2	1324	66.9	1397	74.9	1491
12	Gujranwala	7.6	297	14.7	575	21.3	835	27.5	1077	33.3	1304	38.7	1514	43.7	1709	49.8	1792	56.9	1867	63.1	1924
9	Faisalabad	9.6	274	18.5	526	26.6	756	34	967	40.7	1158	46.8	1332	52.3	1489	59.2	1568	67.9	1648	76.9	1734
8	Sargodha	10.5	272	20	521	28.7	746	36.5	950	43.6	1134	49.9	1299	55.6	1446	62.9	1534	70.2	1628	77.9	1768
8	Rawalpindi	7	202	13.6	390	19.7	365	25.4	727	30.7	878	35.5	1018	40.1	1147	49.8	1279	56.9	1384	64.9	1439
9	Sahiwal	10.1	286	19.4	547	27.9	786	35.6	1003	42.6	1200	48.9	1378	54.6	1537	62.5	1639	70.9	1710	79.2	1834
9	Multan	9.7	286	18.7	549	26.9	790	34.4	1010	41.2	1211	47.4	1393	53	1557	58.9	1621	65.9	1697	72.9	1769
9	Bahawalpur	10.7	294	20.5	562	29.4	805	37.4	1026	44.7	1224	51.2	1402	57	1561	64.9	1648	73.9	1710	80.2	1799
8	D.G.Khan	11.8	294	22.4	560	31.9	798	40.5	1012	48.1	1202	54.8	1370	60.7	1517	67.9	1620	75.6	1724	82.8	1867

Table 8.54 Appendix-E-DHW & Space heating-north Punjab

Solar Thermal generation potential summary for per Household (DHW + Space Heating) by FTC															
Area used in simulations(m²)		50		60		80		100		130		200		300	
Piping used in simulations (m)		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m	
Lahore Division															
Average (OCC)		4		5		6		7		8		7		8	
House GIFA (m²)		21-42m²		63m²		84m²		105m²		125-146m²		167-209m²		230-418m²	
Flat tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m²	23.8	1176	21.9	1135.1	20.4	1116.4	18.5	1059.4	16.5	989.2	16.4	910	14.8	852.2
2	3.92m²	37.2	1985.4	35.5	1986.7	33.7	1974	31.3	1907.4	28.8	1822	28.7	1690	26.8	1632
3	5.88m²	46.6	2632.6	44.2	2580.2	42.5	2604.3	40	2537	37	2440	36.6	2233.6	34.5	2180.4
4	7.84m²	53.7	3150.2	51.8	3157.5	49.7	3144	47	3081.7	44	3000	44	2791.4	42	2733.4
5	9.8m²	59.3	3558.8	57.2	3565.4	55.3	3594.4	52.5	3531	50	3428	49.2	3180	47	3127.7
Sheikhupura Division															
Average (OCC)		3		4		5		5		6		6		7	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m²	30	1510.4	27.7	1457	26	1430.6	24.8	1343.5	22.4	1268	21.4	1186.7	19.7	1137.5
2	3.92m²	43.7	2370.2	41.8	2367.6	40	2359.4	38.5	2246.3	35.8	2174	34.4	2040.4	32.2	1974.5
3	5.88m²	55	3196.8	52.5	3160.4	50.6	3170.7	49.1	3026	46.1	2933	44.6	2775.5	42.5	2723.3
4	7.84m²	62	3695.3	60	3710.2	58	3740.6	56.4	3588	53.2	3513.7	51.9	3343.6	49.4	3267.3
5	9.8m²	67.1	4026.7	65.2	4082.8	63.6	4154.3	62.6	4055.7	59.6	4015.8	58.4	3859.4	56	3808.4
Gujranwala Division															
Average (OCC)		6		5		7		7		9		9		12	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m²	21.5	1261	21.6	1177	19.3	1167	18.3	1093	15.7	1029	14.7	949.2	12.1	887
2	3.92m²	34.8	2192	35.1	2061	32.1	2068	31	1962	27.5	1902	26.4	1798	23.1	1775
3	5.88m²	43.6	2871	43.8	2686	41	2760	39.5	2619	35.8	2583	34.5	2440	30.5	2416
4	7.84m²	50.8	3454	51.3	3263	48.4	3376	47	3207	43.1	3194	42	3049	37.5	3046
5	9.8m²	56	3879	56.8	3697	53.5	3792	52.1	3648	48.3	3666	47	3490	42.4	3509
Faisalabad Division															
Average (OCC)		3		4		5		6		7		8		9	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m²	39.2	1386	35.7	1344	33	1320	30	1271	26.7	1198	24.1	1138	21.8	1082
2	3.92m²	57	2296	54	2299	51.6	2319	48.1	2274	44.5	2197	41	2096	38.4	2059
3	5.88m²	68.5	2941	64.5	2904	61.7	1915	58.2	2896	54.6	2832	51.3	2762	48.3	2716
4	7.84m²	79	3618	75.1	3623	71.8	3617	67.5	3544	63.7	3475	60.5	3419	57.3	3352
5	9.8m²	84.2	3908	81.7	4013	78.8	4066	74.4	4016	70.1	3938	66.4	3828	63.6	3820
Sargodha Division															
Average (OCC)		5		6		7		8		9		8		8	
House GIFA (m²)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m²)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m²	22	1222	20.2	1166	18.8	1138	17	1076	15.3	1005	15	920	14.2	850
2	3.92m²	34.8	2065	32.8	2019	31.3	2015	29.1	1941	26.7	1851	27	1731	26	1644
3	5.88m²	43.4	2690	41.6	2680	40	2685	37.5	2608	35	2512	34.5	2315	33.4	2193
4	7.84m²	50.8	3287	48.8	3272	47	3263	44.6	3197	42.1	3121	42	2895	40.6	2752
5	9.8m²	56.5	3736	54.2	3709	52.4	3724	50	3655	47.3	3577	47	3304	45.6	3160

Table 8.55 Appendix-E-DHW & Space heating-south Punjab

Solar Thermal generation potential summary for per Household (DHW + Space Heating) by FTC															
Area used in simulations(m^2)		50		60		80		100		130		200		300	
Piping used in simulations (m)		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m		Outside-5m Inside-3m	
Rawalpindi Division															
Average (OCC)		5		5		6		7		8		7		8	
House GIFA (m^2)		21-42m^2		63m^2		84m^2		105m^2		125-146m^2		167-209m^2		230-418m^2	
Flat tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m^2	21.2	1291	20.5	1226	19.2	1199	17.5	1139	15.7	1064	15.4	967	14.1	915
2	3.92m^2	34.4	2244	33.6	2155	32.1	2143	30	2067	27.6	1970	27.6	1832	26	1767
3	5.88m^2	43.1	2931	42.3	2819	40.7	2824	38.3	2745.4	36	2659	35..8	2470	33.7	2382
4	7.84m^2	51	3593	50.3	3487	48.2	3461	45.6	3372	43.2	3302	43	3058	41	2983
5	9.8m^2	56.4	4055	56	3965.4	54	3956	51.3	3879	48.4	3767	48.3	3512	46.2	3428
Sahiwal Division															
Average (OCC)		4		6		6		7		8		9		9	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m2	21.4	1241.4	20.4	1162	19.2	1152	17.5	1095	15.7	1020	14.3	959	13.5	892
2	3.92m2	34.5	2134	33.9	2068.2	32.1	2049	30	1991	27.6	1890	25.6	1806	24.8	1718
3	5.88m2	43.5	2814.4	41.4	2767	40.8	3706	38.4	3646	36	2555	33.6	2463	32.5	2333.4
4	7.84m2	51.3	3443.2	49.1	3400	48.3	3321	45.6	3235	43.1	3154	40.8	3069	40	2936
5	9.8m2	57.2	3925	55	3888	53.9	3792	51.2	3719	48.5	3628.5	46	3532	45	3369.1
Multan Division															
Average (OCC)		3		6		6		7		8		9		9	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m^2	29.1	1313	25	1353	24.2	1293	22.1	1239	20.3	1196	18.5	1076	18	1013.2
2	3.92m^2	45	2211	40.7	2378.4	40	2308	37.2	2238.4	35.1	2207	33	2040	32	1926
3	5.88m^2	56	2930	50.5	3074.4	49.7	2997	47	2954	44.5	2903	42	2693	40.8	2546
4	7.84m^2	65.4	3618	59.2	3779	58.3	3659.4	55.4	3606	53	3565	50.6	3366	49.6	3208
5	9.8m^2	71.7	4062.2	65.7	4267	64.8	4179	61.6	4108	59.2	4093.4	56.6	3856	55.3	3653
Bahawalpur Division															
Average (OCC)		4		6		7		7		8		8		9	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m^2	37.5	1410	32.7	1403	30.2	1370	29	1307.5	25.7	1220	24.3	1133	22	1080.4
2	3.92m^2	55	2277.3	51	2403	48.4	2399	46.7	2290	43.2	2212	41.5	2096.8	38.9	2058.8
3	5.88m^2	67.4	3003	62.1	3078.3	59.6	3119	57.6	2973	54	2899	52	2751.4	49	2707.6
4	7.84m^2	78.6	3779	72.3	3812	69.2	3809	67.3	3644	63.3	3551.4	61.4	3387	58.3	3342
5	9.8m^2	84.7	4172	80	4322	76.5	4334	74.3	4155	70	4041.5	68	3856.5	64.7	3815
Dera Ghazi Khan Division															
Average (OCC)		5		6		7		8		9		8		8	
House GIFA (m^2)		21-42m2		63m2		84m2		105m2		125-146m2		167-209m2		230-418m2	
Flat tube Collector															
No of units	Gross Area(m^2)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)	%age of demand met	Energy Saved (kWh)
1	1.96m^2	29.3	1338.4	27.2	1313.5	25.4	1296.5	23.1	1241.1	20.6	1153	18.5	1079.5	18.2	988
2	3.92m^2	46.2	2333.7	43.5	2280.7	41.5	2297.5	38.8	2240.5	35.6	2139	34.4	2032	33	1902
3	5.88m^2	56	2936	53.8	2968	51.4	2967.5	48.5	2917.2	45.3	2832.5	43.6	2666	42	2517.4
4	7.84m^2	65.5	3651.6	62.6	3610	60.2	3625.2	57	3546	53.7	3463.7	52.2	3307.3	51	3174.5
5	9.8m^2	72.7	4151	69.5	4137.8	66.7	4128.6	63.4	4074	60.2	3999	58.1	3768.3	56.8	3625