Energy, Economy, and Sustainability at Household Level in Pakistan

By

Iftikhar Ahmed Shahid

(Registration No: NUST201590305PCES9215F)

Thesis Supervisor: Dr. Kafait Ullah

Co-Supervisor: Dr. Clark A. Miller, Arizona State University

Department of Energy Systems Engineering

US-Pakistan Center for Advanced Studies in Energy

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

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A thesis submitted to the National University of Sciences and Technology, Islamabad

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in

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(2023)

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Annex L

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Student Name: **Iftikhar Ahmed Shahid** Signature ____________

Examination Committee:

a) External Examiner 1:
Dr. Muzaffar Ali
Professor, UET Taxila
Taxila.
Signature ____________

b) External Examiner 2:
Dr. Usman Shakoor
Associate Professor,
COMSATS University, Islamabad.
Signature ____________

c) Internal Examiner:
Dr. Muhammad Bilal Sajid
Associate Professor, USPCAS-E, NUST,
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Name: (Iftikhar Ahmed Shahid)

Dedicated to my grandparents

(Nanajee, Malik Sultan Khan and Nani Maan, Bhaag Bharee)
who dreamt to educate me
despite being illiterate themselves,

and

to my Elementary teachers
(Master Ghulam Muhammad and Master Muhammad Akram)
who laid the foundations for those dreams come true.

May Allah bless them all for their sincerity and efforts;
aameen.

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It has been a long and tiring journey through undulating grounds filled with uncertainties, despair, pessimism, and hope – especially at this age. The belief that these are the last lines I am scribbling to cross over the finish line in this marathon brightens up my day. This sojourn brought a few difficult moments, demanding composure in the face of heart-breaking and disparaging situations –that I had not faced the entire life.

The daunting task of PhD with overwhelming demands on life could neither have started nor seen the completion day without encouragement, eager support and consistent prayers of my wife, Fakhera. Her reassurances made me pursue all my dreams through life; Jazaak-Allah dear.

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Stepping into this quagmire and getting over so many hurdles that seemed impassable belong to Lieutenant Colonel Dr Muhammad Imran Ahmed. And no thanks are enough to acknowledge the tireless assistance of my friend, Dr Muhammad Dawood, New Mexico State University, for using his expertise and sparing countless hours of his life making me understand difficult concepts, refining the empirical results and improving the manuscripts. Dr Dawood challenged me to think big whenever I felt down and stuck. Thank you Imran, thank you Dawood, had you both not been there I would have quit, many times.

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Abstract

The correlation between energy and development, particularly the positive linkage between access to electricity and the quality of life is well supported by the relevant research. Despite lack of consensus on the existence and direction of causality between energy consumption and economic development, most studies exhibit strong correlation between the two. The indicators measuring socioeconomic well-being such as the human development index (HDI) and multi-dimensional poverty index (MPI) also recognize energy as an important resource for human development. Further, recognizing the importance and vital contribution of energy in socioeconomic well-being, it is included as 7th Sustainable Development Goal (SDG-7) in 2030 Agenda for Sustainable Development. The research on interplay between SDG-7 – the energy – and other SDGs offers substantial evidence of SDG-7's direct effect and/or dependence upon achievement of several SDGs and indirect relationship with the remaining ones.

In the above context, this doctoral dissertation attempts to correlate the socioeconomic conditions with the energy access in Pakistani households. It examines whether the state of household energy in Pakistan can predict the earning abilities and how it may validate the correlation between energy and other socioeconomic markers. This is followed by an evaluation of rooftop solar systems' (RTS) contribution in meeting the households' energy needs and identification of few measures that can accelerate RTS adoption in Pakistan. Thus, this thesis brings to fore two dimensions of household energy utilization and adoption in Pakistan: first it shows the robust correlation between the type (and quality) of energy and the socioeconomic well-being of citizens at household level and, second it identifies a critical factor – lack of awareness – inhibiting the adoption of rooftop solar photovoltaics (PV) systems. Though not aimed at establishing a causal relationship, this research provides strong evidence about household energy being an important indicator in measuring a society's economic well-being, leading to the inference that improving the type and the quality of household energy – both for cooking and for lighting – can greatly influence the quality of life. It is empirically demonstrated that energy is an important contributor in human welfare and merits consideration as a factor in calculating the Human Development Index (HDI). With better understanding of energy's role in socioeconomic well-being, this thesis then offers evidence on how psycho-social factors like perception, behaviour and attitude affect the acceptance and adoption of clean-energy sources like solar PV systems.

The data analyzed and presented to address the former dimension is obtained from 2017 Population Survey, Pakistan Bureau of Statistics, Pakistan. Data from this survey disaggregated to district level encompassing all communities across the width and breadth of the country was used for the regression analysis. Using empirical results of this analysis, a robust correlation is established between the energy type Pakistani households have access to, their living standards and per capita income. This outcome offers insights into the household energy's significance and correlation with the income (or poverty). For the latter part, inquiry into the impact of citizen's behaviour based on their level of awareness about household solar energy adoption is based on the data collected by the Institute of Policy Studies (IPS), Pakistan. Statistical results of this inquiry reveal the effects of intangible factors like awareness on the people's willingness to participate in rooftop solar (RTS) energy adoption.

Presenting the groundwork for policy review as well as for future research, this dissertation lays down the foundation for hitherto unexamined policy options to create synergy between poverty alleviation planning and universal energy access in Pakistan. Increased share of renewable energy sources in the energy mix through households' RTS adoption is expected to create better economic prospects for the society through improved energy equity and enhanced energy security for the country through reduced dependence on the energy imports.

Abbreviations

AHP	Analytical Hierarchy Process
ANOVA	Analysis of Variance
ARCH	Auto-regressive Conditional Heteroscedastic
ARE	Alternative Renewable Energy
ASEAN	Association of Southeast Asian Nations
ASU	Arizona State University
BP	Breusch-Pagan
CEF	Cooking Energy Fuels
CIM	Contract Intensive Money
CIs	Condition Indices
DF	Degree of Freedom
DISCOs	Distribution Companies
DW	Durbin-Watson
ECM	Error Correction Model
Ed	Education Level
G7	Canada, France, Germany, Italy, Japan, UK, USA, European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas (es)
GNP	Gross National Product
GW	Gigawatt
HDI	Human Development Index
HDR	Human Development Report
HF	Housing Facilities
HSSC	Higher Secondary School Certificate
HT	Housing Types
IEA	International Energy Agency
IICSS	Info on Installation Cost of Solar System
INM	Information on Net Metering
IPPs	Independent Power Producers
IPS	Institute of Policy Studies
IRENA	International Renewable Energy Agency
ISPVT	Info on Solar PV Technology

kWh	Kilowatt-hour
kWp	Kilowatt-power (peak from a solar PV panel/ system)
LES	Lighting Energy Sources
M&E	Monitoring and Evaluation
MENA	Middel East and North Africa
MPI	Multidimensional Poverty Indicator
MWh	Megawatt-hour
NDC	Nationally Determined Contribution(s)
NUST	National University of Sciences and Technology
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares (regression)
OPHI	Oxford Poverty and Human Development Initiative
PBS	Pakistan Bureau of Statistics
PCI	Per Capita Income
PG	Postgraduate
PLS	Partial Least Squares (regression)
PP	Population Parameters
PV	Photovoltaics
RE	Renewable Energy
RES	Renewable Energy Sources
RET	Renewable Energy Technology
RMS	Root Mean Squared
RTS	Rooftop Solar
SAARC	South Asian Association for Regional Cooperation
SD	Standard Deviation
SDG	Sustainable Development Goal
SE	Standard Error
SE4All	Sustainable Energy for All
SEPAP	Solar Energy for Poverty Alleviation Program
SFIS	School for the Future of Innovation in Society
SHP	Small Hydro Power
SSC	Secondary School Certificate
UG	Undergraduate

UNDP	United Nations Development Program
USA	United State of America
USPCAS-E	United States-Pakistan Centre for Advanced Studies in Energy
VAR	Variance of Random Variable
VDP	Variance Decomposition Proportions
WB	World Bank
WBO	World Bank Organization
WEF	World Economic Forum

CHAPTER 1

INTRODUCTION

1.1 Background

Mankind have been in search of comfort and development ever since the arrival of Adam and Eve (peace be upon them) on the earth [1,2]. While using their mental faculties and physical abilities in the quest to draw maximum benefits from the earthen resources, humanity soon realized the energy's significance in improving the quality of life [1-3]. Exploration of worldly resources forced man to invent tools and gadgets, eventually leading to gradual mechanization to improve productivity and efficiency. Need for and the use of energy accompanied the development process right from the stone age [1-5].

Through the history there have been numerous challenges to human survival on earth's surface. The nature and spheres of these challenges have been changing with time, with shifts in human behaviours, with discoveries and inventions and with scientific advancements. Most factors affecting the changing nature of these challenges have been anthropogenic activities rather than the acts of nature. Moving from the industrial revolution to the internet of things and metaverse, one of the biggest challenges facing life on earth today is sustainable and just energy solutions for humanity [6]. Human survivability has never been so much dependent on the access to and type of energy as in present-day times. Realization about depleting fossil fuel reservoirs and adverse environmental consequences of hydrocarbons-based energy has exacerbated the need for increased attention towards socioeconomic and sociocultural dimensions of energy transitions, instep with scientific research on renewable energy sources and the related technologies [6-8].

Figure 1.1: Energy and sustainability

Knowledge structuring and formalization of education soon started segmentation of learning and intellectual development into multifarious subjects to cover the various dimensions of life – encompassing survival, economic, social, cultural, and sustainability aspects. On the footsteps of knowledge compartmentation came the classification and regulation of research work in line with the demands of every subject. In that, the last half century drew the scholars' attention towards the determinants of economic growth, followed by investigations into the role of energy in economic development [4-7]. While work on the means and sources of energy has been there for quite some time, the two factors of human development and comfort – economic growth and energy – came up as one question just a couple of decades earlier [9,10]. Earliest investigations into correlation between energy and economic development came from the oil shocks of 1970s. Later the reason for ingress into this field was augmented by the motivation to handle the energy (oil) prices. Towards the end of 20th century Kyoto Protocols further intensified the need for exploring energy-growth nexus to guide decisions on energy intensity and energy conservation measures. Inclusion of sustainable energy as one of the goals in the 'Agenda-2030 for Sustainable Development' turned the researchers' attention towards renewable energy technologies, replacement and use of existing equipment, constructs and energy infrastructure, and the means and measures for benefitting from the renewable energy sources [8]. The evolution leading to growth and expansion of knowledge is symbolically represented in Figure 1.2. The word Environment typed in blue font shows how the environment factored in to divert researchers' attention from mere economy–energy relationship towards sustainable energy solutions.

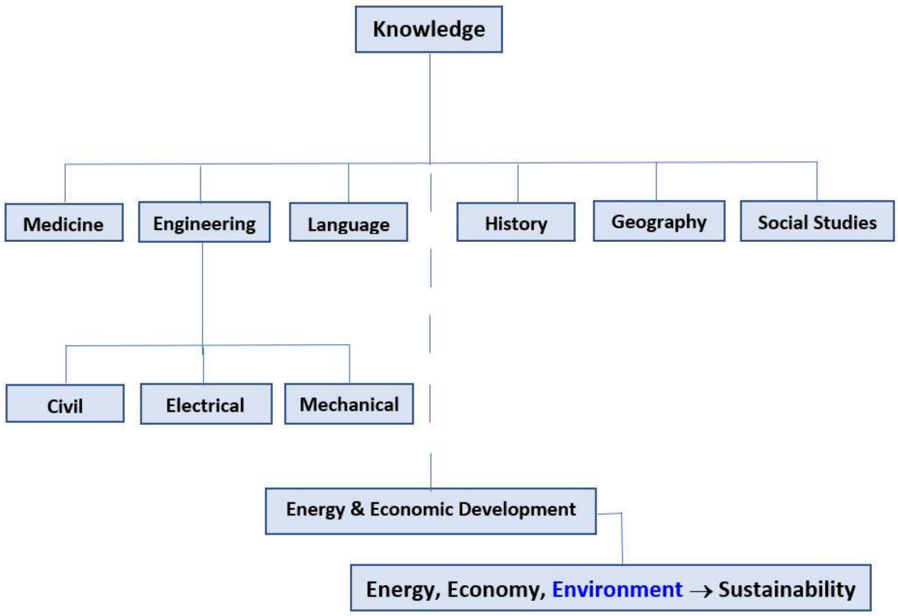

Figure 1.2: Symbolic Representation of Knowledge Structuring

Contemporary literature contains broad and comprehensive research work supporting existence of a correlation between energy and development, with stronger evidence confirming the impact of electricity on wealth creation and suggesting a positive effect of clean energy technologies on the quality of life. Literature on energy – growth nexus is devoid of consensus on the existence or the direction of causality between the two phenomena and has mostly been based on empirical analysis of data aggregated at country level drawn from international sources. Despite lack of consensus on the existence and direction of causality between energy consumption and economic development, most studies confirm presence of correlation between the two [9,10]. The statistics measuring socioeconomic well-being such as the multi-dimensional poverty indicator (MPI) and human development index (HDI) too recognize energy as an important resource for human development [6]. Figures 1.3 and 1.4 illustrate the parameters included in MPI and HDI respectively. The red font in Figure 1.3 highlights the point that while two types of household energy did factor in calculating the MPI, HDI calculations do not incorporate these critical welfare needs.

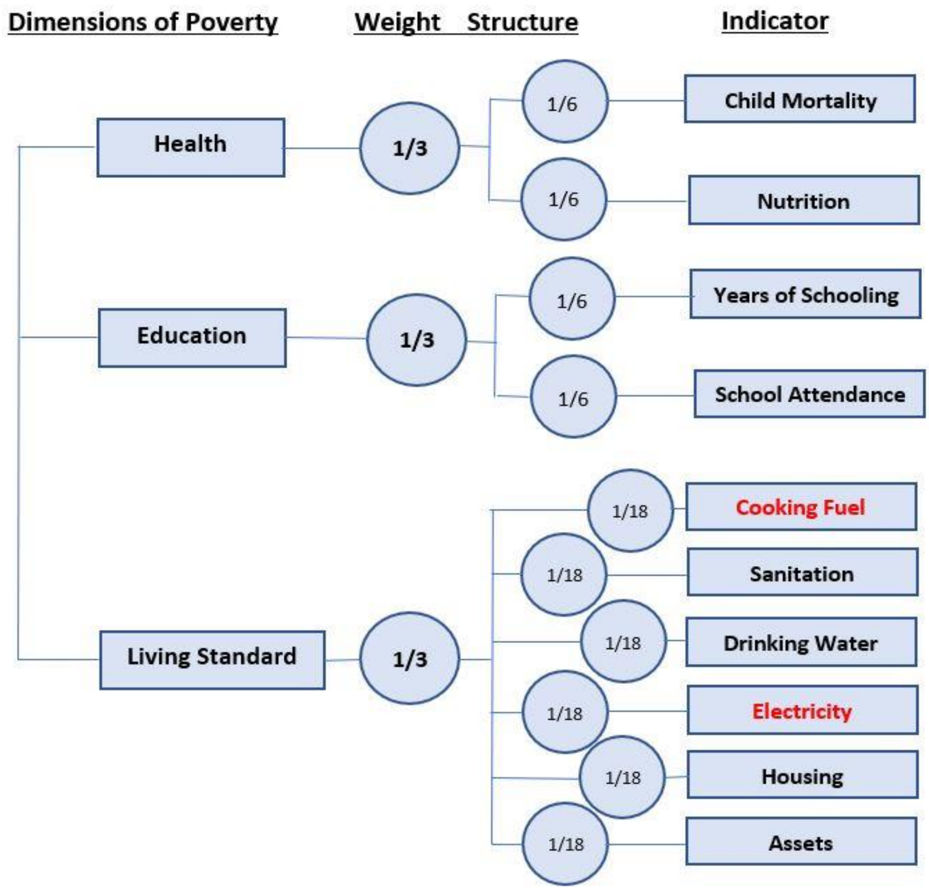

Figure 1.3: MPI (Source: OPHI [6])

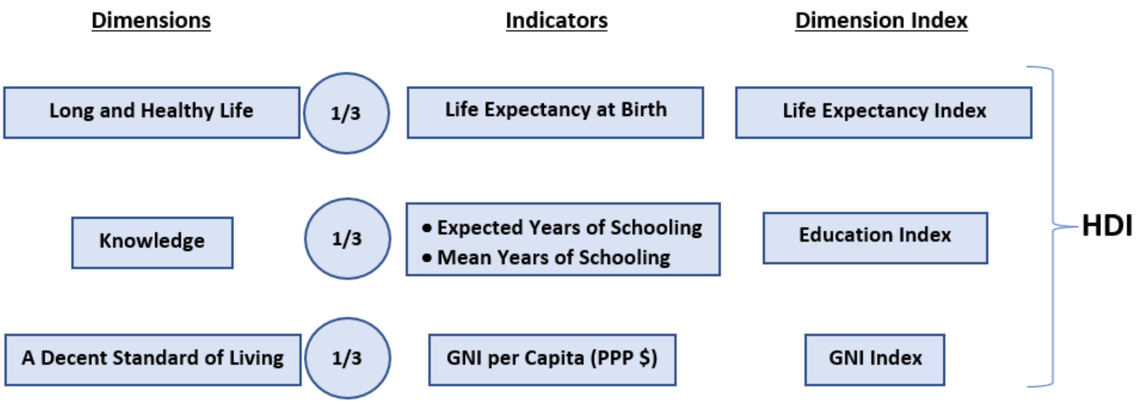

Figure 1.4: HDI (Source UNDP[6])

Towards the late 1980s researchers started exploring correlation between electricity – one form of energy – and economic growth. Almost all the literature on the electricity–growth relationship exhibits the existence of causality between these two parameters, with differences on the direction of this relationship. Inconsistency in the outcomes of empirical studies regarding the relationships between economic growth and energy or electricity has been attributed to several factors like availability and reliability of data, research methodology, sociocultural landscapes, state of economy, economic structures, types of energy mix, regulatory and policy mechanisms, political infrastructure and its stability and the documentation of economy and energy related activities [9,10]. Delivery of quality education is dependent on supply of electricity in the schools and reliable/ affordable electrical power at homes. Access to almost all basic human needs like healthcare, lighting, heating/air circulation, cooking, water supply and sanitation, and telecommunication/information technology is dependent on reliable energy services. Impact of electricity access on the quality and level of higher education too has been proved with empirical evidence. Moreover, access to information technologies and effective means of communication, which are vital especially for higher education, is also contingent upon reliable electricity supply [8]. An illustration of energy's role in society's well-being is given in Figure 1.5.

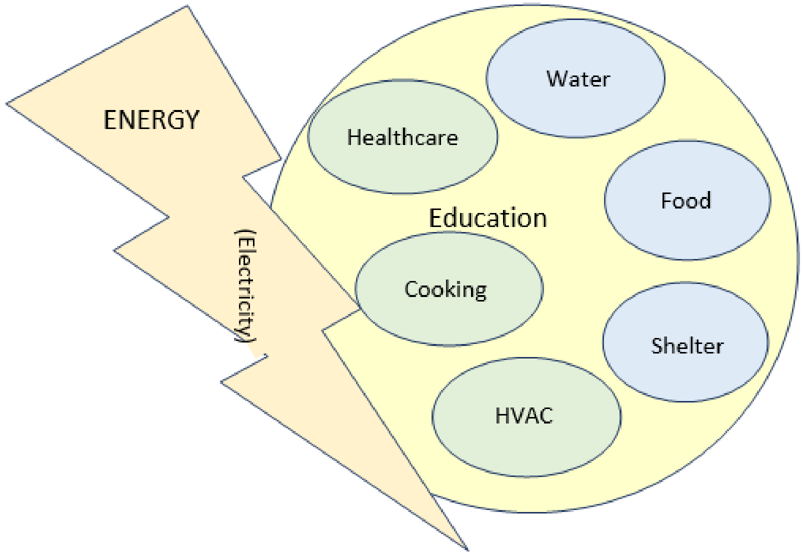

Figure 1.5: Energy and society’s well-being

A stronger correlation is found between renewable energy and economic development in the research exploring linkages between the two. That outcome may not be conclusive since renewable energy sources are still a fractional contributor in the total energy portfolio of most countries. Yet, together with the results of studies into electricity – growth nexus, this correlation supports the existence of strong impact of renewables-based electricity on the overall economic development [6,7]. Further, recognizing the importance and vital contribution of energy in socioeconomic well-being, it has been included as 7th Sustainable Development Goal in 2030 Agenda for Sustainable Development. The research on interplay between the seventeen Sustainable Development Goals (SDGs) offers substantial evidence of SDG-7’s direct effect or dependence upon achievement of several SDGs and indirect relationship with the remaining Goals [8].

Cognizance of fast depleting fossil fuel reserves and their adverse impacts like global warming and environmental degradation, drew the world attention towards renewable energy technologies (RETs) during the last two decades. In that, while some of the developed countries led the transition towards clean energy sources, the realization of a sustainable earth persuaded the world leaders to delineate the sustainable development goals (SDGs). With continually declining costs, the renewable energy sources (RES) becoming cheaper than the conventional energy fossil fuels, the energy system transitions hold great opportunities for the developing countries to benefits through innovative approaches for embracing the RETs [6,7]. However, these opportunities present equally big challenges for the policy makers to rightly identify the local sociocultural dynamics and address the societal peculiarities and demands that are essential for faster acceptance of the transitions.

1.2 The Research Context

Pakistan is confronting one of the worst energy crises in its history – circular debt, line losses, political impediments in way of hydropower projects, highly volatile petrochemical prices intertwined with heaps of foreign debt, population growth, continuously increasing energy demand widening the gap between demand and supply, inconsistent policy and regulatory measures and misplaced priorities of the ruling elite – the challenges are monumental and many. The worst hit segment of the society, in this scenario, are the low- and middle-income domestic consumers. Cost implication of the imported furnace oil based power plants and diesel generators with over dependence on imported, highly volatile hydrocarbon fuels have made meeting the energy demand almost impossible. The energy sector's circular debt has surpassed the figure of Pak Rupees 4 trillion [11]. During recent months power shortages in the form of planned outages and unplanned breakdowns have adversely hit the households and commercial sectors [12]. Liquified Natural Gas (LNG) dependent power plants with decreasing international LNG supply and Pakistan's depleted foreign exchange reserves have further exacerbated the country's failure to tap its enormous hydropower potential. While the current government initiatives towards 'a new solar policy' [12] are a welcome in this direction, it remains to be seen how that policy gets implemented beyond family business interests when seen in the light of corruption-laden Pakistani politics. Socioeconomic implications notwithstanding, the world can ill afford the catastrophic environmental consequences of fossil fuels-dominated energy mix – the recent devastating floods and the blinding smog in Pakistan being just a few of those. Though the challenges to clean energy access are enormous but so is Pakistan's solar energy potential.

1.3 Scope of the Research

In the forementioned context, the scope of this undertaking has been identifying household energy's role as a true indicator of economic well-being/ deprivation based on real life data that represent people across breadth and width of Pakistan. Alongside that, the linked objective has been to identify a few meaningful measures that can invoke citizens' wholehearted participation in the process of the critically needed energy transitions. Thus, this dissertation covers investigation into two dimensions of household energy through energy's correlation with the socioeconomic well-being in Pakistan and the possibility of contributions from one of the major energy consuming sectors – the households – towards energy equity and energy security. The objective of energy equity aims at exploring the possibility of meeting the household energy needs by the households themselves in a way that leads to their improved socioeconomic well-being. Whereas, at the national level, this effort looks into the prospects of enhanced energy security via the households' contribution towards reduced dependence on the energy imports.

1.4 Research Objectives

Within the scope of the research, objectives set for this doctoral dissertation are: -

1.4.1 Nexus between energy and economy in Pakistani households.

- Correlate socioeconomic conditions with the state of energy access in Pakistani households.
- Examine how the state of household energy in Pakistan can predict the earning abilities in the light of respective income.
- Validate if the energy's correlation with other socioeconomic markers supports the discovered status of households' energy as predictor of economic conditions.

1.4.2 Rooftop Solar PV Systems and Household Energy Needs

- Evaluate the possible contribution of solar energy adoption by Pakistani household in meeting the current electricity demand.
- Identify some important measures that can accelerate RTS adoption in Pakistan.

The data for the first part of this research came from the 2017 Population Survey, Pakistan Bureau of Statistics (PBS), Pakistan. This survey covered data encompassing all communities across the width and breadth of the country. Using empirical results of statistical evaluation of data disaggregated at district level, this dissertation presents a robust correlation between the household energy type, their essential needs and per capita income. Having established the interplay between household energy type and the earning abilities, the second part of this research highlights the importance and impact of people's awareness about different aspects of solar photovoltaics (PV) technology and rooftop solar (RTS) adoption by the households based on the empirical analysis of data obtained from Institute of Policy Studies (IPS), Pakistan. Table 1.1 below summarizes the research design.

Table 1.1. Research objectives, questions, and data.

Research Objectives	Research Questions	Data and Information Prerequisites	Sources of Data
Nexus between Energy and Economy in Pakistani Households?	• Are energy access and indicators of social wellness correlated? • Can energy predict economic conditions in Pakistani households? • Does households energy's linkage with other socioeconomic markers support the energy's nexus with the income in Pakistan?	• Real life data. • Data covering most territories across Pakistan • Data be aggregated at the lowest administrative unit. • Data to include most of the important socio-economic indicators.	• Population Survey-2017 Statistics from PBS. • 2017 District level Per capita Income data from PBS
Rooftop Solar PV Systems and Household Energy Needs	• Can rooftop solar energy contribute to meeting current electricity demand in Pakistan? • Possible measures to promote rooftop solar PV technology in Pakistani households?	Survey based data with representation from all areas of Pakistan.	Outcome of Survey on consumers' willingness to become prosumers by IPS, Pakistan.

1.5 Significance of the Research

This research voyage has taken distinctive approaches in selection and achievement of the research objectives. Multiple aspects that make first part (Chapter 4) of this research exclusive are: 1) the data used for establishing statistical correlation between household energy and per capita income covers all four provinces of Pakistan and is not based on sampling survey(s), 2) to the best of our knowledge and in the light of extensive literature review it's the first statistical inquiry exploring linkage between income and household energy type, 3) the model arrived at is based on Pakistan's real data never used for any study so far, 4) the model uses the data aggregated at district level and not at country level, 5) the model uses the type of household energy as explanatory variable and not the amount of energy – that was used in most earlier studies, 6) the household being the lowest tier in the society exhibits the energy-economy correlation at the grassroot level and 7) the investigation into energy-poverty nexus uses final energy – available to households for cooking and for lighting – as predictor variables that can be contrasted with total energy–a phenomenon used in several earlier energy-wellness related studies. The second part (Chapter 5) of this dissertation is unique whereby it is the first ever study exploring the awareness based behavioral factors affecting renewable energy adoption at household level in Pakistan.

This research passed through a process of great learning and personal growth culminating in this manuscript, which is not presented as a final word on the subjects studied but intended to open new venue(s) into the field of energy innovation research and serve as grounds for collaboration and improvement through further exploration of associated sociocultural and socioeconomic dynamics. In pursuit of these objectives this effort is expected to serve as a catalyst to accelerate investigations into and expand the research on energy innovations. Thus, this dissertation presents the groundwork for policy review by competent authorities as well as for future research, laying down the foundation for hitherto unexamined policy options to create synergy between poverty alleviation planning and universal energy access programs. Energy security being Pakistan's one of the biggest economic vulnerabilities too, the outcome of this research is relevant and important for the country's self-reliance in economy as well. With objectives to lay down the foundation for addressing the energy woes of the low-income segment of the society without increasing their economic burden thereby bringing energy-constrained population out of economic poverty, this research can lead to the pathways aimed at energy equity and energy justice in the Pakistani society.

1.6 The Dissertation Layout

Introduction being its Chapter 1, the remaining part of this dissertation is laid out as follows. Based on the literature review Chapter 2 presents a deep dive into the relevant concepts and related work, establishes the theoretical framework, and identifies the gaps in the existing literature. Chapter 3 describes the theoretical framework and the research methodology. Chapter 4 explores the nexus between household energy and poverty by examining predictive value of energy towards earning abilities and income, and Chapter 5 investigates the role of awareness in promoting rooftop solar systems among Pakistani households. Chapter 6 covers the discussion and Chapter 7 concludes with the research outcomes and the recommendations for the future work.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews the relevant literature to establish a theoretical background of the research conducted for this dissertation. Beginning with introduction to the basic concepts of poverty and energy poverty it first touches on the important work on the determinants of economic growth that surprisingly shows negligible role of energy in development. That is followed by references to and discussion on the literature exploring correlation between energy and economic development. Narrowing down, next part illustrates the research about electricity–growth relationship with the renewable energy–growth nexus just following in. The subsequent part shows how the contemporary literature determines linkages between different sustainable development goals, and especially with energy – the 7th goal. The part after that covers some important aspects of sustainability and energy transitions in the light of studies by a few esteemed scholars on the subject. The ensuing two sections are on solar energy – first discussing the literature on socio-cultural dynamics of household solar systems' adoption and the second describing how recent research work found rooftop solar systems impacting the economic well-being at individual and community level. The last part briefly touches on the current situation in Pakistan.

2.1 Poverty and Energy Poverty–The Concepts

Concepts of general poverty and energy poverty can be better understood when seen through the lenses of vulnerability. As per the Oxford Dictionary, vulnerability is the 'state of being exposed to the possibility of being attacked or harmed either physically or emotionally'. Vulnerability is a person's – or a group of persons' – inability to resist or protect itself from the impending harm that might be because of forces of nature or caused by human acts. As per Monitoring and Evaluation Studies [13], vulnerability is characterized with four aspects: 1) It is multi-dimensional – has physical, emotional, economic, social, institutional, and even environmental dimensions; 2) It's dynamic – changes over time and across landscapes; 3) Is scale-dependent – magnitude varies across individuals, households, communities, and countries; and 4) May be site specific – its nature and extent can vary from place to place. In relation to economic poverty and energy poverty, the term vulnerability has been primarily linked to anthropological factors [14].

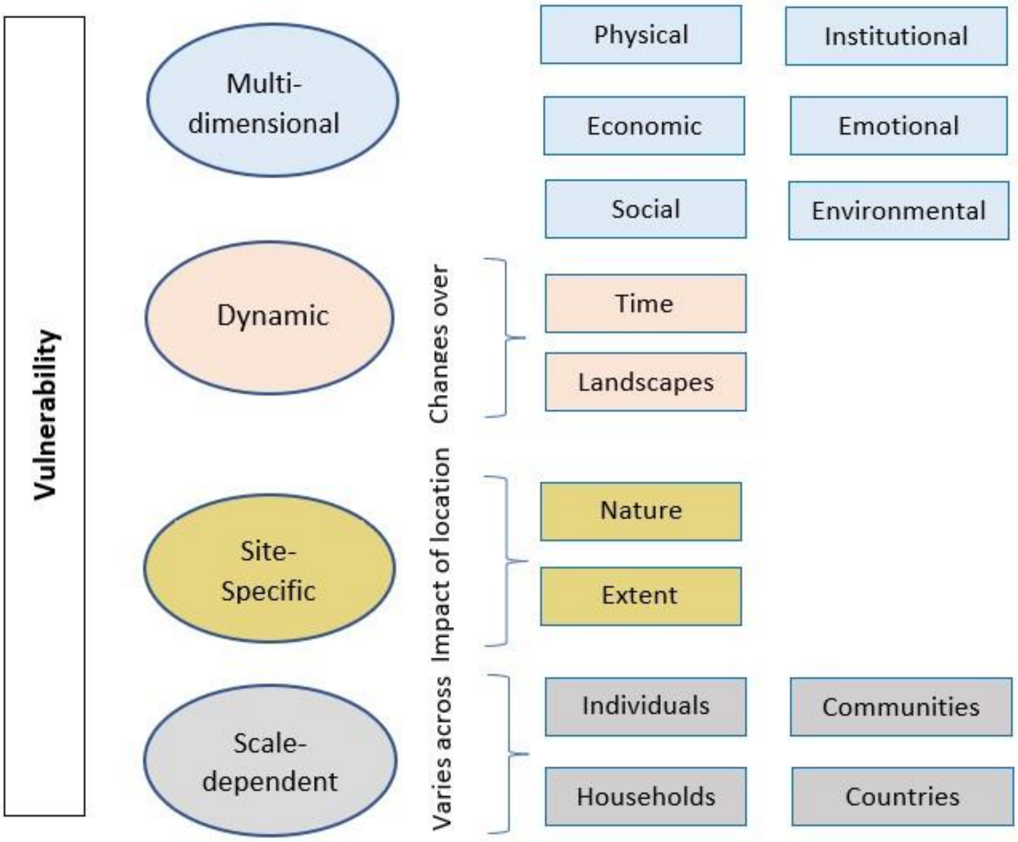

Figure 2.1: Vulnerability (Adopted from MNE Studies [13])

Poverty is not having enough resources to meet one's basic needs. As per World Bank Organization (WBO): 'Poverty is hunger. Poverty is lack of shelter. Poverty is being sick and not being able to see a doctor. Poverty is not being able to go to school and not knowing how to read. Poverty is not having a job, fearing the future' [15]. Poverty that is attributed to social exclusion and inequalities in the living standards has existed throughout the human history and is not a new phenomenon. While among affluent economies the consequences of economic disparity are not much noticeable, in underdeveloped countries there are wider gaps between the rich and the poor in creation as well as distribution of wealth. Poverty in the developing world is also attributed to economic manipulation of developed nations. However, a lot is a result of rulers' malpractices, misgovernance, corruption, and governments' inability to invoke people's participation in the development process [16].

Energy poverty is the lack of access for a person, a household, or a community to adequate energy services for meeting their needs within their affordability. As per World Economic Forum (WEF): 'Energy poverty is the lack of access to sustainable modern energy services and products. And energy poverty is the inability of households 'to consume adequate amounts of energy to maintain a decent standard of living at a reasonable cost' [16]. As per Agenda 2030 [17], energy poverty too has been recognized as a significant issue confronting the humanity. In fact, energy has been rightly regarded as basic human need in view of its environmental impacts, its correlation with the quality of modern-day life and its extended role with high-tech gadgets' ingress in our lives. As would be explained in the following pages, access to modern energy services have a direct impact on other important parameters affecting the quality of life and the phenomenon of poverty and energy poverty have been coupled together by many researchers [14, 17-20].

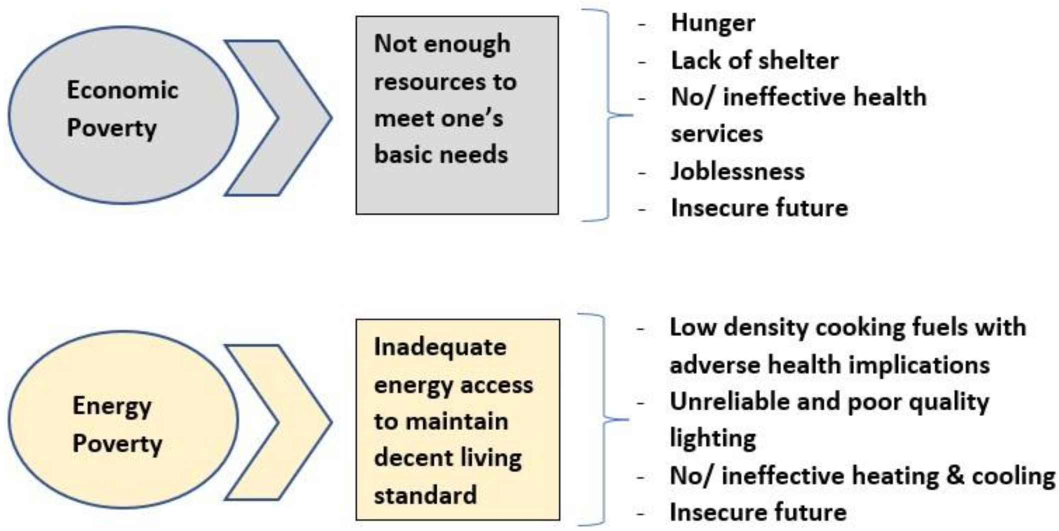

Figure 2.2: Poverty & Energy Poverty (Adopted from WBO & WEF [14,15])

2.2 Economic Growth and Its Determinants

Several researchers have explored the factors contributing towards economic growth for the last 7 – 8 decades. Empirical studies since 1980s present close to 140 predictors of economic activity, both the tangible as well as intangible ones. However, closer look through the robust correlation in the quality work shows that there are far fewer determinants of economic growth (GDP growth). As identified in 2008 by Enrique Moral-Benito these determinants are Initial GDP, Population, Urban Population, Population Density, Population Growth rate, Population under 15 and over 65, Life Expectancy, Malaria, Trade Openness, Consumption as share of GDP, Government consumption as share of GDP, Investment Price, Labour Force, Primary Education, Secondary Education, Political Rights, Civil Liberties, Navigable Water, Landlocked Country, Distance from world economic hubs and Tropical Area [21]. In this investigation Moral-Benito used 35 variables to explore 1960-2000 data of 73 countries. Grouping the variables into four categories – geographic, demographic, economic, and institutional – he concluded that these 22 parameters were the ‘robust determinants of economic growth’. He too acknowledged that ‘drivers of economic growth are not well understood’ despite ‘huge empirical research’ in this field. Few earlier studies provided understanding of how researchers approached to explore the determinants of development. Working on 47 countries’ data in 1985, Roger C. Kormendi and Philip G. Meguire found initial per capita income/ income conditions, population growth, monetary variance, aggregate technology, government spending, inflation (or monetary variance), and ‘openness’ of a country to international trade as predictor variables of economic growth besides ‘civil liberty’ and the investment impacting the economic growth [22]. Thomas Osang presented contract intensive money (CIM), rule of law, distance from the equator, openness to international trade, remittances share and foreign-born share as contributors to economic growth in his study based on 1961-2000 data of 65 countries that was published in 2006 [23].

A valuable contribution to the relevant literature was made by Themba G. Chirwa and Nicholas M. Odhiambo in 2016 [24]. Exploring the ‘Macroeconomic Determinants of Economic Growth’ in developing countries the authors conducted a survey of the literature published between 1999 and 2004. They concluded investment rate, human capital, schooling/ education, quality of institutions, political stability, governmental and public savings, openness of trade, rule of law/ governance, budget surplus, democratic values, and life expectancy to be positively impacting the economic growth. On the other hand, inflation, government spending/ consumption, population growth, being land-locked, and high tariffs had negative effect on the growth rate, while foreign aid and foreign direct investment were found bearing mixed results [24]. All these studies were primarily consulted to see if the researchers exploring the determinants of economic growth found any role of the energy in development. Surprisingly the energy did not appear as a contributor to economic growth in most of the studies on determinants of economic growth.

Much interest couldn’t be found from among Pakistani academia in the determinants of economic growth. One closely related study investigated 17 explanatory variables aggregated at district level for their correlation with the macroeconomic growth. Data pertaining to 46 districts was explored by Anwar Ali Shah G. Syed and Faiz Muhammad Shaikh [25] to conclude that main contributor to macroeconomic development in Pakistan were crop and horticulture, animal farming, forestry and related services, fishing, mining and quarrying, manufacturing, water supply, construction, wholesale and retail trade, hotel and restaurants, transport, storage and communication, financial intermediation, real estate renting and business services, public administration and defense, education, health and social work, community, social and personal services and electricity and gas. Interestingly, this study did find a role of domestic energy in the economic development though that contribution wasn't quantified in terms of its proportionate share in the development. Strangely, the districts table in this study presents the names of districts from Bangladesh instead of Pakistan.

2.3 Energy and Economic Growth

Nexus between economic growth and energy consumption has been of interest for the economists and economics researchers for the last four decades or so. In the contemporary studies we also find increased curiosity among energy enthusiasts to explore correlation between energy and economic prosperity. Researchers from different nations and cultures with varying backgrounds have presented hypothesis and conducted empirical studies to explore the linkages, if any, between the two phenomena.

Based on the data from USA covering the period 1947 to 1974, Kraft and Kraft presented the possibility of a causal relation between energy consumption and economic growth, in one of the first such works [26]. Their research showed that if the GDP improved, the energy consumption would be increased. That concept drew the attention of researchers, particularly the economists, towards exploring this relationship further. One after the other several papers were published based on the data from the USA, with some finding increased energy consumption caused by improved GDP state while others presenting empirical evidence of a non-existing relationship between the two. The works that did not find enough evidence to claim a 'causal' relationship between energy consumption and economic growth were based on the data pertaining to almost the same period [27-30]. While one study that used somewhat longer duration data exhibited corroboration with Kraft and Kraft's findings [31]. A deeper look through this literature revealed some interesting outcomes. We see Stern [32] finding evidence of causal relation between energy and development based on the US data pertaining to the period 1947 to 1990 applying Multivariate VAR model, suggesting improvement in GDP with increase in the energy consumption. This outcome though validated the existence of causal relation between energy consumption and GDP, it pointed the opposite direction for causality. Interestingly Stern had arrived at same conclusions seven years earlier using a multivariate model [33]. With the data pertaining to the same time-period from USA, Yu and Jin [29] and Cheng [30] using Cointegration and Granger causality approaches arrived at a different conclusion, namely non-existing causality between the two.

Following in these footsteps, scholars from other countries also started investigations based on their respective country's/ region's statistics whether increased use of energy resulted in the economic development, or the improved GDP caused increase in energy consumption. Studies were conducted based on multi-country data too, to draw comparisons and develop and see a broader picture of energy consumption and economic growth nexus.

The research conducted during 1990s, in the wake of the US based studies, utilizing data from Taiwan [34, 35], Japan [36] and India [37] – all yielded causal linkage between GDP and energy consumption. While Hwang and Gum (1991) [34] found a bidirectional causality between energy consumption and the GDP, the remaining three studies concluded that improvement in GDP led to increased use of energy. In the research work between 1992 and 2008, we also found 'conditional' outcomes of investigations into energy-growth relationship. For example, in 1992, De Janosi and Grayson concluded that increased energy consumption would lead to higher economic growth in the developing countries than the developed countries, though real benefit from higher energy consumption was also dependent on the existing industrial base and the sectoral energy share in the energy consumption [36]. In 1997, a study based on three Latin American countries found lack of consistency in causality between energy consumption and the economic growth which indicated insignificant causal relationship [35].

Table 2.1: Conflicting outcomes of causality studies – examples

Country	Research Year	Data Period	Econometric Technique	Outcome
USA	1978	1947-1974	Granger Causality	GDP $\rightarrow$ EC
	1980	1950-1970	Sim's Technique	GDP $\neq$ EC
	1984	1947-1979	Sim's Technique	GDP $\neq$ EC
	1989	1947-1987	Granger Causality & Co-integration	GDP $\rightarrow$ EC

Taiwan	1991	1961-1990	Co-integration & Error correction	GDP $\leftrightarrow$ EC
	1997	1954-1993	Granger Causality	GDP $\rightarrow$ EC
Turkey	2001	1960-1995	Granger Causality & Co-integration	EC $\rightarrow$ GDP
	2004	1950-2000	Granger Causality-Hslao's version	GDP $\neq$ EC
	2007	1960-2003	Granger Causality	GDP $\neq$ EC
	2007	1970-2003	Co-integration	GDP $\rightarrow$ EC

In their work published during 1997, Yong U. Glasure and Aie-Rie Lee [39] explored energy-growth relationship in South Korea and Singapore for the period 1961-1990. In their paper standard Granger causality tests showed no causal relationship between energy consumption and GDP for South Korea and unidirectional causality from energy consumption to GDP for Singapore. But the results of cointegration and error-correction models indicated bidirectional causality for South Korea as well as Singapore [39].

Whereas in 2010, while studying causal relationship between energy and real GDP for six countries, Wolde-Rufael arrived at varying conclusions. Two countries data exhibited unidirectional causality from energy consumption to economic growth, two showed causality from economic growth to energy consumption and bidirectional causality was found in two countries [40]. During the same year research on Hungary also showed bidirectional causality between energy and economic growth [41].

A study on 85 countries in 2013 led Nicholas Apergis and Chor Foon Tang to conclude that 46 of them confirmed the 'energy-led growth hypothesis' while 9 of them totally rejected the existence of any causality between energy and growth [42]. During the same year Robert U. Ayres et.al established that energy was a critical factor of production in addition to labour and capital [43]. Similarly, another research by Andrea Baranzini, et.al found evidence of unidirectional causality from GDP towards the consumption of different types of energy [44].

Some Variations

In 2004 Shyamal Paul and Rabindra N. Bhattacharya presented their work on the conflicting outcome of different studies on energy-growth nexus. They hypothesized that there is a strong impact of energy consumption on the economic growth in the short run, whereas economic growth drives the energy consumption in the long run in India.

However, they could not present convincing evidence in support of the conclusions they had drawn [45].

Utilizing data pertaining to the period 1971 to 2002 from six developing countries, Sari and Soytas took a different approach in 2007 to conclude that energy was an essential, and possibly a more significant factor of production and thus could be used to predict the income [46]. Examining 108 countries data pertaining to the period 1971 to 2000, Chontanawat et al. arrived at another varying outcome in 2008 [47]. They found enhanced two-way causality between aggregate energy consumption and GDP in 78 OECD countries as compared to 30 non-OECD countries under consideration [47]. Incorporating two additional variables of labour and capital while using 1971-2004 data from 17 African countries, Wolde-Rufael deduced in 2009 that energy too contributed to the output growth though its impact was considerably less than the other two factors – labor and capital – under consideration [48].

During 2011, David I Stern presented his investigation results by identifying the factors that affected the relationship between energy and economic growth. He found out energy's significant role in economic growth in the economies facing energy shortage whereas energy was not so significant towards changing the rate of economic development in the societies having access to abundant energy sources. This outcome laid down boundaries between the developing countries and the developed world vis-à-vis the impact of energy on economic development [49].

In 2014, Usama Al-mulali disaggregated the countries under evaluation into six groups comprising, 1) South Asia and Sub-Saharan Africa, 2) North Africa and Middle East, 3) Europe and Central Asia, 4) East Asia and Pacific, 5) Latin America and Caribbean and 6) Central Asia and Europe. He concluded a positive relationship of the energy consumption with the economic sectors in the long run, using data spanning 1999 to 2009 pertaining to these developing countries [50]. In 2015 with data spanning 1980 to 2010 pertaining to 16 countries Usama Al-mulali and Abdul Hakim Mohammed used a different approach to their exploration into the energy-GDP relationship. They disaggregated the energy types as well as the consumer sectors into groups to arrive at the overall conclusion that oil, coal and natural gas consumption had a bidirectional causal relation in three sectors namely manufacturing, industry and services sectors while only oil consumption had a unidirectional causality in the agriculture sector [51].

One investigation during 2016 into energy-development nexus used dataset pertaining to 99 countries covering 40 years from 1971 to 2010 showing a steady linkage between per capita GDP and per capita energy use. Exploring two dimensions of energy-growth relationship, i.e., how this relationship varied across countries at any point in time and how the correlation evolved over time within the same country or the same group of countries, Zsuzsanna Csereklyei et.al. used simple regression techniques to arrive at this conclusion [52]. With focus on the developing Asian economies (including Pakistan), in 2019 Muhammad Azam found out that energy consumption had a direct impact on the economic growth in these countries [53]. The study based on the data from five SAARC countries including Pakistan in 2020 led to conclusions supporting the principle of inverted U hypothesis while providing a foundation for likely increasing role of RETs towards improving the HDI in these countries [54].

While the research on the correlation between energy consumption and economic growth in individual/ multi-country scenario continued, some researchers conducted survey of the related literature in search of robustness and corroboration in the results of different studies. Among these efforts we find significant contributions by two researchers in 2010, one by Ozturk [9] and the other by Payne [10]. In their work both Ozturk and Payne surveyed the studies on the nexus between total energy and economic development to explore the outcome of these studies in this relationship. The two surveys on the total energy and growth nexus yielded one common outcome of mixed results on the existence of causality as well as its direction for any individual country and/ or across countries.

Investigations during different periods by different authors remained focused on different aspects of the relationship between energy and economic development using different techniques. However over four decades of research neither yielded a consensus among the scholars on the existence of a causal relationship between the two nor in support of the direction of causality – unidirectional or bidirectional. Even within the same technique and while using the same data, different researchers arrived at varied outcome of their research into the causal relationship between energy consumption and development leading to continued inconsistency. The empirical studies on energy consumption and the economic development exhibited different results on the existence as well as direction of causality. The literature is devoid of any conclusive outcomes pertaining to even one country that could strengthen the confidence on the existence or the direction of causality between energy consumption and the economic growth. The surveys conducted into the literature on energy – growth nexus by Ozturk and Payne also confirmed the conclusions of a lack of consensus on the causality or correlation between energy consumption and growth [9,10]. Whereas literature also presents prosperity and economic activity closely linked with access to clean, affordable, and reliable energy, especially since the start of industrial revolution [55].

In his attempt to explore other factors impacting outcome of investigations into the energy's role in the economic growth rate David I Stern identified four important factors altering the significance of energy in the economic production [56]: 1) substitution between energy and other inputs within an existing technology; 2) technological change; 3) shifts in the composition of the energy input; and 4) shifts in the composition of economic output. His approach to the issue yielded two pertinent outcomes. One he concluded that energy scarcity directly and adversely impacts the growth rate whereas energy abundance diminishes that effect considerably. His second significant finding was that one unit of energy from poor quality fuels yielded much lower economic output than one unit energy from the clean, high-quality fuel, like electricity [56].

Availability and reliability of the data too has been a likely contributor towards the varying – and in several cases conflicting – outcomes of investigations into the energy-economic growth relationship. Whereas the data pertaining to developed countries has been highly reliable, for developing countries the researchers have mostly struggled to even find the relevant data, notwithstanding its reliability or quality, for research and/ or comparative analysis [9].

There may be reasons peculiar to sociocultural dynamics of each nation that lead to varied results. However, a few possible contributing factors are also the research methodologies adopted and the quality and type of data used. Poor documentation of the economic activity owing to numerous tangible and intangible reasons was identified as one of the key reasons leading to variability and lack of reliability in the results of investigations into energy – development nexus [57]. Other country specific parameters that were found to be directly or indirectly affecting the outcome of related research have been socioeconomic affairs, sociocultural landscapes, state of economy, traditional economic structures, the type of energy mix available and being utilized, regulatory and policy mechanisms, political infrastructure, and its stability and more importantly documentation of economy and energy related activities [58]. Though academic research on energy-growth nexus has yet to find a consensus outcome, World Bank report titled 'Beyond Connections—Energy Access Redefined' presented in June 2015 identified 'Access to energy as a key enabler of socioeconomic development' [59].

2.4 Electrical Energy and Growth Rate

Regardless of the technique used or the approach adopted, the literature on energy-growth nexus till date is lacking consensus on the existence or the direction of causality between the two phenomena. While the research into energy-growth nexus continued, some researchers embarked upon exploring linkage(s) between the electrical energy and economic growth, as discussed in the ensuing paragraphs. Early works on the energy-growth relationship by segregating electrical energy as separate factor started in the late 1980s. Almost all the literature on the electricity–growth relationship exhibits existence of causality between these two parameters.

In 1988 B. W. Ang [60] published his research pertaining to eight developing countries in Asia concluding strong correlation between electricity consumption and the economic growth in all countries less Indonesia wherein the correlation was not found to be so strong. Dividing the total period of 1960 to 1984 into sub-periods of 5 to 7 years each, he found gradual reduction in the impact of electricity consumption on the economic growth rate [60]. He attributed this observation to Brookes' hypothesis [61] of 'development effect' which implies that energy consumption's impact starts diminishing as a country attains higher stages of economic development. During 1972, Brookes had used 22 countries' data –including Pakistan's –covering 16 years period from 1950 to 1965 to arrive at this conclusion [61]. Finding a statistically 'significant' relationship between energy consumption and GDP, a similar conclusion was drawn in 1984 by The-Hiep Nguyen while exploring energy-growth nexus in 23 OECD countries utilizing the data from 1959 to 1978 [62]. Another study that led to varying impact of energy consumption on growth between the developing countries and the developed economies was conducted by Ferguson et al. during the year 2000 [63].

We see Ramcharran finding electricity consumption's impact on the economic activity in Jamaica in his work published during 1990. He used data covering 1970 – 1986 for this analysis [64]. In 1993, Jin-ping Huang hypothesized [65] that per capita electricity consumption in China caused an increase in per capita GDP, based on the empirical evaluation of the data from 1950 to 1980. He also concluded that electricity and GDP had a dynamic relationship which depended on several factors such as price of electricity, the technology in use, the development sector under consideration and the demographic/ sociological parameters [65]. In 1997 based on the G7 countries' data Ferguson et al found a stronger relationship between electricity consumption and income generation, the nexus missing in case of total energy consumed [66]. There are fewer electrical energy focused studies prior to the year 2000 after which we find somewhat increased interest in this subject area.

While analyzing data pertaining to over 100 countries in their study published during 2000, Ferguson et al. found more robust correlation between the electricity consumption and wealth creation in the developed countries as compared to the underdeveloped economies [63]. Additionally, Ferguson et al also established [66] that electricity consumption had much stronger correlation with the income generation than the total energy consumed. As mentioned earlier, his study on G7 countries in the same context during 1997 had revealed a similar outcome – a strong correlation between electricity consumption and wealth creation but no correlation between total energy and economic growth [66].

Analyzing time series data for India from 1950-51 to 1996-97, Sajal Ghosh, in 2002, found a unidirectional causality from per capita GDP growth to per capita electricity consumption [67]. Whereas in 2004 Alice Shiu and Pun-Lee Lam arrived at opposite conclusion i.e., causality running from electric power consumption to real GDP in China from 1971 to 2000 [68]. During the same year Risako Morimoto and Chris Hope concluded that increase in electricity consumption directly impacted wealth creation in Sri Lanka based on the 1987-1997 data analysis [69]. Study of Turkey's 1950-2000 data in 2005 exhibited unidirectional causality from electricity consumption to income, based on two different techniques, both leading to the same result [70]. Interestingly a year earlier the same authors, Galip Altinay and Erdal Karagol, had found no causality between aggregated primary energy and GDP [71]. Paresh Kumar Narayan and Russell Smyth found employment and income impacting the consumption of electricity in Australia in 2005 based on 1969/70-1996/7 data [72].

S.-H. Yoo's study of electricity-growth nexus in four ASEAN countries for the period 1971-2002 concluded bidirectional causality between electricity consumption and economic growth in Singapore and Malaysia, and unidirectional causality from economic growth to electricity consumption in Indonesia and Thailand [73]. A study on 10 developing Asian countries – that included Pakistan – by S-T Chen et.al., exhibited unidirectional causality from economic growth to electricity consumption in the short-run and a bi-directional causality between electricity consumption and economic growth in the long-run [58]. *Do these results imply that fiscal policies have to first successfully enable the higher electricity consumption, after which increased use of electricity will lead to added wealth creation and more wealth will enable more electricity consumption*? During the same time another study also concluded bidirectional causality between per capita electricity consumption and per capita real GDP in the developed countries but only unidirectional causality from per capita GDP to per capita electricity consumption in the developing economies [74]. The study, covering Bangladesh from 1971-1999, conducted by Pallab Mozumder and Achla Marathe during 2007, concluded a unidirectional causality – per capita GDP to per capita electricity consumption [75].

A 2009 investigation by Ciarreta, A. and Zarraga, A. showed no causality between electricity and economic development in the short run, but they found electricity consumption affecting the economic activity in the long run in 12 European countries based on the data from 1970 to 2004 [76]. Around the same period Lebanon based research using data from Jan 1995-Dec 2005 ended up showing electricity consumption affecting economic growth only in the short-run [77]. Exploration of Nigeria's 1980-2006 data by A.E. Akinlo exhibited unidirectional conditional causality running from electricity consumption to real GDP [78]. Evaluation of Barbados 1960-2004 statistics during 2010 resulted showing unidirectional causality from electricity consumption to real GDP in the short-run and bidirectional causality between the two in the long-run [79]. One study by Hooi and Smyth during the same year working on the data from five ASEAN countries concluded that there existed unidirectional causality from electricity consumption to economic growth [80]. In their second work during the same year Hooi and Smyth brought out bidirectional causality between electricity consumption and aggregate output using a multivariate model for Malaysia [81].

In Search of Improved Reliability of Results:

Nicholas Apergis and James E. Payne took different approaches in 2011 to investigate correlation between electricity consumption and economic growth. Using 1990-2006 data from World Bank Development Indicators for 88 countries they explored the electricity-growth nexus by dividing the countries into four income based groups to find bidirectional causality between the two factors in upper and upper middle income group, a short run unidirectional causality from electricity consumption to economic development but bidirectional long term causality between the two in lower-middle income group and, only unidirectional electricity consumption to GDP growth causality in the lower income group countries [82]. With a varying approach in the study published by Ilhan Ozturk and Ali Acaravci during the same year, they dropped 4 of the 11 MENA countries they had considered for their investigation. Of the remaining seven, they concluded no causality between electricity consumption and real GDP in two, GDP to electricity consumption in two in the short-run and in two in the long run and electricity to real GDP in one [83]. A study in 2012 by Henryk Gurgul and Łukasz Lach exhibited [84] bidirectional causality between electricity consumption and real GDP as well as between electricity consumption and employment in Poland based on the 2000-2009 data. They arrived at the same result based on two different econometric techniques in pursuit of improved reliability of their results [84].

During the last decade there has been an increased realization to include 'missing' variables in the researchers' quest to improve consistency in their results and find energy's 'right' relationship with income, wealth creation or growth. A paper published in 2013 on Malaysia's 1970-2009 data included technology innovation as a 'new' variable with electricity consumption, economic growth and energy prices in the research conducted by Chor Foon Tang and Eu Chye Tan [85]. They found: 1) bidirectional causality between electricity consumption and economic growth, 2) income having a positive effect on the electricity consumption and, 3) technology innovation causing economic growth as well as electricity consumption but energy prices and technology innovation negatively affecting the energy consumption [85]. These findings had new dimensions to ponder upon for the economists as well as energy enthusiasts with implications for creating synergy in the SE4All and poverty alleviation plans.

Same year another study by Usama Al-mulali et.al. based on 1980–2010 data of eighteen Latin American countries, found renewable and non-renewable electricity positively impacting the GDP growth with feedback effect. Using electricity consumption, labour, total trade and gross fixed capital formation they identified the existence of cointegration between all these variables [86]. This outcome highlighted the importance of and need for renewable electricity, especially in the light of its significant advantages over non-renewable electricity, like global warming mitigation and improved energy security.

Highlighting the issue of biased outcome in omitted variable studies, Eyup Dogan found long run unidirectional causality from renewable electricity to economic growth but a bidirectional causality between non-renewable electricity and economic growth during 2015 in a multivariate analysis [87]. Investigating living standards/ wealth creation merely based on the energy consumption may not be appropriate, as Richard F. Hirsh and Jonathan G. Koomey very analytically proved during 2015 that despite decline in the electricity intensity since 1990 – they worked the data spanning 1949-2014 – the US economy had grown considerably [88]. Using per capita electricity consumption and per capita GDP data from 160 countries, Karanfil and Li concluded [88] that 'the electricity-growth nexus is highly sensitive to regional differences, countries' income levels, urbanization rates and supply risks'. However overall, they too arrived at existence of bidirectional causality between the per capita electricity consumption and per capita GDP in respective countries. They also hypothesized that electricity-GDP causality is weak in the developed economies and is stronger in the developing countries [89].

During 2017 Muhammad Maladoh and Muhammad Azam claimed no causality between electricity consumption and economic growth in South Africa based on their analysis of 1971-2012 data [90]. In 2017 Suleman Sarwar et.al. investigated 210 countries data to find bidirectional causality between electricity consumption and GDP using 1960-2014 data [91]. Cheng-Feng Wu et.al., explored energy-growth correlation in three major world economies namely the US, China, and India during 2019 using 1971-2014 data from the World Development Indicators' database. They concluded unidirectional causality between electricity and economic growth in India and a bidirectional causality between the two in the US. While in China their findings pointed to a negative correlation between electricity consumption and the growth rate [92].

Of particular interest are the results of S.-H. Yoo's (2006) study of electricity-growth nexus in four ASEAN countries, namely Indonesia, Malaysia, Singapore, and Thailand [73]. Using time-series technique for the period 1971-2002 he found bidirectional causality between electricity consumption and economic growth in Singapore and Malaysia, but only unidirectional causality from economic growth to electricity consumption in Indonesia and Thailand. This outcome has many implications in relation to these two parameters' causal relationship e.g., 1) it varies from country to country, 2) it likely is linked to the state of economy, 3) it depends on other factors that merit exploration, and 4) the results of bivariate evaluation of electricity consumption and real income may not be taken as conclusive outcome.

David I Stern et.al. presented a few case studies to highlight the impact of electrification on the economic development. Diving into the experience of the countries that had successfully benefitted from their investment in electrification, he noted strong impact of electrification on the economic development in all cases and attributed it to pursuit of one objective – universal access to electricity – through the involvement of local governments and the communities [56]. Two of the nations he studied are China and South Korea that achieved more than 95% electricity access with more than 1 MWh per capita usage by 2014. As per van Gevelt, rural household incomes in Korea increased by 27% per annum in the 1970s – a period during which electricity access in rural areas increased from 12% to 98% [93]. Similarly, Yang (2003) found provinces spending higher on rural electrification seeing much faster increase in the citizens' income [94].

In one of the earliest studies on Pakistan Professor Donald A. Murry and Gehuang D. Nan concluded unidirectional causality providing evidence of impact of electricity consumption on the economic growth in Pakistan while analyzing data pertaining to a mix of 15 developing and industrialized nations [95]. Among researchers from Pakistan, Faisal Abbas – with Nirmalya Choudhury – explored relationship between electricity consumption and economic growth based on India and Pakistan's data from the period 1972-2008. They concluded a bidirectional causality between the two at aggregated level [96]. In one of the rarest approaches, Bebonchu Atems and Chelsea Hotaling studies the impact of electricity generation, rather than consumption on the economic growth in 2018 using 174 countries' data including Pakistan [97]. The drew important conclusions; 1) there is linkage between electric losses and the economic development and, 2) renewable and non-renewable electricity generation were both strongly related to economic growth. Again in 2018, we find an investigation on the linkage between energy consumption, electricity access, population growth and economic growth in a multivariate analysis using 1990-2016 period data from Pakistan which concluded that while electricity access in the urban areas had a 'significant' impact on the economic growth, electricity access to rural population would negatively impact the economic growth [98]. Working on Pakistan's data covering 1990-2016 in 2020, Anam Azam explored gross domestic product, electricity supply, investment, gross capital formation and exports through a multivariate study to declare unidirectional causality from GDP to electricity consumption [99]. This result was in divergence with several earlier studies on Pakistan's electricity consumption-development linkages.

Results of these studies have been varying and inconsistent. We did not find conclusive evidence in the literature exploring time series data on electricity use and economic growth or in the meta-analyses of the relevant research. The essential outcome in the case of studies on electricity-economic growth relationship is that the relationship is not homogenous across all countries. Exploring country specific as well as multi-country data, researchers found variation in existence as well as direction of causality on different countries. However almost all outcomes exhibited presence of causality between electrical energy and the growth rate – unlike absence of any relationship that was more frequently found while exploring linkages between total energy and economic growth. Hence, though the researchers failed to develop a consensus on the direction of causality between electricity consumption and economic growth, we find unanimity in the existence of a correlation between the two in almost all investigations. Further, in most cases we find electricity consumption causing economic growth or a bidirectional causality between the two phenomena. Additionally, the study of literature on investigations into electricity-growth nexus leads to infer that developing countries see more demand for electricity with improvement in GDP while developed economies are able to create more wealth with increase in electricity consumption.

The factors affecting diverse results of the electricity-growth causality studies identified during the literature review can be categorized into two types: country-specific that include sectoral energy share, economic history and policies, country-specific energy mix, political system, socio-cultural dynamics, regulatory mechanisms, and institutional structures, and the econometrics-related, like the differences in the dataset used and the investigation technique(s) applied.

2.5 Renewable Energy and Economic Impacts

While last decade saw a conscious approach for multivariate analysis to explore near-real relationship between electricity consumption and economic growth, there has been increased interest in the diffusion of modern renewable energy technologies with the traditional energy sources too. Many researchers explored the RETs' impact on the economic growth and the income generation. The renewable energy related studies published during initial exploration phase pertain to the period and the countries where the only renewable energy was hydropower, and the countries under consideration had not even realized the importance of modern renewable energy technologies or the need for policy formulation on RETs' adoption. Such work in the literature is inconsequential under the present-day situation and has therefore been ignored. However, studies involving the latest clean energy sources and those that were initiated post SE4All initiatives are relevant to this research and are being referenced.

In their study published during 2010, Manuel Frondel et.al. dived into the economic impacts of RETs promotion in Germany [100] – the lead country in RETs adoption (REN 21). Based on their research, they hypothesized that German government's supportive RE policies at the time had failed to yield the intended – as against common perception – benefits like reduced carbon emissions, increased employment, or improved energy security. Regarding German's experience in RET's promotion as a 'massively expensive energy policy devoid of economic and environmental benefits', they recommended review and revision of RET related policies [100].

During 2011, Nicholas Apergis and James E. Payne carried out multivariate analysis of 16 emerging market economies' 1990–2007 data to discover equilibrium relationship between renewable electricity and non-renewable electricity consumption and real GDP, real gross fixed capital formation, and the labour in the long run. Their research further revealed short-run causality from economic growth to renewable electricity and bidirectional causality between the two in the long run [101]. This study is one of the initial investigations into the correlation between renewable 'energy' and wealth creation. The same pair worked on 80 countries data of the same period using the same econometric approach during 2012. Interestingly they found long run causality between all variables under consideration i.e., renewable energy and non-renewable energy consumption, real GDP, the labour force and real gross fixed capital formation. Additionally, they found substitutability between renewable and non-renewable energy in all cases which was a valuable outcome towards policy formulation ahead [102].

Covering the period 1990-2008 from 20 OECD countries, Adrienne Ohler and Ian Fetters chose a different path for exploring correlation of economic growth with 'electricity generation' from renewable sources (biomass, geothermal, hydroelectric, solar, waste, and wind) – rather than 'total electricity consumption' that had been the key variable in most work so far. This study evaluated source-based correlation yielding valuable results with overarching significance towards policy formulation. The paper, published during 2014 highlighted bidirectional relationship between aggregate renewable energy and real GDP and hypothesized that increase in wind energy and hydroelectricity will positively impact real GDP besides other outcomes [103]. One interesting aspect of the study is that out of twenty countries being investigated only six had a portion from solar in their total renewable energy portfolio for which the authors concluded: 'When utilized, wind and solar energy exhibit the largest growth rates'.

A worth mentioning work during 2015 came from Tsangyao Chang et.al., who investigated the G7 countries' 1990-2011 renewable energy data to find its correlation with the economic growth [104]. Their research brought out overall bidirectional causality between the two parameters. However, in relation to each country, the data presented insignificant linkage for Canada, Italy and the US; GDP to renewable energy causality for France and the UK and renewable energy causing economic growth in Germany and Japan. This being shaping period in RETs' adoption; the result may not provide a benchmark on the direction of the causal relationship between renewable energy and economic development [104].

Highlighting the issue of biased outcome in omitted variable studies, Eyup Dogan found long run unidirectional causality from renewable electricity to economic growth but a bidirectional causality between non-renewable electricity and economic growth in a multivariate analysis while evaluating Turkey's 1990-2012 data [88]. A study published by Bhattacharya et.al. [105], while working on 38 selected countries' 1991 to 2012 data, suggested renewable energy's positive impact on economic output in 22 countries notwithstanding the fact that 31 out of 38 countries had less than 30% share of renewable energy in their total final energy consumption and only 3 countries had 50% or more of renewable energy. The heaviest component of the renewable energy in these studies has been biomass and hydro with just a fractional contribution of modern clean energy technologies [105].

During 2017 Montassar Kahia et al. published their research after disaggregating the energy data into two parts: renewable energy and non-renewable energy. They used 1980 to 2012 data pertaining to 12 oil importing countries from MENA region. Their analysis offered evidence in support of a bidirectional causality between both the energy types and the economic growth. Based on the empirical results they concluded that interdependence between energy and growth was visible in the short term as well as the long-term. While providing rationale in support of substitutability between renewable and non-renewable energy, they recommended that oil importing countries needed to continually increase the share of renewable energy sources in their energy mix so as to bring down the energy import bill [106].

In his study using 1980-2015 data of 26 OECD countries Mucahit Aydin [107] concluded that while non-renewable energy had bidirectional causality with economic growth, renewable energy did not exhibit a correlation with the economic growth. On the other hand, he did find robust correlation between electricity consumption and economic growth based on which he hypothesized that countries must pay attention to electricity generation through adoption of modern RETs to meet their energy demands while achieving their nationally determined contributions (NDCs) to climate change mitigation [107].

Adopting a different approach on the SAARC countries' 1990-2017 energy mix data, Tehmina Zahid et al. discovered a U-shaped relationship of renewable and non-renewable energy mix with the HDI meaning thereby that, at low levels of energy mix renewable energy is positively correlated with HDI but at high levels the relationship gets negative. In their study published during 2020 the authors used HDI as a dependent variable instead of economic growth or GDP [54]. They hypothesized that addition of renewable energy technologies negatively impacts the development process initially, owing to high acquisition cost, high risk involved and long payback period. However, in the long run these disadvantages are offset, and renewable energy compensates for its negative impact by positively affecting the HDI.

In their study published during 2020, exploring the effect of renewable energy on economic growth, Shahbaz et.al. [108] examined 1990-2018 data pertaining to 38 supposedly renewable energy consuming countries. They hypothesized positive effect of renewable energy on the economic growth 'for 58% of the sample countries' [108]. However, a closer look through their research article presents a different picture. Four types of renewable energy sources were considered in the research. Where among 38 countries under study, 30 countries have less than 0.5% solar energy share, 31 have less than 5% hydro, 29 have less than 1% wind and 35 have less than 10% biofuel in their total energy mix. Linking respective national economic growth to such fractional input from renewable energy sources may not be realistic or reasonable.

The research exploring linkages between renewable energy and economic development establishes the existence of a strong correlation between the two. The outcome of the research may not be highly reliable due to the fractional contribution of renewable energy sources in the overall energy mix for most countries so far. However, these results, when coupled with the outcome of investigations into electricity–growth nexus, indicate the possibility of a robust correlation between renewables-based electricity and the growth rate.

2.6 Energy and Sustainable Development Goals (SDGs)

The agenda for the year 2030 demands attainment of 17 sustainable development goals (SDGs) for the future of humanity, the planet, and the atmosphere [17]. Of these, SDG-7 demands universal access to reliable, affordable, clean, and sustainable energy. As seen through the related research, achievement of SDG-7 affects the overall human welfare with attainment of sixteen other SDGs [109]. As per Agenda 2030 the accomplishment of SDG-7 is to be ensured through five targets, that are: 'ensuring universal access to affordable, reliable, and modern energy services; increasing the share of renewable energy in the global energy mix; doubling rate of improvement in energy efficiency; enhancing international cooperation for access to clean energy research and technology and promoting investment in energy infrastructure and clean energy technologies [17]. Likewise, each SDG is linked with several targets. A closer look at the SDGs' targets reveals multi-dimensional linkages and multifarious interactions between various targets. Viewed through the lenses of sustainability, SDGs primarily aim to achieve 'greater welfare and well-being' by building 'physical and social infrastructures of development' through 'sustainable management of natural resources'. Clear understanding about the subtle linkages between SDGs and their targets can help in formulating policies leading to synergies between various goals [109]. The succeeding discussion highlights how energy systems (SDG-7) are essential for social welfare and economic growth and how the production and delivery of energy services impact the achievement of other SDGs.

There are lot of inter dependencies between various SDGs and the bidirectional causalities between most SDGs too have been identified in the relevant research since the

UN adoption of Agenda 2030. Researchers have identified more than 100 targets pertaining to other sixteen SDGs that depend on and/ or support the achievement of SDG-7 [109-112]. For example, research on the impacts of education amply shows its effects on earning potential and thus the income, health, well-being, gender equality and quality of life. Similarly, several synergies have been highlighted in the literature relating the targets of different SDGs that can be simultaneously pursued through informed decisions on designing the energy transitions [109]. Relevant research in this field has established this fact that access to sustainable, reliable, and affordable modern energy can ensure greater human welfare. In another study energy has been identified as one of the primary sources to end poverty (SDG-1) [113]. Similarly access to modern energy services can greatly aid elimination of hunger (SDG-2) [114-115], provision of dependable healthcare facilities (SDG-3) [116], quality education (SDG-4) [117-118], and clean water [114,118] and, laying down a durable sanitation infrastructure (SDG-6) [110-112]. Research into the effects of high-quality household energy has provided strong evidence on its impact towards attainment of Gender equality (SDG-5) [119].

Notwithstanding the impact of education, improved health and better living standard on the earning abilities, contribution of clean, high density and reliable energy towards increased income (SDG-8) has also been amply brough out by the researchers [120-121] since the declaration of Agenda 2030. Improved quality of life in urban and rural households (SDG-11) has been justifiably linked with provision of clean/ high density energy services [122-123]. Globally energy systems have been found to be the anthropogenic source of more than 60 percent of greenhouse gas emissions [124] and therefore they are to be the primary focus for environment protection (SDG-13). Most critically the life on earth is now dependent upon the ‘Climate Action’ which is directly linked with the primary energy source(s), the way energy is produced, methods of its conversion and the manner it is used [124-127]. Additionally, the adverse impacts of air pollution, water contamination and environmental degradation on the eco-system and the life on the earth as well as life under water exhibit SDG-14 and SDG-15 indirectly affected by the source (s) and type of energy systems [125,128-129]. Electricity, one of the cleanest forms of high-density energy is vital for provision of access to information technology without which it may not be possible to reduce the global inequalities (SDG-10) [123]. Effective means of communication, alongside information technology, are also necessary if the world has to move towards a result-oriented partnership for achieving the

‘Agenda-2030’ goals (SDG-17). And last but not the least, the importance of energy for the industrial activity and infrastructure development cannot be over emphasized as seen in the light of its impacts on the production and productivity since the industrial revolution (SDG-9). Energy’s critical role in the economic growth as a factor of production has been adequately discussed in the preceding lines (SDG-8 & 9). Notwithstanding its direct and indirect implications for other SDGs, access to high quality energy can support greater welfare and improve the standard of living through provision of basic amenities like health, education, and water and by raising household incomes. Energy has a vital role in powering food production – from agriculture to food processing (SDG-2), in efficacious and efficient medical services (SDG-3), in water treatment and supply, and in running the sanitation infrastructure (SDG-6). Energy is a direct input to the industrial activity and is essentially needed for sustainability of production as well as consumption [130].

While the researchers have highlighted several synergies among targets of different SDGs, they have identified certain trade-offs too, depending on the individual country’s sociocultural dynamics and economic conditions. These studies may not provide definitive evidence of supportive impact between the SDGs or their targets. However, they do lay down a foundation of existence of interlinkages between SDG-7 and the other SDGs. It may be relevant to recall here that ‘energy systems’ is a wholesome phenomenon and includes all activities related to extraction, production, conversion, delivery, and use of energy and disposal of associated materials. The interlinkages between SDG-7 and other SDGs have to be explored within the same context. Therefore, it is important to understand that energy systems must be designed and implemented keeping in view the local socio-cultural dynamics and the socio-economic ground realities to ensure just and equitable energy solutions [131].

2.7 Energy Transitions & Sustainability

Cognizance of the factors critical to human sustainability on earth converged the research on human development to sustainable options. During last 2 decades there has been an increased understanding of the necessity to seek sustainable solutions for the challenges confronting the humanity. That realization led to sustainability taking centre stage in energy options as well, thereby leading to co-consideration of sustainability with economic development strategies, environmental protection, and the society to ensure a livable future on earth.

Socio-technical transitions pass through four non-linear stages before they take root in a society and become sustainable. New ideas almost always face setbacks and demand feedback for review and revision before maturing. Success of niche theories depends on how their handlers take them through these stages – prototype, demonstration, early adoption, and maturity. Prototyping entails conception and visualization of a new concept or scheme after evaluating its pros and cons. This stage may not demand heavy expenditures in terms of cost and effort. The demonstration – Application of the niche concept(s) on a broader scale to extend its benefits to a community or a society demands much greater effort, more patience, and higher costs. A desirable adoption rate brings hope for success despite associated costs even if the risks are still high. It is this early diffusion stage where, subject to the implementation of right policies, the concept starts maturing and finds increased acceptance by the target population.

Societies can be guided to embrace the newer ways of life, newer concepts and newer technologies with correct policies coupled with purpose-oriented strategies. At this, the 'maturity stage', transitions proliferate by way of learning-by-doing [132]. 'Diffusion of Innovation model' introduced by Everett Rogers et.al. lays down certain conditions for the new concept, product, or technology to gain ground in the societies that are 1) relative advantages against the in-use parameter, 2) its simplicity or complexity, 3) its observability, 4) its trialability and 5) its compatibility with existing needs and past experiences [133].

With suitable regulations in place, most of these conditions can be met by building people's confidence in the government's seriousness and sincerity, through sharing of information. The changed citizens' perceptions can accelerate the adoption of rooftop solar systems by the household and lead faster achievement of net metering regulations' objectives. Rogers, whose first research on the diffusion of innovation was published in 1962 and the last one in 2003, highlighted few critical dimensions of acceptance or rejection of new 'idea, practice or object'. He alongside other experts on the subject hypothesized that individuals and societies 'experience a high degree of uncertainty' while deciding to adopt any innovative idea. As per their research, awareness and knowledge are essential for changing attitudes and aiding decisions for implementation and diffusion of innovations. A clear understanding of the diffusion of innovations theory can guide policies that invoke individuals', communities', and organizations' participation to make the technological innovations sustainable [133].

Sustainability requirements necessitate that energy solutions must cover three essential dimensions of life – economic, environmental, and social. Studies on sustainable energy scenarios have concluded greater share of renewables like wind, solar, hydro, geothermal and biomass in the energy mix. The literature also highlights the importance of a life-cycle approach for comprehensively covering different aspects of sustainability in energy-mix options [134-137]. In case of energy mix, the life cycle entails activities such as extraction, production, conversion, delivery, and use of energy and disposal of waste materials.

Sustainable solutions, particularly for energy futures, demand availability of relevant, reliable, and updated data for policy formulation, its continual review and regular revision. Realistic results from the statistical analysis demand customized and multifarious data gathering techniques like participants' observation, in-depth interviews, and ethnography studies in addition to the common means like surveys, public offices records and relevant state departments' databases as seen through the literature [133,136]. Unfortunately, it is not possible to find the relevant data for energy policy analysis with any of the stake-holder government offices in Pakistan. Partial data, if at all available somewhere, lacks reliability. And still worse, the departments responsible for data gathering are not willing to share data with researchers and academia owing to factors like possessiveness and feelings of insecurity from the disclosure of truth to the public and the world. As an example, World Bank's Policy Research Working Paper on Pakistan states: 'while official estimates in 2016 suggested approximately 5 million people off-grid based on household survey, the data from the 2017 census and utility connections exhibited about 10 times higher number – almost 50 million people without electricity access' [138].

2.8 Solar Energy Adoption

We find several recent studies demanding greater attention to the socio-cultural and political dimensions of energy transitions. The literature points out that enactment of rules and policies alone may not yield the desired results and active participation of target population is critical to the success of any government initiative [139-143]. Researchers have concluded greater role for the governments, especially, in diffusion of renewable energy technologies encompassing monetary incentives, educating people, financing arrangements, and defining public perceptions besides regulatory and monitoring responsibilities [144-148]. The government efforts aimed at informing the people about different aspects of smart metering have yielded rich dividends in promoting household solar PV systems among citizens [149]. Studies have established that powerful public support is essential for transitioning from traditional fossil fuel energy systems to renewable energy technologies. In 2014 Sunil Luthra et.al. found critical role of people's awareness, behavior, and their level of information in their willingness for solar energy adoption in India based on Analytical Hierarchy Process (AHP) analysis of experts' opinions [150]. In 2022 Angel Echevarria et.al. argued based on their case study of Puerto Rico that public imaginations play a central role in not only achieving energy equity and energy justice in the society but are also central to value creation from deployment of renewable energy technologies [151].

The energy related behaviors – like several other life-practices – get so ingrained in the socio-cultural landscapes that changing them becomes a real arduous task. Last decade has seen significant expansion in the research into social acceptance of renewable energy technologies and ensuing innovative ideas. The related research has found quantitative methods based on household surveys very useful in result-oriented policy formulation for the energy futures based on renewable energy technologies [152-155]. Citing people and social structures as obstacles to thriving of niche innovations, the authors emphasize policies, means and methods to promote social acceptance of renewable energy technologies. Scientific research on renewable energy technologies has provided a golden chance for the humanity to challenge the fossil-fuel driven capitalist economic infrastructure. However, that may only be possible through innovative approaches on renewable energy adoption based on individual country's respective sociocultural and socio-economic dynamics [154-155].

2.9 Solar Energy in the Households and Poverty Alleviation

Solar energy promotion for the household can lead to energy equity and energy justice, starting a change from the grassroot levels. Countries leading the renewable energy adoption have continuously worked to formulate policies aimed at rooftop (RTS) solar energy adoption based on the prospects of its contribution to socioeconomic development of the low-income population. One such example is the China's 'Solar Energy for Poverty Alleviation Program' (SEPAP) that sought to electrify over two million households in 35,000 villages adding 10-gigawatt (GW) capacity by 2020. China's 'National Development and Reform Commission' hoped to add average of 3,000 Chinese Yuan annually to every household's income through the RTS systems [156]. Contemporary research from several developing countries carries evidence of improved earning abilities and increased household income through the use of solar PV technology in meeting their energy needs [157-160].

Results of a post program investigation into the impacts of China's targeted poverty alleviation through solar PV technology were published in 2020. The research based on data from 211 counties that benefitted from the PV based poverty alleviation program from 2013 to 2016, revealed a 7–8% increase in the disposable per-capita income. Further, the researchers found that while there was a significantly positive effect of the program right from the first year, the impact was much higher in the following 2-3 years. The research also showed that poorer regions benefitted more from the program [161]. So far, no focused research could be found into the socioeconomic impacts of solar PV systems' adoption in Pakistan, though sparsely one can see people making effective use of the technology even in the far-flung areas. Similarly, there has not been much attention to exploring the impact or correlation of household energy with the respective income or the earning abilities.

2.10 Situation in Pakistan

As per World Bank's report on South Asia close to one fourth of Pakistan's population lived without electricity in 2017. This, coupled with some of the worst power outages in the world, leads to adverse energy-deprivation of Pakistani households costing heavily on their quality of life and earning abilities [138]. The World Bank's Policy Research Working Paper concluded that lack of reliable electricity access was costing the country more than $4.5 billion a year. This was first ever investigation into the impacts of Pakistan's household energy on her national GDP. Few earlier studies had only touched the correlation between electricity and income in Pakistan [162-163]. These estimates do not include improvements in earning abilities and income brought about by improved health conditions and the enhanced productivity affected by better education opportunities. Neither they include the avoided costs of adverse health effects of poor-quality, low-density cooking fuels or the restricted earning potential due to lack of knowledge and skills.

Pakistan has been blessed with enormous renewable and clean energy potential in the form of year-round sunshine and several wind corridors, besides hydro, biomass and geothermal sources. As per the world bank, Pakistan's entire energy demand can be met by covering 0.071 percent of the country's entire area with solar PV panels. Despite this massive solar potential coupled with vast wind corridors, Pakistan's installed solar and wind project is merely 4% of the total energy supply as of November 2020 [164]. As per IRENA 2018, Pakistan could add such huge amount to her GDP by developing the right plans to benefit from her large renewable energy sources – solar and wind [165].

2.11 Key Take-aways from Literature Review

Energy did not draw academics' attention as a determinant of economic growth or as a contributor to development till the late 70s i.e., till the oil embargo times. Available research on the correlation between energy and economic growth lacks consensus on existence as well as direction of causality between the two phenomena. Whereas literature on electricity–economic growth linkages – though inconsistent about the direction of causality – offers reasonable evidence on the existence of causality between the two.

Investigations by some leading researchers offer corroboration on energy (electricity) consumption in developing countries accelerating economic growth while in developed countries the economic development appears to be causing higher energy/ electricity consumption – i.e., opposite causality directions in developing and developed countries. While the research on developing economies is limited, this is further hampered by the data quality and reliability.

Under the spiraling cost of fossil fuels and the resulting greenhouse gas effects, researchers started focusing on the renewable energy technologies. Emerging evidence of renewable energy technologies' positive footprint on the socioeconomic well-being of affected populace is growing.

Most literature on the nexus between energy, electricity and/ or renewable energy and economic growth is based on data aggregated at country level drawn from international organizations. Disaggregated community or district level data used in few studies, was sampling based and represented selected communities and limited areas only. Nonavailability of quality and reliable data from many developing countries made it difficult for the researchers to provide dependable results.

Underscoring the importance of energy in development was its inclusion in sustainable development goals. SDG-7, universal access to quality and reliable energy services, directly impacts attainment of most SDGs and have indirect influence on others.

Solar energy at household level, where and when adopted, has positively impacted the communities' income. On the other hand, people's behaviours and attitudes have direct implications on their acceptance of lifestyle changes and adoption of innovations. This behavioral pattern is reflected in adoption of RETs as well. Pakistan is blessed with enormous solar energy potential and appropriate related policy measures can lead to universal energy access for its population helping in substantial economic poverty alleviation.

2.12 Gaps Identified in Literature

Extensive literature is available on energy–growth and electricity–growth linkages, though no research work directly addresses the correlation between household social wellness, income, and quality/ type of energy used for cooking and for lighting. Furthermore, none of the earlier studies quantitatively established 'energy-poverty nexus' linking per capita income and the households' energy type at community, county, or district level. Almost all studies on energy–economic growth (GDP) correlation used one of the few traditional econometric techniques in the analysis – like Granger Causality, Co-integration, and Error Correction Model etc.

To the best of our knowledge based on extensive literature search, no research paper in the reviewed literature was identified having a quantifiable linkage of the state of household well-being with the available energy type. Earlier studies that examined the energy–income relationship, none explored any such linkage(s) at household level. Empirical investigation on energy–growth nexus based on country-wide household data disaggregated at district level is also not found. For the specific case of Pakistan, limited published literature is available exploring the energy–growth relationship, while research establishing energy–wellness correlation at household level is not available. Further, literature on the role of awareness on acceptance and adoption of rooftop solar systems is scarce which is further limited to developed countries. In the case of Pakistan, academic research on exploring household solar energy is almost nonexistent.

CHAPTER 3

THEORETICAL FRAMEWORK & METHODOLOGY

3.1 Theoretical Framework

3.1.1 Literature-based Hypothesis

The literature on correlation between energy and economic well-being exhibits evidence about the positive impact of electricity on the quality of life. The research in this area is mostly based on the country or higher-level data obtained from sources like the World Bank Development Indicators database. The researchers exploring linkages between energy and economic growth, or gross domestic product mostly relied on one or more of the econometric techniques like Error Correction Model, Cointegration or Granger Causality. This finding from the literature review offered an opportunity for attempting and introducing a different methodology that could add to or supplement the existing approach(es) in empirical studies.

As seen through the relevant literature, the researchers exploring the socioeconomic-development contributors did not find energy's role while investigating the determinants of economic growth for long time. The need for research into energy-growth relationship was first felt owing to the oil embargo situation during the late 1970s. The ensuing work in this field failed to arrive at an agreement on the existence and/or direction of causality between energy and economic growth. Notwithstanding energy-growth relationship, the proportion of articles presenting existence and direction of causality between electricity and economic well-being has been much higher. Significant finding of our interest from the literature review was the varying impact of electricity consumption in the developed and the developing countries: couple of significant researchers concluded that while economic development led to increased electricity consumption in developed countries, increased electric (energy) consumption brought in improvement in the economy in the developing countries. This outcome provided one of the key inputs for the framework of this dissertation.

Another finding from the literature used as a second building block for this dissertation's framework is the issues of quality and reliability of data pertaining to developing economies. Through the literature survey it was found that universal access to quality and reliable energy services has a direct impact on the attainment of several other sustainable development goals. Also, the Solar PV technology wherever embraced at household level, had shown direct improvement in the communities' earning abilities and income. This finding offered the opportunity and possibility of meeting multiple socioeconomic needs through improvements in energy supply at the grassroot level in Pakistan. Evidence found in the literature about people's acceptance of innovations and change being dependent on their behaviours and attitudes also augmented the formulation of outline for this work.

3.1.2 The Current and Future Scenario

Facing the worst energy crisis in its history, successive governments in Pakistan have been firefighting to handle the widening gap between energy supply and demand in addition to the predicaments like line losses, circular debt, political impediments to hydropower projects and unsustainable population growth rate. This situation has adversely impacted the middle- and the lower-income households in Pakistan. That coupled with Pakistan's over dependence on the imports for meeting her energy needs, highly volatile international oil market and ever-increasing burden of international debt has been another factor in the formulation of this PhD research pathways. The fossil-fuel linked global warming and its impact on the climate and the environment are a threat to sustainability and survival of a livable earth. The obligations for the signatory nations of '2030 Agenda for Sustainable Development' to meet their NDCs (Nationally Determined Contributions) of greenhouse gas emissions have therefore been also a consideration while finalizing the synopsis for this work. And finally, rapid decline in the cost of solar PV technology and the associated energy storage devices coupled with abundant sunshine in Pakistan contributed towards completion of an outcome-based research layout.

3.1.3 Key Considerations for Theoretical Framework

With focus on the household being the smallest societal unit for just and result-oriented energy transitions, the theoretical framework for this research plan has been based on these key considerations: 1) the undertaking should have strong backing from the evidence presented in earlier research work in this area; 2) it must advance the knowledge beyond the existing levels while investigating energy–economy or energy–development nexus; 3) empirical analysis should be based on reliable real-life data, covering all/ most territories across Pakistan; 4) statistical analysis should preferably involve newer/ more credible econometric techniques; 5) the inquiry results should lead to inferences that can help identify relationship between energy poverty and economic poverty (or energy access and affluence) at grassroot level; and 6) the research should yield one or more measures for improving the state of energy access with direct impact on the socioeconomic well-being while reducing environmental degradation and decreasing dependence on energy imports.

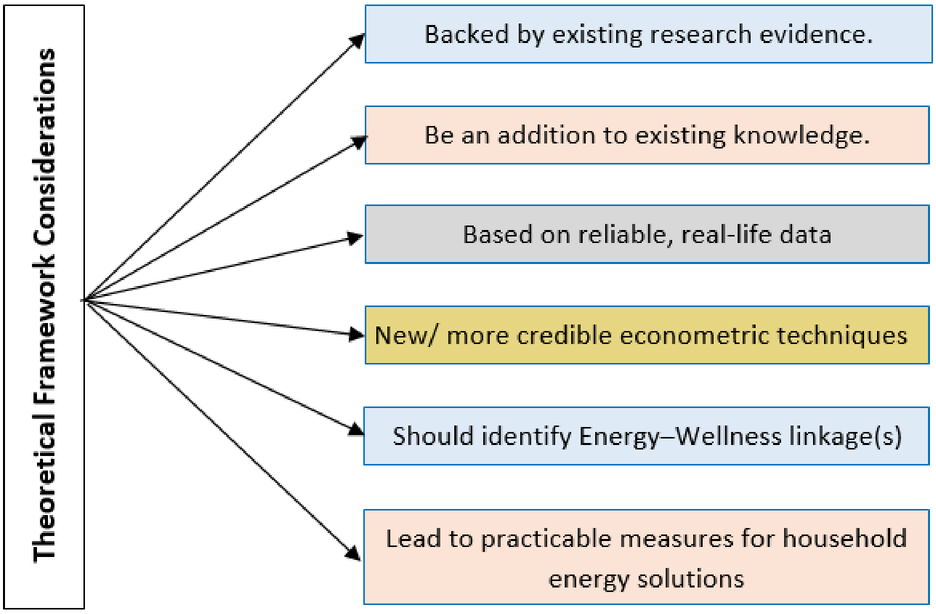

Figure 3.1: Key Considerations for Theoretical Framework

3.2 Methods

3.2.1 Energy and Economy at Households Levels

For arriving at the results representing households across most parts of Pakistan it was decided to use secondary sources data since customized data collection at such massive scale was not possible. Search for relevant data revealed that none of the governmental or semi-government organizations had the data that could be used to explore correlation between energy access and its socioeconomic impacts, especially at household level. The quest for data sources led to the 2017 Population Survey questionnaire that covered much needed aspects of household energy – cooking and lighting – besides couple of other important parameters directly related to the households' socioeconomic conditions. Raw household-level data was obtained from Pakistan Bureau of Statistics (PBS) to extract suitable statistics for this research. Forty (40) spreadsheets listing more than 350 fields were analyzed and sifted through to identify the desired parameters for meaningful results. The data pertained to demography, literacy rate, education level, source of income, housing ownership, type and quality of housing, household amenities and facilities, the energy used for cooking and the energy access for lighting, number of persons living in a household, water, and access to media. Out of these literacy rate/ education, housing type and quality, water supply, availability of kitchen and bathroom, and energy available for cooking and lighting were found directly relevant to the household's economic conditions in the light of their contribution in calculation of Human Development Index (HDI) and/or Multidimensional Poverty Index (MPI) and, as noted during the literature review. Data reflecting district level per capita income (PCI) pertaining to federal capital and provincially administered districts was available with PBS, that being a good indicator to measure poverty it was decided to examine the correlation of district level household parameters' data for evaluating energy's nexus with the per capita income. Thus, these household survey parameters are explanatory variables and PCI is the outcome variable for this investigation.

Since the data pertaining to desired parameters had to be sifted out of that enormous raw data, 31 districts with proportionate number from each province were randomly selected for this study. Randomization was essential to obviate the possibility of any bias while the number of districts (31) fulfilled the sample-size condition of minimum 30 data-points so as to make the t-distribution quite similar to the z-distribution [198]. Further, the predictor variables' values were converted into percentages of respective population and/ or the number of households. Twenty predictor parameters were grouped into five categories, namely: 1) Population parameters (PP)—literacy level, primary, secondary school certificate (SSC), degree (undergrad and above), and employed (working), (5 predictors); 2) Housing types (HT)—pakka (cemented houses), semi pakka (partly cemented), and kacha (not cemented/mud houses), (3 predictors); 3) Housing facilities (HF)—potable water, kitchen, bath, and toilet, (4 predictors); 4) Cooking energy fuels (CEF)—wood, gas, kerosene oil (K2 Oil), and others, (4 predictors) and 5) Lighting energy sources (LES)—electricity, K2 Oil, gas lamps, and others (4 predictors). Of these ten parameters were dropped after correlation analysis and collinearity test in order to avoid skewed results in regression analysis.

The retained ten predictors – primary, SSC, degree, employed, pakka, potable water, kitchen, bath, wood, and electricity – were once gain tested for multicollinearity before being used as independent variables. These predictors with the corresponding per-capita income were tested for linear regression fit through the “stepwiselm” function of MATLAB® with F-statistics’ *p*-value less than or equal to 0.05 that led to a linear regression model bringing out primary, SSC, degree, pakka, bath, wood, and electricity as important predictors of per-capita income (PCI) in Pakistan. The resultant model covered a reasonably wide range of (minimum to maximum) values for each explanatory variable. The outcome was also tested for non-existence of autocorrelation and heteroscedasticity to confirm the soundness of the resultant regression model. The model was further validated by applying it to 15 randomly selected sample districts’ data as well. With positive individual correlation of all predictors with the PCI except wood, and negative individual correlation of wood, the model confirmed that PCI is likely to increase with an increase in all predictors except wood and vice versa.

3.2.2 Citizens’ Involvement for Sustainable Energy Transitions

This part aimed at evaluating impact of consumers’ perception of the rooftop solar (RTS) technology and its associated parameters on going solar, the data for which was harvested from an anonymized survey conducted by Institute of Policy Studies Pakistan. The survey had recorded multiple factors linked with solar energy adoption by Pakistani households that included parameters like economic conditions, energy reliability, government policies, awareness about technology and cost of going solar etc. Out of the wide-ranging survey data, this study was restricted to the awareness aspects of consumers’ decision on RTS adoption. The respondents’ inclination for acquiring Solar System was used as “response variable”.

The data had been collected via an online survey questionnaire mostly targeting under-grad and post-graduate respondents, first it was examined whether their education level had any impact on their willingness for solar PV systems. Multinomial Logistic Regression function in “MATLAB®” showed that respondents’ inclination to adopt RTS had no direct linkage with their education level. Key findings from these empirical analyses led to the conclusions that: 1) 50% of even the college and university graduates in Pakistan were not reasonably informed about basic parameters related to RTS and net metering, and 2) Awareness level had a direct impact on the consumers’ inclination to adopt rooftop solar systems. Viewed in the light of domestic and commercial sector's combined share in the national electricity demand, RTS adoption offers promising prospects of significantly cutting down the energy import bill while accelerating the achievement of SDG-7 – universal energy access – across Pakistan.

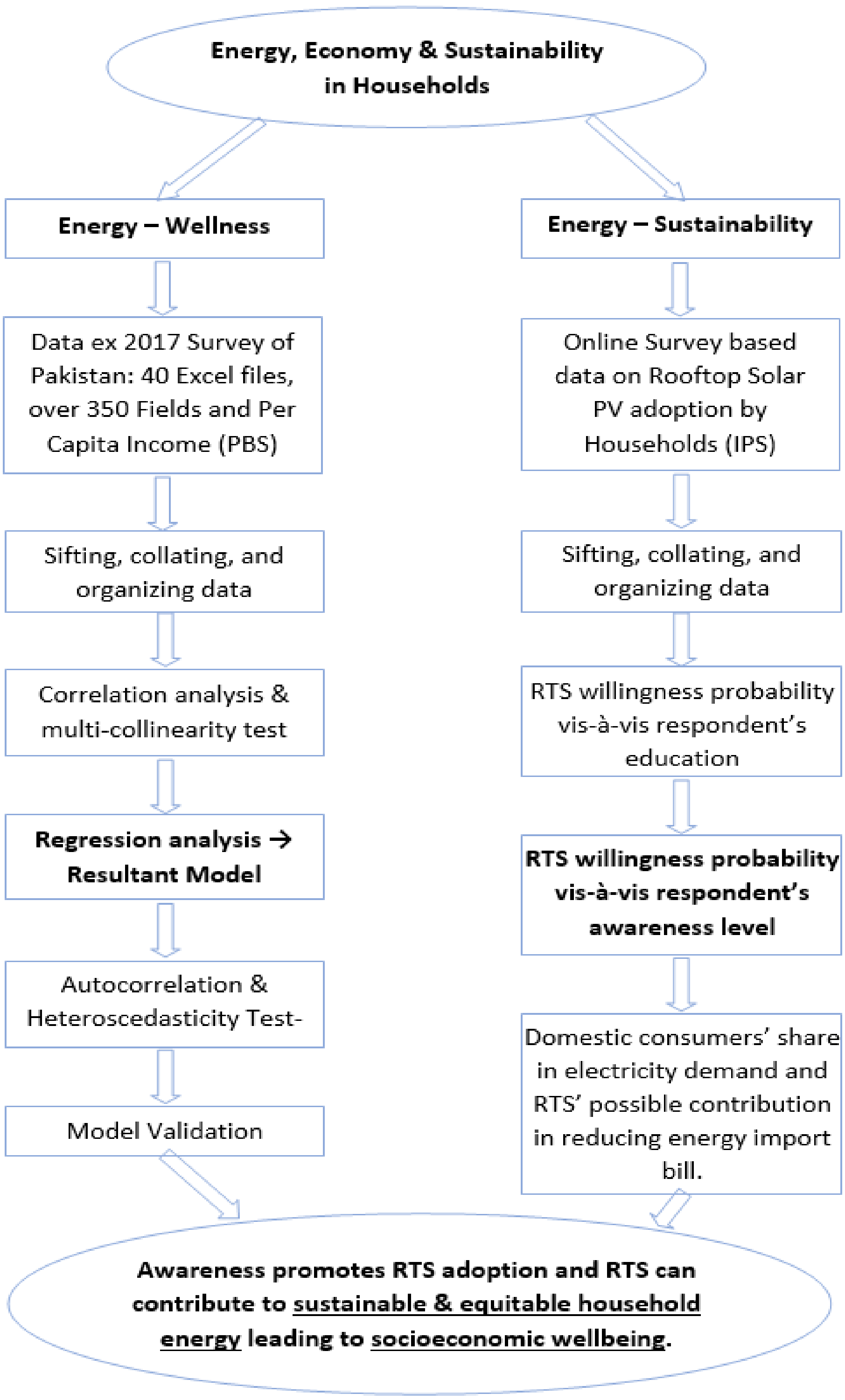

Figure 3.2: Research methodology

CHAPTER 4

ENERGY AND ECONOMY AT HOUSEHOLD LEVELS

4.1 Prelude

The indicators measuring socioeconomic well-being, such as the human development index (HDI) and multi-dimensional poverty indicator (MPI), recognize energy as an important resource for human development. However, energy did not find due weight in determining HDI or MPI, except as a fractional contributor to MPI calculations. It is hypothesized that energy has a predominant impact on the state of poverty and, energy-based poverty indicators are as relevant in defining poverty as other indicators. This hypothesis is explored in this chapter to develop energy-based poverty indicators for Pakistan. As a first step, the aggregated district level data is analyzed to establish correlation (positive or negative) between education levels, housing types and facilities, and energy-type used by the household. This is further developed to explore the impact or dependence of these parameters on the well-being of respective population. Finally, a regression model to establish an energy–poverty nexus in Pakistan is presented along with relevant discussion and conclusion. Defining poverty in terms of per-capita income (PCI), the proposed model incorporates education-based parameters along with the energy-dependent indicators linked to households in Pakistan. The data aggregated at districts level are extracted from the Census 2017 campaign, Pakistan Bureau of Statistics (PBS). Statistical analyses indicate that energy-based identifiers correlate well with the PCI and augment the education-only model, capturing 94% variability in PCI vs. 78% for the education-only model. The study highlights the criticality of relevant data collection and data-driven planning in Pakistan for creating synergy in energy planning and poverty alleviation programs and provides recommendations for considering energy as an important and integral contributory factor in the human development index (HDI).

4.2 Background Literature and the Rationale

Energy, similar to food, clothing, and shelter, has long been an essential human need. As the world moved towards a more civilized living and increased mechanization, energy's role in attaining other human needs became apparent [166]. When energy-related developments started gaining momentum during the 20th century, access to and sustained availability of energy started impacting every facet of human life and development. A growing body of research emphasizes that existing approaches for assessing energy poverty that focus solely on access to affordable energy fail to fully account for the complex and dynamic feedbacks that occur between energy insecurity and impoverishment [166,156]. In particular, last few decades saw increased interest of researchers in exploring energy's role in the societies' socioeconomic well-being [167-172]. In 1990, Alam et al. found a 'significant' link between the physical quality of life and per-capita energy consumption using 'World Energy Supplies' data, 1950–1974 [167]. During the year 2000, Alan D Pasternak, utilizing data from World Energy Supplies, 1997, delved into a quantitative relationship between energy consumption and human well-being [168]. Volkan Ş. Ediger recommended the integration of energy as a component in calculating HDI in 2006, establishing a correlation between energy and HDI, which has education and income as two of the contributory factors in its calculation, through the statistical evaluation of HDR 2002–2003 [169]. By analyzing 1975–2005 human-development-related data from UNDP's database, Julia K. Steinberger and J. Timmons Roberts suggested in 2010 that a certain amount of energy must be provided for meeting human needs [170]. They used education and income as two of the related parameters in their study. Kalu Uduma and Tomasz Arciszewski attributed poverty in urban and rural Nigeria to poor energy supply in 2010 [171]. Again, in 2018, Christine W. Njiru and Sammy C. Letema established that there is a direct or indirect effect of energy on the living standards in society in Kenya using education and income as two of the studied elements [172]. Many contemporary experts agree that energy security can lead to the eradication of poverty, particularly in developing countries [173]. However, despite energy's dominant role in human development, the World Bank's "SE4All Global Tracking Framework" finds 840 million without electricity access and 2.0 billion people without clean cooking facilities as of 2017 [174]. This situation is not ameliorating over the years, in spite of a tremendous decline in the cost of renewable energy technologies between 2010 and 2017, the period during which the costs of solar energy and storage batteries reduced by 85% and of wind power generation by 49% [175].

Access to clean, reliable, and affordable energy has significant implications towards making a society affluent and sustainable, with direct as well as indirect effects on its long-lasting role towards poverty alleviation [166,171,173,176]. The indicators such as the human development index (HDI) and multi-dimensional poverty indicator (MPI) have been formulated and used for measuring socioeconomic well-being. Both indicators recognize energy as an important resource for human development, but energy did not find due weight in determining HDI or MPI, except as a fractional contributor to MPI calculations [177,178]. However, in 2015, energy did find recognition of its due importance through inclusion in seventeen Sustainable Development Goals (SDGs) adopted by the United Nations.

Available literature is replete with the evidence that energy impacts the earning capacity and, thus, income of a household through many enabling parameters such as learning opportunities, health, preventing loss of time, and better living conditions [166–173]. Access to modern energy services has been fully recognized as one of the critical resources for meeting daily life needs [179]. It has also been understood that dynamics and facets of the energy–poverty nexus vary across national economies and cultural contexts [171,172,158,100]. A growing body of research emphasizes that existing approaches for assessing energy poverty or access to affordable energy fail to fully account for the complex and dynamic interplay between energy insecurity and poverty [71,180]. Due to its social, economic, and environmental dimensions, harnessing the available renewable energy resources and their full utilization is now one of the most critical needs for any sustainable development and poverty alleviation program [166,179,181,182]. Additionally, the thriving living standards and growth rates of nations possessing, controlling, efficiently expending, and utilizing energy resources vs. abysmal living conditions and stunted growth rates of energy-deprived economies point towards a strong relationship between energy availability and its efficient utilization and overall well-being of the society [167,169]. It is, therefore, important to develop research contexts that characterize and explain the energy–poverty nexus within specific sociocultural and economic contexts.

Similar to many developing countries, Pakistan is also heavily dependent on foreign energy resources for meeting its energy needs [100,183]. Dependence on the import of oil and gas to meet the energy needs alone has been the main contributor of trade imbalance for many decades, thus depleting foreign exchange reserves and raising foreign debt to an unsustainable level [100,184]. The allocation of a sizeable portion of national income for importing primary energy and for debt servicing has had adverse impacts on socioeconomic development in Pakistan [100,185]. This is another dimension of the energy–poverty nexus, revealing how dependence on energy imports drains the resources of a poor country, resulting in the worsening of the overall state of poverty.

Despite the energy–poverty nexus being a reality, energy has not found its rightful place in studies and in poverty alleviation programs in developing countries including Pakistan. Numerous studies have already established the impact of household energy choices on education, health, quality of life, and wellness in society, indicating the interactive relationship between these parameters [167,180,186,187]. However, no research has quantitatively linked household energy type and wellness indicators such as per-capita income (PCI). Available literature is also limited in size and scope for linking the required amount and type of energy for raising the low-income population in Pakistan above the poverty line [100,183,184]. To the best of our knowledge, the energy–poverty nexus is not fully examined within the context of developing economies including Pakistan. Consequently, there has been no realization of the critical need for relevant data collection either. The availability of appropriate and reliable data could lead to synergized and sustainable poverty alleviation programs incorporating measures for the provision and productive use of energy [175,182]. Research on the impact of low-density, unclean, and unaffordable energy resources on the state of poverty is also limited [180,185,188,189]. Pakistan does not have any energy-linked poverty indicators based on which its energy policy can be aligned to contribute towards the reduction in poverty. The realization of the energy–poverty nexus within the context of developing economies in general, with particular reference to Pakistan, would help to align the poverty-reduction strategies and efforts.

It is well understood that education has a profound effect on alleviating poverty and improving earning abilities [186,187,190,191]. In this chapter, in addition to education, statistical methods are applied to establish the energy–poverty nexus through examining the close relationships between poverty levels, living standards, and types of household energy access and consumption at the district level across Pakistan. Preceding that investigation, household energy's correlation is drawn with education levels and housing types and facilities to explore the linkages if any. The energy–poverty nexus is established by examining and analyzing the household data collected through the Census campaign in 2017 [192]. Our analyses provide an improved understanding of energy–poverty interplay, highlighting its oversized role in poverty/ wellness, defined in terms of per-capita income (PCI). Further, this research attempts to provide a clear linkage between the PCI, and education, other economic indicators (i.e., living standard, etc.), and the type of household energy sources. This is likely to provide an insight to the policy makers to incorporate the household energy in the strategic planning for poverty alleviation programs.

This research suggests that energy poverty is better understood as an energy-poverty nexus in which energy insecurity acts through multiple mechanisms to exacerbate poverty and impede economic development at the community level and that poverty, in turn, also impedes the successful development and use of new energy resources and infrastructures [71,180]. To establish the energy-poverty nexus, we used linear regression analysis. Regression analyses are suitable for predicting continuous dependent variables, i.e., PCI, based on independent variables including education, living standards, and types of energy consumed. Remaining parts of this chapter deal with data collection and analysis methods, model used for analysis, findings, discussions, limitations, and the conclusions.

4.3 Data and Analytical Methods

4.3.1 Data Collection and Preparation

The socioeconomic well-being of a society is measured in terms of HDI, MPI, and/ or PCI, among which HDI and MPI are better indicators. HDI, comprising three parameters, incorporates education and income. MPI has education, cooking fuel, sanitation, drinking water, electricity, and housing assets as six of its seven contributory elements. The district-level Census 2017 data for this research came from the Pakistan Bureau of Statistics (PBS). The data contain different parameters such as demography, literacy rate, education level, employment including that in foreign countries, homeless people, category, vintage and ownership status of housing, household facilities, the type of energy used for cooking and for lighting, household density, water, and access to media [192]. Unfortunately, HDI and MPI data covering the entire population of Pakistan is/ was not available. On the other hand, while PCI/ income is not the optimum choice for measuring human development, it is often considered as the right indicator to evaluate poverty [172,179]. Available PCI data aggregated at the district level pertaining to federal capital and provincially administered districts (total 117 districts) were, therefore, obtained from the Pakistan Bureau of Statistics.

Thus, the explanatory variables for this study are based on selected parameters from both HDI and MPI besides the factors evaluated in earlier energy-wellness related studies [167,172,179,182,185,186], whereas PCI, which depends on the earning ability and productivity of the household members, has been used as the outcome (dependent) variable. The PCI values are the average income per person per year for the respective district.

Census-2017 data conditionally shared by the Pakistan Bureau of Statistics covered every district in 40 Excel files, spread over multiple books. Data pertaining to desired parameters had to be sifted out of that enormous raw data, before compilation, collation, and analyses. Therefore, after due deliberation and to economize on effort, it was decided to randomly choose 31 districts, such that the selected dataset had proportional number of districts (representation) from each province. Randomization ensured removal of any bias from the analysis while this number (31) satisfied the condition of picking a sample size comprising minimum 30 data-points so as to make t-distribution quite similar to z-distribution. [193]. All independent parameters pertaining to a given district were converted into percentages with respect to the population and number of households of that district. The selected parameters, termed predictors, are grouped into five groups or categories, with 20 predictors in total:

A. Population parameters (PP)—literacy level, primary, secondary school certificate (SSC), degree (undergrad and above), and employed (working), (5 predictors).

B. Housing types (HT)—pakka (cemented houses), semi pakka (partly cemented), and kacha (not cemented/mud houses), (3 predictors).

C. Housing facilities (HF)—potable water, kitchen, bath, and toilet, (4 predictors).

D. Cooking energy fuels (CEF)—wood, gas, kerosene oil (K2 Oil), and others, (4 predictors).

E. Lighting energy sources (LES)—electricity, K2 Oil, gas lamps, and others (4 predictors).

4.3.2 Preliminary Data Analysis

As a preliminary step, the data matrix consisting of the above independent variables (or predictors) and the dependent variable, PCI, were subjected to correlation analysis. In that, the district-wide average or mean values of predictors showed a correlation (r) of 0.73 (p, 0.000) with the PCI. Additionally, strong positive and negative correlations were observed within various predictor variables. Literacy was correlated with primary and SSC (r = 0.85) and SSC with degree (r = 0.78). Cooking and lighting energy exhibited negative correlations: a very strong negative correlation (r = −1) between “gas” and “wood”, the two cooking fuel types, means the houses with gas supply do not need wood for cooking, and vice versa; a reasonable negative correlation (r = −0.78) between “electricity” and “K2 oil”, the two lighting sources, indicates that there is less likelihood that households with electric availability will need K2 oil for lighting; a correlation (r = −0.94) value between “pakka” and “kacha”-type houses implies that the two types are inversely interrelated. Additionally, all predictors are linear, ranging from 0% to 100%. This preliminary analysis indicated that a linear regression model may be suitable to provide a linkage between the predictors and the outcome, PCI, provided the following assumptions are met: (1) no predictors are perfectly correlated with each other (collinearity), (2) residuals have constant variance (homoscedasticity), (3) residuals are normally distributed, and (4) residuals are not correlated with each other (autocorrelation). We decided to explore the linear regression model via ordinary least squares (OLS) as well as Ridge regression. Since strong multicollinearity is indicated by the predictor variables, we decided to resolve this first as shown below. Ridge regression was discontinued after resolving the collinearity issues, as OLS provided adequate estimates. Detailed residuals analyses are presented in Section 4.4.3.

4.3.3 Correlation Analysis

The above data matrix (call it X) comprising 31 districts and 20 predictors is subjected to the intra-category correlation, resulting in the following, as would be expected in a real life scenario [185]. These results also vindicate the reliability of the data set used in this study.

A. A very strong correlation (-1.00%) between ‘Gas’ and ‘Wood’, the two cooking fuel types, means the houses with gas supply do not need wood for cooking, and those dependent on firewood do not have access to gas.

B. Similarly, the convincing correlation (-0.78) between ‘Electricity’ and ‘K2 Oil’, the two lighting sources, indicates that there is less likelihood that households with electric connection will need K2 Oil for lighting.

C. A (-0.94) correlation value between ‘Pakka’ and ‘Kacha’ type houses implies that the two types are inversely interrelated.

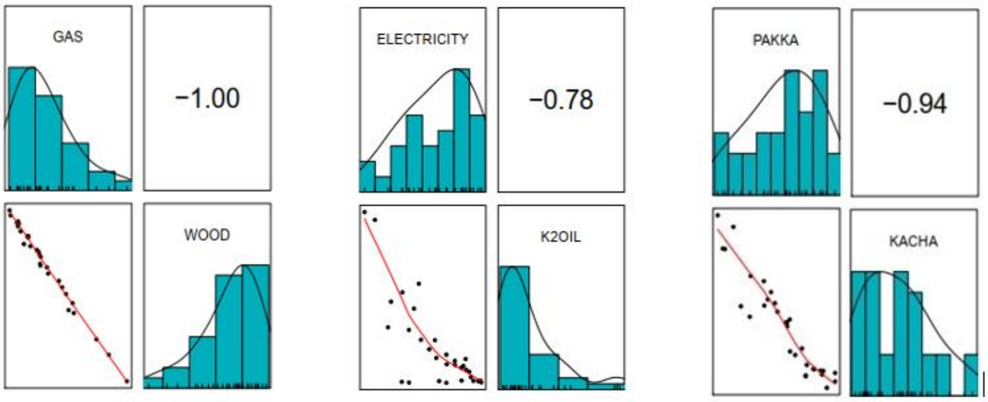

Figure 4.1: Intra Cooking Fuel, Lighting Energy and Household Types Correlations

D. The correlation coefficients between different education standards’ exhibit the evidence that districts with higher literacy rate have higher number of primary qualified people and more high school graduates. Similarly Matric and the Degree also have strong correlation within respective district.

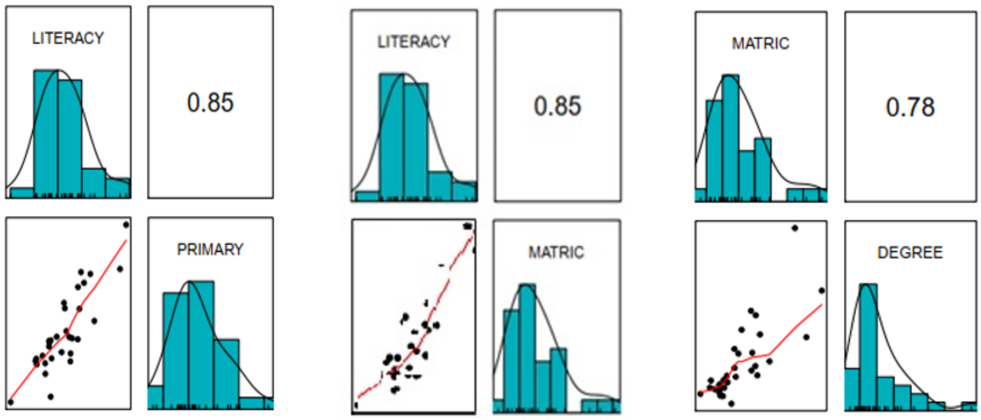

Figure 4.2: Education Levels correlation matrices

4.3.4 Resolving the Collinearity Issue

In statistical analysis, two (or more) predictor variables are subjected to a multicollinearity test, since the phenomenon of multicollinearity leads to skewed results in regression models [194-195]. Therefore, the selected parameters have been subjected to two-step analyses. The first step as explained below explores the existence of collinearity, resolves it by dropping the redundant independent variable(s), while retaining the remaining variables for regression analysis. During the second step, the retained variables are subjected to regression analysis.

The data matrix X consisting of 20 predictors (columns) and 31 districts (rows) are tested to establish a suitable predictive regression model. Since regression analyses are very sensitive to collinearity within the data matrix, the data matrix "X" is analyzed using Belsley [195] collinearity diagnostics function "collintest" in MATLAB® software. This test provides the "condition indices (CIs)" and the "variance-decomposition proportions (VDPs)" of the data matrix "X". The CIs identify the number and strength of near dependencies in the data matrix "X", whereas VDPs identify groups of predictors with interdependency coefficients between 0 and 1, and the extent to which the dependencies may degrade the regression. This test identified five interdependent groups with greater than 10 CIs (typical) and greater than 0.5 VDIs, namely, literacy and primary in PP, bath and toilet in HF, and all predictors within HT, CEF, and LES. In the light of this test, 10 predictors x1 through x10 (primary, SSC, degree, employed, pakka, potable water, kitchen, bath, wood, and electricity) were retained for subsequent analysis. These predictors were tested again for collinearity, and the resultant CIs and VDPs are shown in Figure 4.3 for each predictor variable. As can be observed in Figure 4.3, there is a mild collinearity between variables x1, x2, and x10 and variables x6 and x8. However, these are very close to the VDPs tolerance of 0.5, indicating a marginal influence on regression, thus retained.

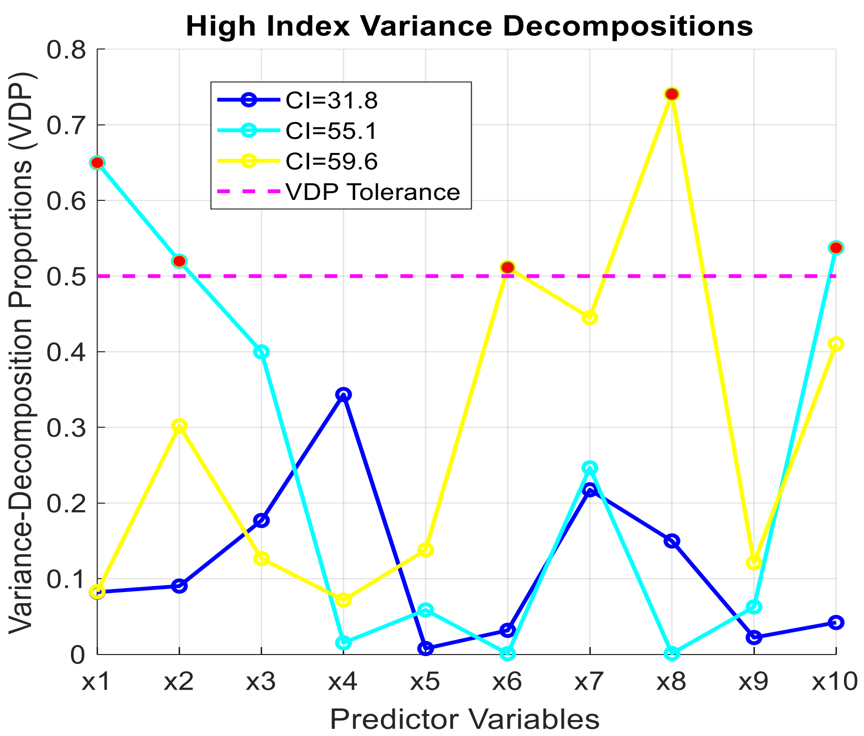

Figure 4.3 High-index variance decomposition of predictor variables, x1 through x10.

4.3.5 Data Analysis: Proposed Regression Model

The abovementioned 10 predictor variables along with the corresponding per-capita income (PCI), labelled as "y", was tested for linear regression fit through the "stepwiselm" function of the MATLAB® with the *p*-value of F-statistics less than or equal to 0.05. This function creates a linear regression model using stepwise regression to add or remove predictors, starting from a constant model. At each step, the function searches for terms to add to the model or remove from the model, based on the *p*-value. This resulted in the following form of the regression model.

$$y \approx \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_5 x_5 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{39} x_3 x_9 + \beta_{910} x_9 x_{10} + \varepsilon \quad (4.1)$$

where $\boldsymbol{\beta_0}$ is constant intercept, $\boldsymbol{\beta_i}$ for $\boldsymbol{i = 1, 2, ..., 10}$ are the coefficients or weights for each predictor variable, x_i. Further, there are two interaction or interdependent terms, x_3, x_9 and x_9, x_{10}, along with their respective coefficients, $\boldsymbol{\beta_{39}}$ and $\boldsymbol{\beta_{910}}$.

The model in Equation (4.1) indicates that primary, SSC, degree in PP, pakka in HT, bath in HF, wood in CES, and electricity in LES might be the important predictors of per-capita income (PCI) in Pakistan.

4.4 Results

4.4.1 Model (4.1) Statistics and Its Fit to the Data

Table 4.1 provides pertinent statistics related to this model. ANOVA summary statistics are in Table 4.2. As is evident from Table 4.1, model (4.1) accounts for roughly 94% variability in PCI, with the *p*-value being extremely small, indicating a robust fit and rejection of the null hypothesis. Similarly, the individual regression coefficients in model (4.1) have F-statistics based *p*-values much less than 0.05, indicating a reasonably strong fit for each predictor. Further, regression models are used typically to provide interpolated predictions of y (in this case, PCI) for scenarios in which the data for predictor parameters are available. The proposed model (4.1) is likely to provide reasonable PCI estimates if the model variables, $\boldsymbol{x_i}$, $\boldsymbol{i = 1, 2, 3, 5, 8, 9, 10}$ are within the min/max limits in Table 4.1.

Table 4.1. Statistics pertaining to regression model (4.1).

Variables	Estimate	SE	tStat	DF	MeanSq	F	*p*-Value	Min	Max	Mean	SD
Intercept	−68.6156	224.2643	−0.3060				0.763				
x_1	11.4929	2.0395	5.6351	1	14,296	31.755	1.360×10^{-5}	7.94	30.83	16.94	5.11

x_2	−18.2715	3.4234	−5.3372	1	12,825	28.486	2.715×10^{-5}	5.27	20.31	10.22	3.49
x_3	−28.6171	9.5445	−2.9983	1	2599	5.7724	0.025608	1.43	8.56	3.10	1.52
x_5	2.0789	0.3603	5.7695	1	14,986	33.287	9.991×10^{-6}	2.37	85.38	49.29	24.09
x_8	1.3080	0.4936	2.6502	1	3162	7.0238	0.014969	58.74	98.46	84.15	11.78
x_9	4.4239	2.6253	1.6851	1	6275	13.939	0.0012267	9.26	97.94	70.32	21.98
x_{10}	5.9280	2.7878	2.1264	1	4429	9.8379	0.0049846	61.66	98.70	84.73	10.41
x_3x_9	1.1797	0.1908	6.1842	1	17,218	38.244	3.902×10^{-6}				
x_9x_{10}	−0.1127	0.0298	−3.7791	1	6430	14.281	0.0011005				
Error				21	450						

Number of observations (districts)	Error degrees of freedom	Root mean squared error	R-squared	Adjusted R-squared	F-statistics vs. constant model	Model *p*-value
31	21	21.2	0.957	0.939	52.1	2.36×10^{-12}

Table 4.2. ANOVA summary.

Variables	**SumSq**	**DF**	**MeanSq**	**F**	***p*-Value**
Total	2.2074×10^5	30	7357.9		
Model	2.1128×10^5	9	23,476	52.144	2.3556×10^{-12}
Linear	1.9159×10^5	7	27,370	60.794	1.6186×10^{-12}
Nonlinear	19,693	2	9846.3	21.87	7.3441×10^{-6}
Residual	9454.4	21	450.21		

All predictors except x9 – wood – individually are correlated positively with the PCI, as shown in Table 4.3 below. Therefore, PCI is likely to increase with an increase in all predictors except x9, wood, while increased use of wood would result in decreased income of the household.

Table 4.3 Predictors' independent correlation with the PCI.

Variables	**x1**	**x2**	**x3**	**x5**	**x8**	**x9**	**x10**

Corr. Coef.	0.7921	0.6717	0.6128	0.7547	0.2311	−0.6158	0.8533
p-Value	0.0000	0.0000	0.0002	0.0000	0.2110	0.0002	0.0000

The differences between the magnitude and the signs of the coefficients in the regression model and the individual/independent correlation coefficients could be explained as follows: The regression model attempts to minimize the sum of the error squared between the regression-predicted PCI and the given PCI. The resulting weights (regression coefficients) and their respective signs (+/−) are assigned during this minimization process to estimate a linear line, as shown in Figure 4.4. As an example, x2 (SSC) variable in Table 4.1 has a regression coefficient of (−18.2715), indicating that PCI will be depressed 18.2715 times for 1 unit increase in the SSC level of education of the underlying population. This inference is obviously not correct as the above correlation coefficient indicates for x2. The weights and signs of regression coefficients are therefore adjusted to provide a regression model that minimizes the squares of the error.

Figure 4.4 depicts the regression model (4.1) and its fit to the data. This figure also provides 95% confidence bounds, indicating that (4.1) is an appropriate model to represent PCI in Pakistan.

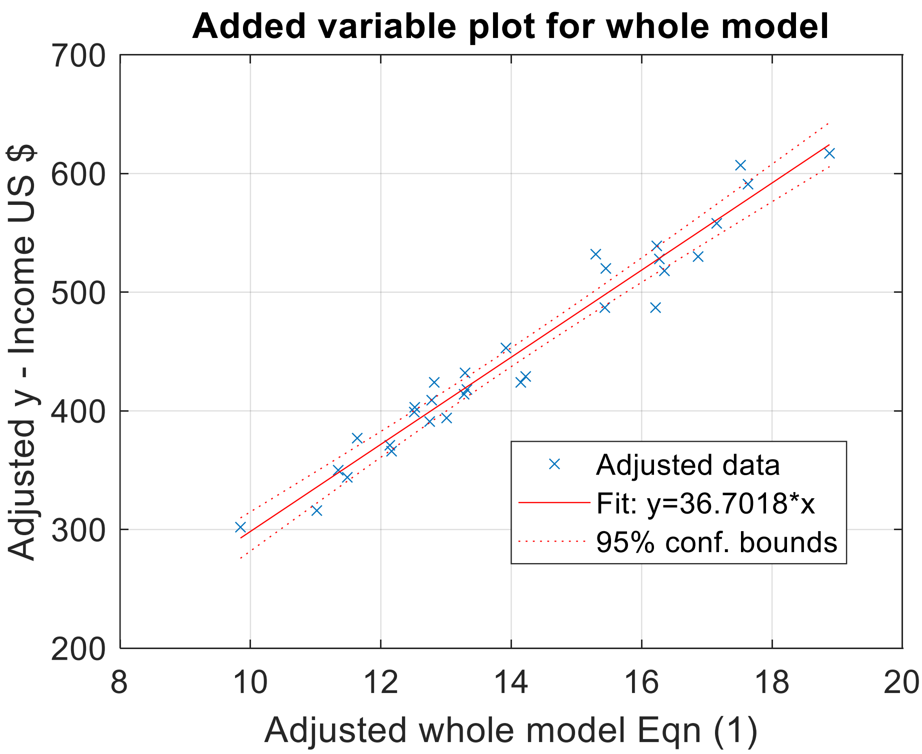

Figure 4.4 Regression model (4.1) vs. income in USD.

4.4.2 Interaction Terms in Model (4.1)

The model in Equation (4.1) has two interaction terms, x_3 and x_9 (degree and wood) and x_9 and x_{10} (wood and electricity). Both these interaction terms reinforce the validity of our hypothesis there is a strong correlation between the type of energy available to and in use by the households and the income at the district level in Pakistan. Figure 4.5 shows the interaction between the percentages of degree holders and the users of wood. This suggests that PCI is depressed, as the use of wood increases until the degree holders' percentage is less than 5%. On the other hand, PCI is higher or likely to increase if the degree percentage is above 5% and the use of wood increases. This scenario points to the fact that while the increased use of wood indicates lowering the PCI of a household, more than 5% of members of the society with a higher education (degree) can compensate and improve the earning potential even in gas-deprived districts. Notwithstanding the impact of higher education, the interaction terms' relationship also indicates that increased use of poor-quality, low-density cooking fuel has depressing effects on PCI until another factor mitigates its impact.

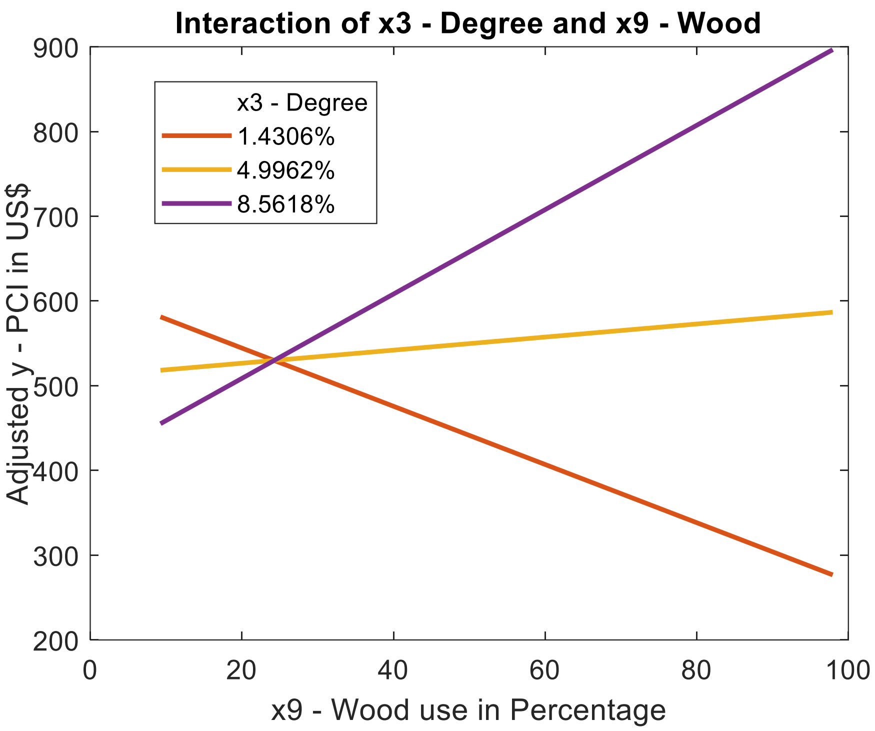

Figure 4.5 Interaction between degree and the use of wood in percentage.

As seen in Figure 4.6, there exists a strong negative correlation between x_9 and x_{10} (wood and electricity) beyond certain percentages of wood and electricity. Figure 4.6 indicates

PCI increasing as the use of electricity increases provided the use of wood is less than 50%. Whereas we see the PCI becoming depressed when the use of wood is beyond 50%, even if the electric connectivity is higher. This interactive relationship again confirms the dominant impact of poor-quality, low-density, and labor-intensive cooking fuel on the earning abilities of a household, even when they are provided with a better-quality and convenient lighting source. This phenomenon leads to the inference that it is necessary to improve the quality of energy for all the households' needs for eradicating poverty.

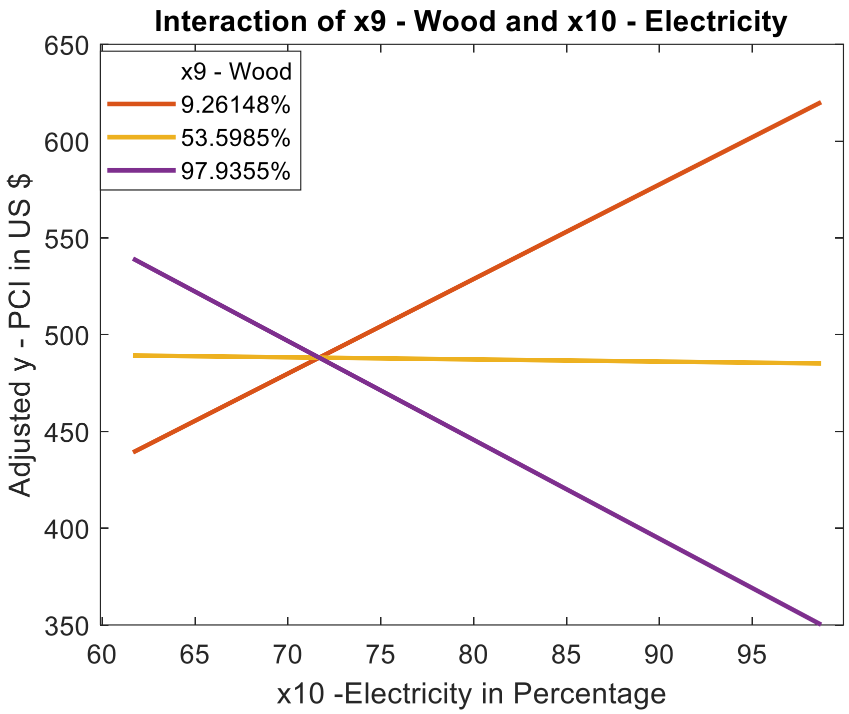

Figure 4.6 Interaction between the use of wood and electricity.

4.4.3 Residual Analysis of the Model (4.1)

Residuals, $(y - \hat{y})$, are helpful in detecting outlying PCI values and checking error term assumptions in the regression models. Three of the four assumptions (collinearity, normality, autocorrelation, and homoscedasticity) mentioned in Section 4.3.4 are analyzed in this section. Collinearity is already discussed under Section 4.3.4.

Normality: Shown in Figures 4.7 and 4.8 are two plots pertaining to the residuals of model (4.1). Figure 4.7 is Cook's distance vs. rows of observations, i.e., districts. Cook's distance is useful for identifying outliers in the data [195-196]. An observation with Cook's distance much larger than three times the mean Cook's distance is possibly an outlier. Figure 4.7 indicates that four districts fall slightly outside the range established by the Cook's distance. These four districts are, however, not considered as outliers when viewed in conjunction with the normal distribution plot in Figure 4.8. Figure 4.8 indicates that residuals are normally distributed, as assumed in the model; therefore, these four districts can be retained without violating normality assumptions.

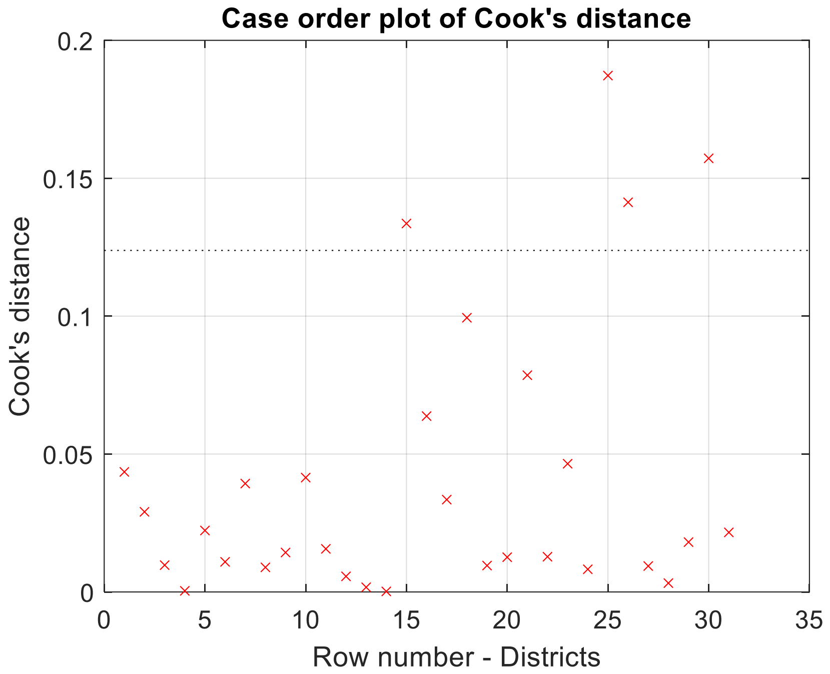

Figure 4.7 Cook’s distance vs. observations, indicating 4 possible outliers.

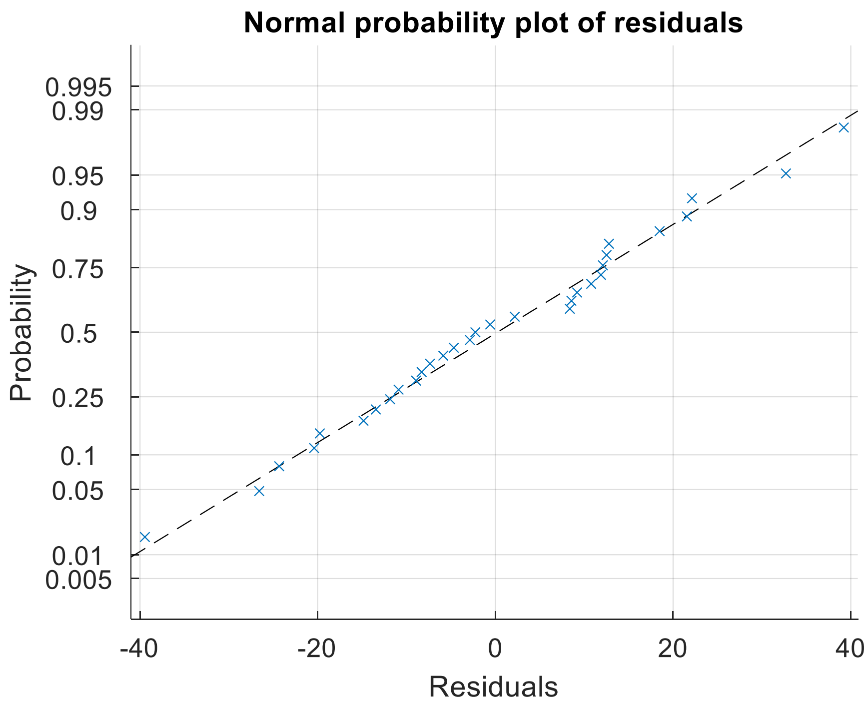

Figure 4.8 Normal probability plot of residuals, indicating approximate normal distribution.

Autocorrelation: Figure 4.9 shows the sample autocorrelation function or correlogram of raw residuals resulting from the difference between the fitted PCI and the observed PCI. The residuals are indicated within the 95% confidence bounds and are, thus, without significant serial correlation. This is further tested using Durbin–Watson (DW) [197] and Ljung–Box Q (LBQ) [198] tests for residual autocorrelation in MATLAB. Both tests assume no serial correlation as null hypothesis and return statistics upholding or rejecting this. DW statistics range from 0 to 4, with values between 1.5 and 2.5 indicating no significant serial correlation. For the data under consideration, DW statistics were 2.2 with a *p*-value of 0.78, indicating that no significant autocorrelation exists among the residuals. The LBQ test has the additional flexibility of testing various lags. Since there exist some mild serial correlation at lags 2, 4, 5, 9, and 19, the LBQ test is used to identify this. The LBQ test returns either 0 (not rejecting null hypothesis) or 1 (rejecting null hypothesis) with a respective *p*-value at each location. The statistics for all lags were 0 with *p*-values ranging from 0.11 to 0.35, indicating that no serial autocorrelation exists among the data under consideration.

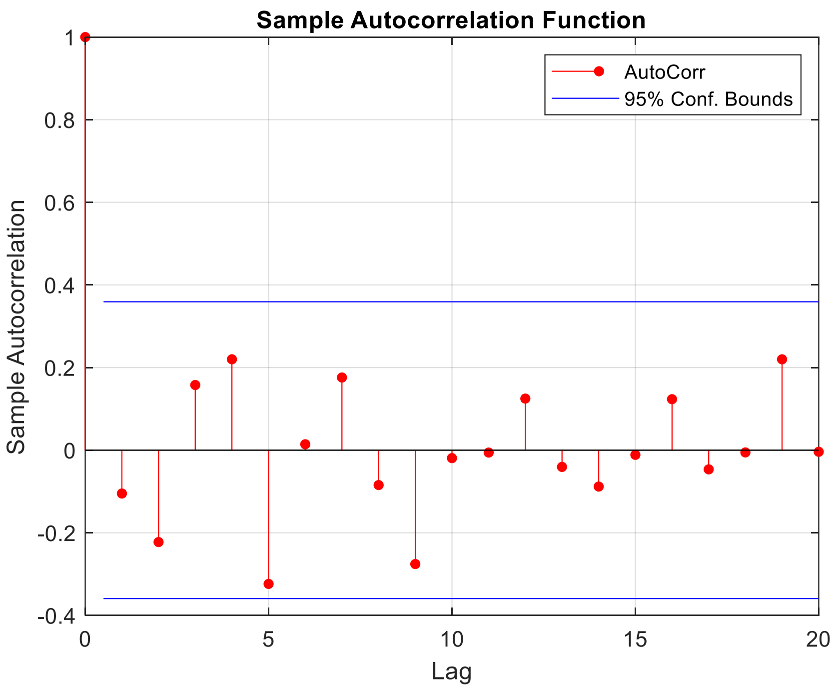

Figure 4.9 Sample autocorrelation function of residuals along with 95% confidence bounds. No significant serial correlation exists between the residuals.

Homoscedasticity: Homoscedasticity refers to all residuals having same variance. We used MATLAB's residual diagnostic function to test this. Shown in Figure 4.10 are residuals vs. fitted PCI. Although an obvious trend is not visible in Figure 4.10, we further tested the data to rule out possible heteroscedasticity. To this end, Breusch–Pagan (BP) [199] and Engle's autoregressive conditional heteroscedastic (ARCH) [200] tests were used. Both tests assume null hypothesis with no heteroscedasticity and return statistics upholding or rejecting this. The returned *p*-values of 0.6829 and 0.1023 for BP and ARCH, respectively, indicate upholding the null hypothesis so that there is no significant heteroscedasticity in the residual data.

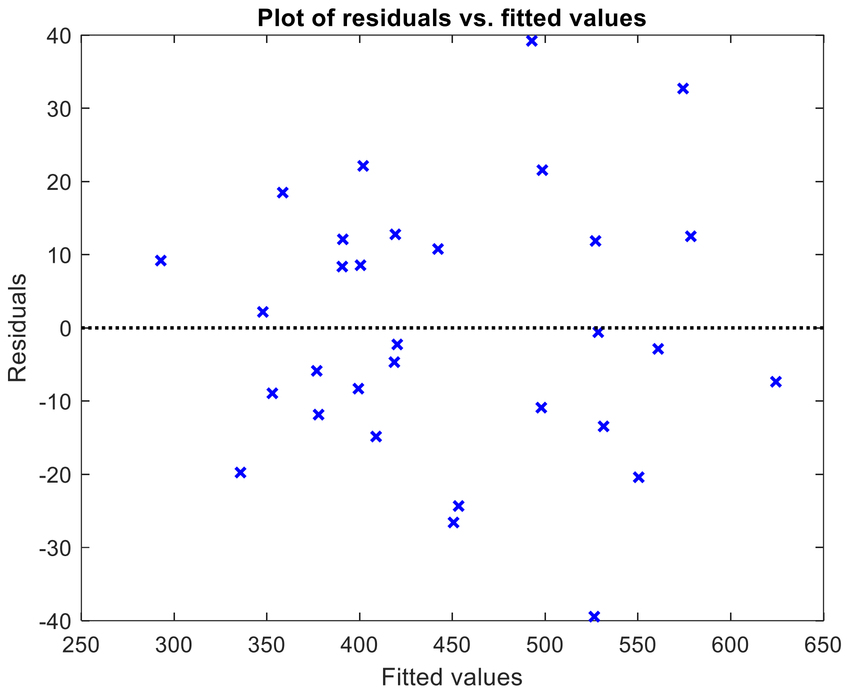

Figure 4.10 Residuals vs. fitted PCI, showing no significant heteroscedasticity.

Comparing residuals resulting from PLS and OLS: We compared residuals from PLS with those of OLS in Figure 4.11. The mean and standard deviation of the residuals, respectively, for OLS and PLS are 0.00 and 17.75 and 0.00 and 29.93. Although we did not analyze PLS extensively, the residuals indicate an almost identical performance for both methods.

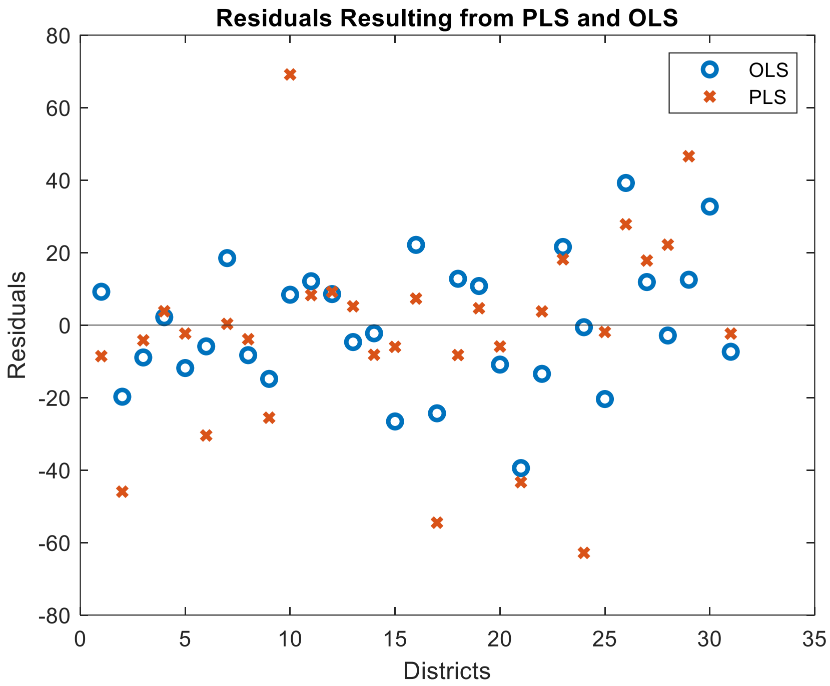

Figure 4.11 Residuals resulting from OLS and PLS, showing no significant difference.

Fitted or predicted OLS and PLS PCI for out-of-sample districts: The stepwise OLS model is generally considered not fitting the out-of-sample data adequately. To this end, 15 additional out-of-sample random districts are processed. Depicted in Figure 4.12 are fitted PCIs for these districts for OLS and PLS. The mean and standard deviation of the error resulting from fitted and observed PCIs (residuals), respectively, for OLS and PLS are 17.47 and 156.62 and 34.75 and 141.25. These results and the graphical representation in Figure 4.12 indicate an almost identical performance for both methods.

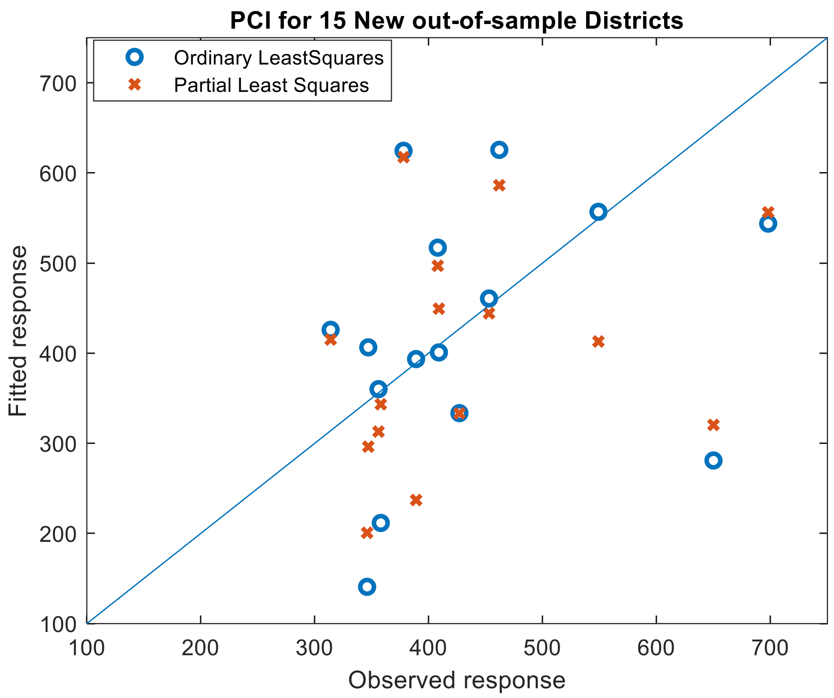

Figure 4.12 Comparison of fitted OLS and PLS PCIs for out-of-sample 15 districts. This shows no significant difference.

4.4.4 ***Comparison of the Proposed Model (4.1) with Education-Only Model***

Several researchers have established the overarching impact of education on the individuals' earning abilities and the households' income [186-187,190-191]. In this section, a comparison is provided for the education-only model with that of the proposed model (4.1). For Census 2017 data, the education-only model accounts for 78% variability in PCI, as shown in Table 4.4. The mean regression plot pertaining to this model is shown in Figure 4.13. Comparing Figures 4.4 and 4.13 and Tables 4.1 and 4.4, model (4.1) captures 94% variability in PCI as compared to the education-only model with 78% coverage. Therefore, the proposed model (4.1) incorporating energy-related variables is more inclusive and better for estimating PCI for Pakistan. The proposed model augments the education-only model and, thus, establishes the relevance of household energy towards affluence/poverty in Pakistan. This model may be applicable in other developing economies too.

Table 4.4 Summary statistics pertaining to the education-levels-only model.

Variables	**Estimate**	**SE**	**tStat**	**DF**	**MeanSq**	**F**	***p*-Value**	***Min***	***Max***	***Mean***	***SD***
Intercept	196.41	26.189	7.4999				4.5584×10^{-8}				
x_1	15.157	2.2327	6.7888	1	73467	46.088	2.7254×10^{-7}	7.94	30.83	16.94	5.11
x_2	−12.108	4.8643	−2.4891	1	9876.1	6.1956	0.019266	5.27	20.31	10.22	3.49
x_3	38.765	8.4913	4.5653	1	33223	20.842	9.7948×10^{-5}	1.43	8.56	3.10	1.52
Error				21	1594						

Number of observations (districts)	Error degrees of freedom	Root mean squared error	R-squared	Adjusted R-squared	F-statistics vs. constant model	Model *p*-value
31	27	39.9	0.805	0.783	37.2	1×10^{-9}

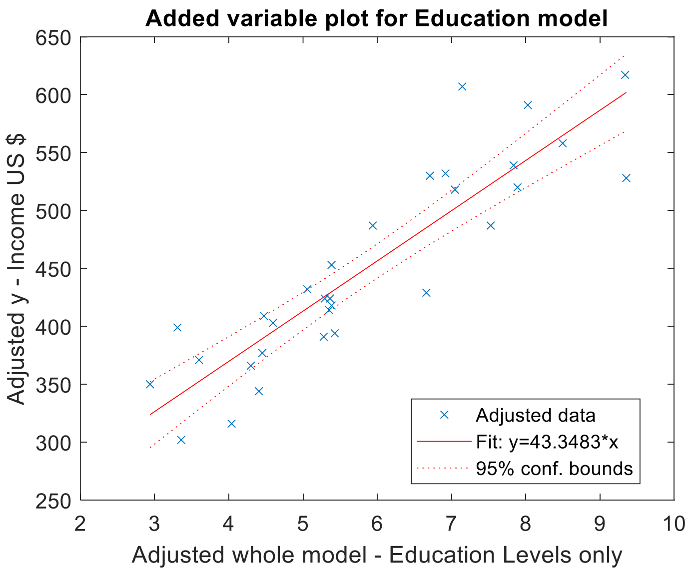

Figure 4.13 Education-only regression model vs. PCI in USD.

4.5. Findings

In light of Sections 4.3 and 4.4, we summarize the findings as follows:

- The data used in this research, though collected over extended time and by numerous individuals, are reliable, reflecting the real-life on-ground situation in Pakistan. Although this study has used a limited subset of this data, the analyses are likely to be applicable across the entirety of Pakistan except for a few highly developed urban centers or extremely remote rural areas.

- Education has an important linkage with the earning ability (PCI) of people in Pakistan, as is the case worldwide. The affluent population tends to aspire for better schooling; improved high school/college and higher education enables for and offers better earning opportunities.
- Housing types and the facilities too are dependent on household income and are a good predictor of PCI.
- The critical energy–poverty nexus established through this work provides quantitative correlational evidence between energy and PCI at the district level in Pakistan. This correlation leads to the proposed model in Section 4.4, accounting for almost 94% variability in PCI.

4.6 Inferences

Notwithstanding the limitations mentioned towards the end of this section, the robust correlation between energy and one of the key indicators of social welfare, the per-capita income (PCI), opens venues for exploring some important dimensions of this relationship. Does this correlation fit into the existing predictors and indicators of wellness and poverty? Did energy find the right place in poverty alleviation programs in Pakistan? Should the energy type be included as an indicator in evaluating and reporting wellness/poverty/HDI and be incorporated in the development programs?

Historically, there exists a strong linkage of primary energy sources and the energy conversion industry with the state of affluence/poverty [171,173,179,187]. Based on the importance of energy in human development, energy found a central place in seventeen SDGs adopted by the UN in 2015 [201–203]. Energy access and poverty interdependence is well documented, and the importance of adequate energy had been identified earlier too: in the production of goods and supplies, in comfortable housing, for the provision of essential services such as health support and education, and even for the consumption of food [170,175,193,210–220].

During the last four decades, a few researchers concluded that energy-poor nations would experience a steep rise in human development relative to energy consumption [167,169]. In our study, we see a reasonably strong negative correlation of firewood with average PCI at the district level (Figure 4.14), pointing to the fact that increased use of poor-quality/inconvenient, low-density fuel contributes towards reduced income. Conversely, electric connectivity–PCI statistics indicate a positive correlation (Figure 4.15), meaning thereby, that increased availability of clean and convenient energy would lead to better income. These findings closely mimic the energy–development relationship established through the earlier studies indicating the existence of the energy–poverty (affluence) nexus even at the district level in a developing country, specifically Pakistan [167,169]. Thus, these graphs further validate the model arrived at through this research.

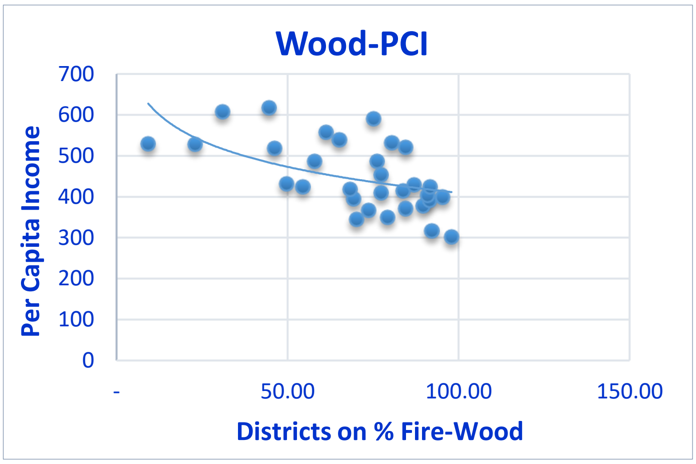

Figure 4.14 Negative impact of firewood on PCI at district level.

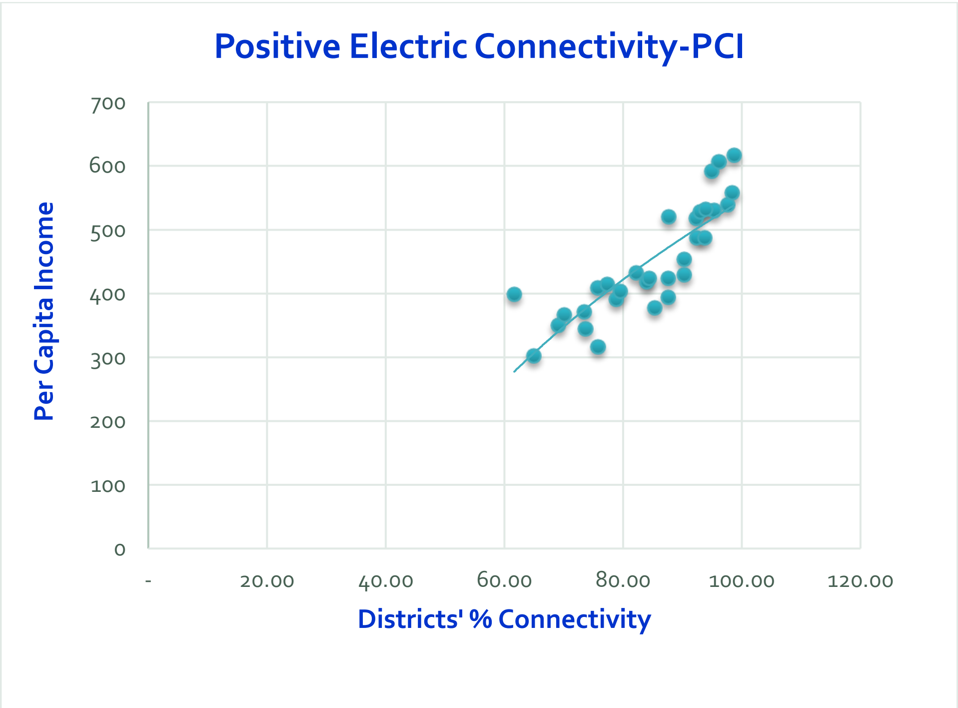

Figure 4.15 Positive electricity–PCI correlation at the district level.

The internationally accepted indicators of human development and state of wellness such as the human development index (HDI) and multi-dimensional poverty indicator (MPI) are mostly in use for measuring affluence and deprivation. Among these, HDI does not include energy as a component of human development [170], and household energy merely appears as a small fraction in MPI calculations [177-178]. The key statistic on the energy–poverty nexus brought forward through this work has shown a clear linkage of energy in measuring socioeconomic wellness in terms of PCI. Further, these statistical analyses corroborate some of the established and already in-use socioeconomic relationships such as the quality of dwelling and poverty, the households' facilities and economic well-being, and the education levels and economic growth of the household [166,176,188,190-191,210-211].

Lack of adequate energy access has multi-faceted impacts on the social welfare of affected families in the form of poor health conditions, drained productive time, decreased chances of value addition through quality learning, diminished productivity, and limiting the wherewithal for income generation, thereby retarding overall development [100,207,213,215]. Similarly, continuous burning of wood for cooking has serious implications for the user, the society, and the world and is not at all sustainable [206,207,215]. In developing countries, mostly women and children are constrained to collect and bring the biofuels such as wood, straw, and animal dung in the energy-constrained households [205–207,211,214]. Such activities take the precious time of women and children, respectively, away from income-generating activities and schooling [205–207,216-217]. Lack of access to adequate energy resources is also partly responsible for child-labor practices in Pakistan [217]. Additionally, the lack of clean energy sources is also the cause of the ill effects of indoor pollution, leading to 1.6 million yearly premature deaths, respiratory illnesses, eye diseases, and low-weight births [218-219]. Further, our planet, and particularly Pakistan, can ill afford the deforestation caused by firewood with serious environmental degradation and global warming impacts [185,205-206].

Millennium Development Goals (MDGs) adopted in the year 2000 were succeeded by Sustainable Development Goals (SDGs), which espoused seventeen goals and established interconnectivity between them [220]. Our statistical results and the ensuing discussion showed how most SDGs are directly correlated with SDG7, "Affordable and Clean Energy". The attainment of SDG1, poverty eradication, is not possible unless everyone has access to "affordable" clean energy. The ill effects of unclean cooking fuels are a denial of SDG3, human health. The obligation to run for pollution-heavy biomass takes children away from the critical SDG4, quality education. The data presented above, and related analysis indicate a strong electricity–education correlation of 72% (Table 4.5). Provision of clean water (SDG6) too has 48% dependence on electricity as per these data. The employment opportunities (SDG8) are also strongly correlated with electric connectivity (63%). Conversely, the unclean and inconvenient firewood that has adverse environmental impacts too (atmospheric degradation, deforestation, and increased carbon footprint) has a negative correlation with all these wellness parameters, highlighting the significance of affordable clean energy for other SDGs. Other SDGs were not covered during the Population Census 2017; however, SDG11—sustainable communities, SDG13—environmental protection, and SDG14/15—the life on earth are directly linked with the primary energy source types. Similarly, industrial/infrastructure development (SDG9) cannot be imagined without reliable and sufficient energy as its blood line. It is feared the SDGs will be far from achievement in 2030 if the developing economies do not realize and incorporate the provision of sustainable and affordable clean energy in their development plans.

Table 4.5 Impacts of clean and unclean energy on four SDGs.

	Correlation Coefficient/Statistic			
Energy Source	**Education**	**Employment**	**Pakka Household**	**Water Accessibility**
Electricity-Lighting	0.72	0.63	0.73	0.48
Wood-Cooking	−0.42	−0.23	−0.30	−0.25

The developed world and a few developing countries embraced the technological advancements and adopted policies for self-reliance in energy and for socioeconomic progress. In Pakistan, instead, the share of imported energy increased as reported by International Energy Agency, and it is no surprise that as of 2017, Pakistan's HDI was the lowest in South Asia, after Yemen, Afghanistan, and Syria: three war-ravaged countries [214]. In per-capita energy consumption, Pakistan stood at 140th as per the latest available World Bank report [209]. Pakistan's indicators on the productive use of energy as reported by the IEA are: Pakistan used 0.43 toe per 2005′s one thousand USD of GDP as against Bangladesh where 0.23 toe was consumed for the same outcome [221]. This elucidates the need for planning beyond energy supply and the importance of the productive use of energy in driving the economies towards poverty eradication.

Energy did appear as one of the nine pillars of development and poverty reduction in Pakistan's agenda too during 2012, but it did not find any resources allocated for itself in the poverty-reduction plan [222]. On the energy side, focus has been on increasing energy supply and power generation similar to most developing countries [223]. Additionally, poverty alleviation programs never incorporated energy as a poverty-reduction goal either. In the 3rd quarter of 2019, Pakistan's electric power generation surpassed the demand by many thousand megawatts, and the government was looking for "plans to utilize the surplus energy" [223]. Conversely, a repeated raise in electric tariffs is poised to reduce electricity demand further [224]. Unconsumed surplus power generation, extremely lopsided power purchase agreements with independent power producers (IPPs), continuously rising circular debt, decreasing electricity demand owing to price escalation, heavy financial drain in subsidies, and heavily import-dependent power plants highlight the need for comprehensive outlook towards energy planning, its management, and governance in Pakistan. Not incorporating energy in poverty alleviation programs is likely to remain a major contributor to unachieved poverty alleviation and socioeconomic development goals.

Our findings validate the fact that households' fuel choices are dependent upon the socioeconomic conditions of the population [214,225-226]. This study does not assume a causal relationship between energy (and other explanatory variables) and the PCI except for the fact that life needs are met with physical and other resources, including energy. In line with the experts' opinion, there is also strong statistical evidence of the fact that the districts with more households using unclean and inconvenient source(s) of energy have much lower per-capita income [166,212,215]. Another critical dimension of energy usage is the outcome: whether it adds to the financial burden or is a resource for improving economic well-being [180,212,215]. The energy–income correlation shows a two-way interaction between energy and socioeconomic wellness, i.e., the energy is the means as well as the end [180,215]. Sustainable programs for poverty eradication and socioeconomic development through clean and affordable energy can be constituted based on relevant data only. The input data must cover all aspects of two-way interaction between energy and poverty so as to enable policy formulation and establishment of sustainable programs for poverty alleviation and development [225-226].

Data-driven inferences are dependent critically on the processes of data collection and subsequently on the quality of the collected data. Additionally, no inference is valid unless mediated through local sociocultural environment. Based on the knowledge gained through the literature review and the sociocultural dynamics of Pakistan, certain limitations pertaining to available data used in this study are highlighted. The Census 2017 was a population survey and not an energy-related survey, although it captured predominant energy used in each household. The Census 2017 thus provides, among other variables, information on the number of households using different type of energy for cooking and for lighting. However, information on the use of electricity for lighting is based on connectivity and does not cover reliability, quality, and affordability aspects of electrical energy. While according to the IEA's/IRENA's "The Energy Progress Report 2019" [203], Pakistan has the 4th largest unserved population, with another 144 million confronting reliability problems owing to frequent power outages. Data on the amount of energy consumed and the proportion of household income spent on energy are also not available. Households in Pakistan, similar to other developing countries, are constrained to use multiple sources of energy instead of relying on one, owing to inaccessibility to clean/high-density energy or unreliability of primary energy source [185,205,219]. Although the use of mixed fuels phenomenon remains unevaluated, the data used in this study cover the entire population of Pakistan, which may not be possible while conducting a customized survey. Thus, despite few limitations, the outcome of this study opens new avenues for taking a fresh look at the energy and its impacts on the poverty in Pakistan.

4.7 Epilogue

This chapter is a preliminary attempt to examine quantitatively the energy–poverty interplay in Pakistan with a possible extension to other developing countries. The study is unique, as it utilized detailed real data for Pakistan never used in any study thus far. The proposed regression model highlights the energy–PCI statistical correlation and energy's impact on aggregated household PCI. Since the study uses the final energy (wood and electricity) available to the households as two of the explanatory variables, it may be compared and contrasted with total energy input to the society in a country—a phenomenon used in earlier studies for exploring energy linkage with wellness. In addition to the education levels (a typical matrix linked to poverty) and other economic wellness indicators, the proposed model highlights a close connection between energy and poverty, thereby augmenting the education-only model and suggesting it as one of the reliable factors to predict PCI. The model provides quantitative evidence on how a lack and/or availability of clean energy sources affects earning abilities and the income aggregated at the district level in Pakistan.

The critical energy-poverty nexus established through this work should help in better understanding the sustainability requirements and provide suitable guidelines for data collection and dissemination, as the availability of reliable data is critical in data-driven planning and implementation. This preliminary work may provide impetus to, 1) the customized/focused data collection to fully explore the energy–poverty nexus in Pakistan; 2) creating synergy in energy planning and poverty alleviation programs, i.e., poverty mitigation through the adoption of clean and convenient renewable energy options; 3) drawing the researchers' and policy makers' attention to consider energy as an important contributory factor in human development and incorporate it as a parameter in calculating HDI; 4) invoke researchers' interest in further investigation into energy–poverty interplay in Pakistan and further studies comparing socioeconomic well-being between the communities with access to clean energy and those utilizing low-density unclean energy sources.

CHAPTER 5

CITIZENS' INVOLVEMENT IN SUSTAINABLE ENERGY TRANSITIONS

5.1 Prelude

With substantial decrease in the cost of renewable energy technologies (RETs), governments around the world stepped up efforts to transform the ways energy is produced, and the manners it is consumed. Focusing on attainment of SDG-7 through clean energy transition, the aim has been to achieve energy security as well as energy equity while reducing dependence on energy imports. Although ongoing technological breakthroughs and maturity offers promising opportunities, many developing nations have been grappling with intertwined socioeconomic dynamics and policy prioritization. Under the resource-constrained financial situation, Government of Pakistan adopted prosumers' approach to harness year-round available solar energy. Regulatory measures were accordingly instituted, and the electricity distribution companies (DISCOs) were instructed to facilitate people in becoming prosumers. The adoption rates were, however, well short of the desired outcomes. Besides cultural and socioeconomic dynamics, human interaction with technology, and their level of awareness about related policy parameters play a critical role in the technology adoption. In part, this realization led Institute of Policy Studies (IPS) Pakistan to conduct a survey on the consumers' willingness for taking up the prosumers' role and, on the parameters contributing to their decision e.g., economic conditions, energy quality and reliability, relevant government policies, and their level of awareness about going solar. Utilizing data from the IPS survey, this study explored the linkage between consumers' inclination to install solar energy systems and their awareness about solar photovoltaics (PV) technology, the cost factor and relevant government policies. The study revealed significant correlation between target populace's awareness level and their willingness to become prosumers, highlighting the need for taking policy measures to enhance public awareness on relevant aspects of roof-top solar (RTS) for their due contribution towards sustainable energy solutions in Pakistan.

5.2 Theoretical Background

Access to sustainable and reliable energy is one key prerequisite for socioeconomic well-being of a country[166–172]. This realization provided impetus to inclusion of energy as sustainable development goal (SDG)-7 in the United Nations' 2030 Agenda for Sustainable Development [201]. Research further highlighted the importance of energy and its pivotal role in the attainment of other SDGs [227]. Technological advances in renewable energy technologies (RETs), in particular solar photovoltaics (PV) technology, and their declining cost offered promising prospects for reliable, clean and affordable energy access [227–229]. The transition to sustainable energy options however demands strong policy support with result-oriented strategies leading to desired objectives [230–233]. Several countries initiated outcome-based processes, enacted rules/ regulations and offered incentives to embrace RETs. The successful initiatives show simultaneous measures at individual, community, and national levels[248]. Early success or niche hurdles did not hold them from further research in the development and promotion of RETs [230,234], a measure that maintained the momentum in RETs' adoption.

Rapid development, fast declining cost, and key success in solar PV technology presented the domestic and commercial (building based) consumers as important power (electric) generation partners. The hardware portability with maintainability and abundant solar potential worldwide made solar PV a good choice for the distributed generation as well as off grid energy solutions. The households with their open sky rooftops appeared as an ideal option for capturing maximum solar irradiance. However the residents' willingness in adoption of solar PV as roof top solar (RTS) appeared critical in order to reap the real benefit from this promising opportunity [233–236]. Cognizance of this fact diverted the leading countries' attention to the role the end-users could play in promoting the conveniently available and sustainable RTS. The role of awareness in transitioning to new initiatives in terms of people's attitudes and behaviour towards adopting RETs has been critical [233–236, 149, 237-238, 239-243]. With reference to sustainable energy options, awareness implies individuals' knowledge about and perceptions of the technological and socioeconomic aspects of RETs/RTS and the related governmental policies [236,238]. Numerous studies have established that powerful public support is essential for transitioning from traditional fossil fuel energy systems to renewable energy technologies. In 2014 Sunil Luthra et.al. found critical role of people's awareness, behavior, and their level of information in their willingness for solar energy adoption in India based on

Analytical Hierarchy Process (AHP) analysis of experts' opinions [150]. In 2020 Angel Echevarria et.al. argued based on their case study of Puerto Rico that public imaginations play a central role in not only achieving energy equity and energy justice in the society but are also central to value creation from deployment of renewable energy technologies [151].

Pakistan has over 95% of its territory suitable for generating 1400 to 2000 kWh/kWp/year of solar electricity, one of the highest in the world [244]. Household share of electrical energy consumption accounts for close to 50% (49.1 percent) of the total electricity demand in Pakistan. Autonomous energy production at the households' level can therefore greatly contribute to reducing energy-poverty, cut the energy import bill and lead to overall poverty reduction in the society. Realization of the domestic consumers' role as prosumers in reducing the burden of energy supply from capacity-limited public utilities led to enactment of net metering regulations in Pakistan in 2015/16 [245]. However the measures taken to adopt RTS at household level remained disappointingly short of the expected and desired results, with just around eight thousand (8,000) prosumers out of about 30 million grid-connected consumers from 2016 to 2020 [246]. Despite the policy and the regulatory measures, the outcome indicates RTS have been almost ignored in there [246-247]. To understand the underlying dynamics, the Institute of Policy Studies (IPS) initiated the study into the "Barriers and Drivers of Solar Prosumage", highlighting various factors meriting attention for promoting household solar PV. Although, IPS study mentioned contribution of consumers' motivation towards adoption of RTS but level of awareness about RTS related parameters was considered satisfactory [246].

While looking into the factors that could be critical in changing the people's attitudes and improving the adoption of RTS, most studies found awareness as an important element, thereby establishing critical role of awareness in sustainable energy transitions [236, 242, 248–256]. We find Yash Chawla and Anna Kowalska-Pyzalska finding strong impact of awareness on adoption of smart meters in Poland [242]. Oksan Bayulgen inferred that awareness can play a key role in clean energy transitions and that can be better raised through/by the local govts [230]. Binod Prasad Koirala in Ireland found out that awareness about the clean energy initiatives was one of the important factors in the success [233]. In 2011, Leenheer et al. identified technology affinity as one of the important drivers for Dutch households to adopt the prosumer's role and linked it to the awareness measures [255]. While in 2014 Korcaj et al. found autarky benefits as one of the contributory elements in promoting prosumerism, linking them to awareness efforts [256]. In Germany, Maximilian Engelken concluded that tailored information strategies could greatly change the homeowners' attitudes in adopting and promoting RETs [235]. In Saudi Arabia, awareness was found affecting people willingness to adopt RETs [243, 257]. Yu-Chung Taso et.al concluded in their study that governments need to communicate information to people in order to promote smart metering and exhibit responsible behaviours [242]. Similarly, several studies in India during the last decade, explored the effective role of awareness in the success of sustainable energy initiatives [237, 258–261].

This chapter is the first preliminary attempt at evaluating the role of awareness in solar energy adoption in Pakistan, utilizing data collected by IPS. Although, IPS survey did not cover many aspects of awareness, the participants' response to three primary solar PV related questions and their willingness to adopt RTS (RTS Considered -Yes) are statistically examined to understand the impact of awareness of primary solar related parameters on achieving meaningful adoption rate of RTS. To that end this chapter is organized as follows: Section 4.2 introduces the research context, Section 4.3 explains the motivation leading to this research, Section 4.4 covers the data and methods, Section 4.5 gives preliminary findings and discussion, and Section 4.6 sums up the conclusion and recommendations.

5.3 Motivation

Thermal power constituted close to 60% of Pakistan's electric supply during July 2020 to April 2021 [262]. Thus, hypothetically, given that entire commercial and non-commercial electricity demand (which stood at 56.5% of the total during this period) is met with RTS, Pakistan could meet possibly almost her entire electrical energy demand domestically. In Pakistan, even the Alternative Renewable Energy (ARE) Policy 2019 did not recognize RTS as an important contributor in the achievement of the targets of 20% RETs' share by 2025 and 30% by 2030 [247, 163]. Pakistan is faced with one of the worst energy crisis in its history when viewed in the light of its heavy dependence on energy import, power sector losses, circular debt, capacity payments, addition of coal-fired power plants with adverse environmental impacts and very small share of ARE in its energy portfolio [263]. This scenario has drawn the attention of all stake-holders like the concerned govt departments, semi-govt research institutes, private think tanks and the academia to look into avenues that can help Pakistan come out of this unsustainable situation [264–266]. In line with that effort, this work is the first attempt looking into the effect of awareness in moving the households from consumers to prosumers, viewing RTS as a promising contributor towards energy security, energy autonomy and energy sustainability. The awareness in this manuscript is described in terms of 1) Information on the solar PV technology (ISPVT), 2) Information on Installation cost of the solar system (IICSS), and 3) Information on Net-metering (INM).

5.4 Methods

A. ***Participants*:** The data for this study is drawn from an anonymized survey conducted by IPS Pakistan, which recorded a number of parameters linked with and/or contributing towards solar energy adoption by the households. Survey participants included students, employed, self-employed, retired, unemployed, and homemakers, aged 18 years and above, spread across Pakistan, mix of rented/owned houses, and comprising mostly the lower, the lower middle, the middle and the upper middle-income groups. This being an online survey, most participants were college/university graduates (over 86%) with access to and understanding of the internet.

B. ***Data Collection and Preparation***: As stated earlier, the data for this study has been drawn from the online survey conducted by IPS, an independent think tank in Pakistan. IPS had conducted separate surveys for prosumer and non-prosumer categories. The non-prosumers' questionnaire aimed at recording influential parameters (economic conditions, energy reliability, government policies, awareness about technology and cost of going solar etc.) affecting consumers' willingness for taking up the prosumers' role. Although the survey data is wide-ranging, the present study considered only the awareness aspects of consumers' decision to RTS adoption. The awareness (or level of information) aspect is covered under three different headings in the survey, namely: Information on the solar PV technology (ISPVT, now coded X_1), Information on Installation cost of the solar system (IICSS, now coded X_2), and Information on Net-metering (INM, now coded X_3), and the response variable is "Whether Solar System Considered–No/Yes". This is coded as RTS-No/Yes, to avoid confusion with the educational level SSC. A total of 578 consumers responded to the survey. After removing 43 missing data points, the remaining 535 participants' response was used in this study.

The education level (Ed) of participants was coded as: 1 – Primary (Elementary), 2 – SSC/HSSC (Higher and/or Secondary School Certificate), 3 – UG (Under-graduation), and 4 – PG (Postgraduation). The information (Info) level for all three awareness parameters (ISPVT, IICSS and INM) was coded as: 1 – No Info, 2 – Somewhat Informed, 3 – Informed, and 4 – Well Informed. The response variable RTS is coded as: 1 – Not considered (No), and 2 – Considered (Yes). Therefore, the predictor multinomial data matrix 'X' has 535 rows and 4 columns, and the binomial Y column vector is of 535 length.

C. **Data Analysis**

a) ***Education Levels vs. RTS Consideration***: Tabulated in Table 5.1 are the number of participants with their education (Ed) level who responded with RTS-Yes. The majority of the respondents are either in postgraduate (PG, N=277) or undergraduate (UG, N=196) category. It is evident from Table 5.1 that there is no obvious pattern with respect to respondents' education level of the total 277 (51.78%) who responded with 'RTS-Yes'.

Table 5.1: Education Level and Willingness for RTS

Education Level (Ed)	Count	RTS-Yes	
		Count	%
Primary	5	2	40%
SSC/HSSC	57	34	59.65%
UG	196	85	43.37%
PG	277	156	56.32%
Total	535	277	51.78%

The data (X and Y) were analyzed using Multinomial Logistic Regression function 'mnrfit' in Matlab. The model for relative probability between RTS-No vs. RTS-Yes is the ratio of the two probabilities, which can be simplified to obtain either the probability of RTS-No or RTS-Yes.

$$\text{Prob(RTS-Yes)}=\frac{1}{1+e^{\beta_0+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3+\beta_4 X_4}} \qquad (5.1)$$

Where, $\beta_i, i = 0,1,2,3,4$ are the regression coefficients, and $X_i, i = 1,2,3,4$ are the predictors Ed, ISPVT, IICSS and INM, respectively.

Salient results from the above model are tabulated in Table 5.2 and shown in Figure 5.1. The p-Value for education level (Ed) is 0.1157, which indicates Ed is not significant in deciding on RTS-Yes or No, i.e., willingness for adopting RTS is almost equally dependent on the info level among participants of all education levels. The same is evident in Figure 5.1 too.

Table 5.2: Probabilities for RTS-Yes and regression coefficient values

Info/Ed	**Probability (RTS-Yes), p-Value = 0.1157**			
	Primary	**SSC/HSSC**	**UG**	**PG**
1- No Information	0.1779	0.2134	0.2538	0.2989
2- Somewhat Informed	0.3115	0.3619	0.4155	0.4712
3- Informed	0.4861	0.5424	0.5978	0.6507
4- Well Informed	0.6641	0.7125	0.7565	0.7957
$\beta_i, i = 0,1,2,3,4$	2.4938, -0.2260, -0.3580, -0.6779, 0.2986			

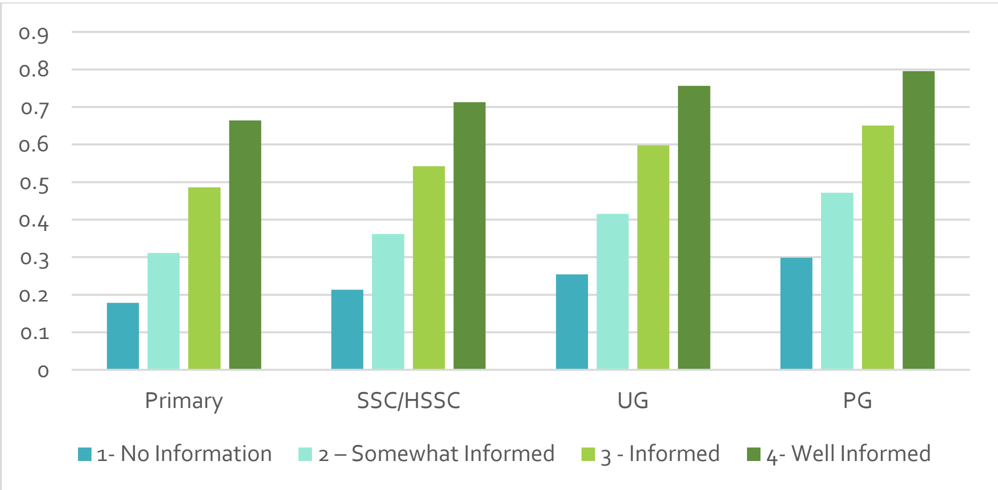

Figure 5.1: Probability of considering Solar System, given Education Level

b) ***Awareness Level vs. RTS Consideration***: Given the non-significant impact of Ed, this factor was removed. For the remaining three predictor variables (ISPVT-X_1, IICSS-X_2, INM-X_3), the probability of the participants' willingness for RTS-Yes is given as:

$$\text{Prob(RTS-Yes)}=\frac{1}{1+e^{\beta_0+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3}} \quad (5.2)$$

Where, $\beta_i, i=0,1,2,3$ are the regression coefficients, and $X_i, i=1,2,3$ are the predictors ISPVT, IICSS and INM, respectively.

The resulting outcomes of the model are tabulated in Table 4.3 and depicted pictorially in Figure 5.2. The results are significant at p-Value less than 0.05.

Table 5.3: Probabilities for RTS-Yes and regression coefficient values.

Info	Probability (RTS-Yes)			
	ISPVT-X_1	IICSS-X_2	INM-X_3	All three (X_1, X_2, X_3)
1- No Info	0.3220	0.3121	0.4777	0.2781
2- Somewhat Informed	0.4603	0.4856	0.5240	0.4430
3- Informed	0.6050	0.6627	0.5700	0.6214
4- Well Informed	0.7333	0.8035	0.6147	0.7721
$\beta_i, i=0,1,2,3$	1.3298**, -0.5854**	1.5235**, -0.7333**	0.2749, -0.1855*	1.6787**, -0.3432**, -0.6634**, 0.2818*

(Note, ** = pValue < 0.01, and * = 0.01< pValue < 0.05.)

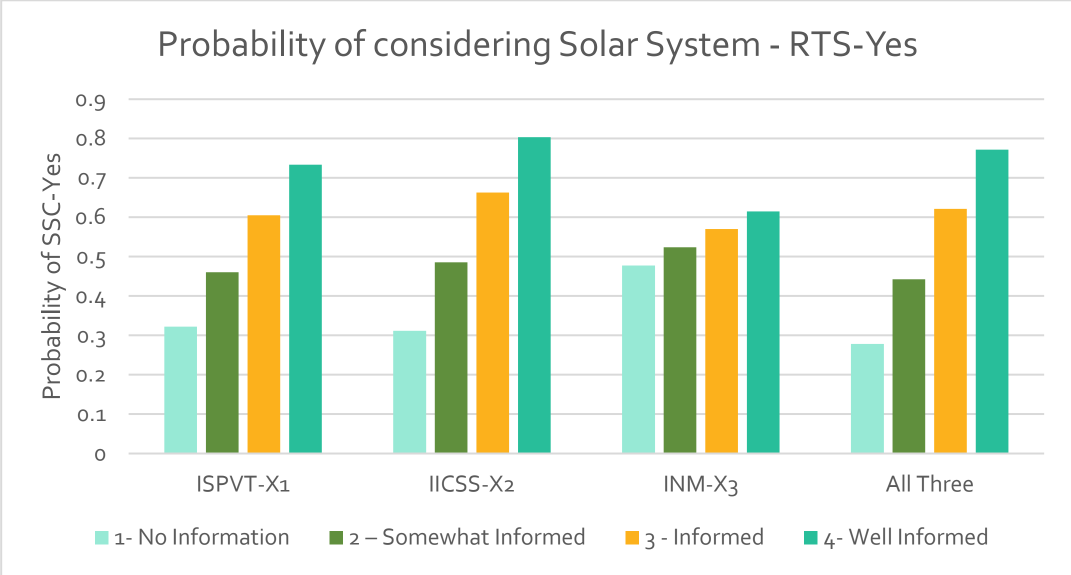

Figure 5.2: Probability of considering solar system vs. availability of info/ awareness

c) ***Education Level vs. Awareness Level*****:** Shown in Table 5.4 are the percentages of Informed and Well-informed UG and PG survey participants. It is evident that necessary information about the basic parameters related to installation of solar PV systems and net metering does not reach even 50% of the college and university graduates in Pakistan. Figure 5.3 pictorially depicts the state of college/ university graduates' info level.

Table 5.4: %age of College & University Grads vs. their Info Level

Education	Solar PV	Cost of Solar System	Net Metering
UG	49%	40%	25%
PG	49%	37%	33%

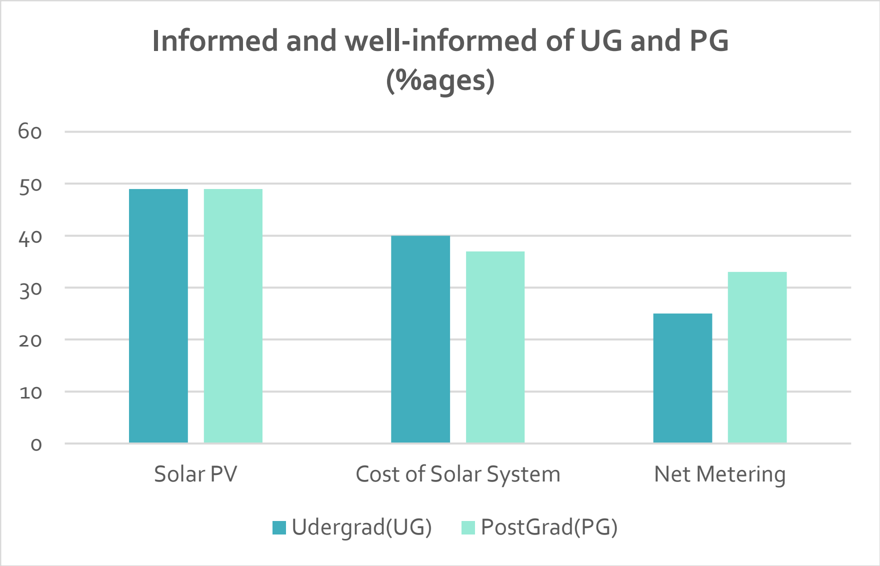

Figure 5.3: Informed and well-informed %ages of UG and PG

5.5 Findings and Inferences

Technology-led transitions bring about changes in institutional, economic, political, and sociocultural landscapes and demand policy support with regulatory mechanisms to take root. Rightly called the socio-technical transition, adoption of RETs/ RTS too has to progress on the shoulders of all stakeholders who must be correctly identified and fully involved for the ultimate success. Success stories in RETs adoption convey only one lesson: Transition to just, equitable, and inclusive energy solutions is only possible with whole-hearted involvement of the citizens and the community.

Awareness has significant behavioral implications at individual as well as community level that need to be understood. Changing life-long dogmas and affecting deep-rooted perceptions demands strong engagement of all stake holders. Focused efforts may necessitate dedicated campaigns involving local volunteers, prayer leaders, community leaders, and academia. Clear understanding of the real consequences of delayed response to the call of the time and the long-term benefits of RTS adoption for the household as well as for the country is sure to invoke interest as well as participation.

The outcome of IPS survey exposed a bitter truth: public awareness about solar PV technology and its socioeconomic benefits has hardly been considered a parameter in accelerating the diffusion of RTS technology in Pakistani households. The statistical correlation between the consumers' information level about three RTS related parameters (solar PV technology, cost of solar system and net metering) and their willingness to adopt RTS confirms the primary literature findings on the subject, i.e., the awareness level, in Pakistan too, has a direct influence on individuals' perception about and response to the energy transition and, their decision to consider RTS. Knowing how a technology will improve their quality of life with fewer changes in the lifestyle and negligible long term financial burden, can greatly support the proliferation of solar PV technology. Sifting through the literature we find countries extending subsidies for rooftop solar PV systems as early as 1990s (Germany) and 2004 (Japan) followed by Italy, Spain, the United States, China and India by 2010 [267-268].

Evaluation of IPS dataset to see the effect of participants' education on their willingness for RTS' adoption revealed no linkage between the two. However, the majority participants' education data exhibited few important features. With more than 86% survey participants being college/university graduates (UG/PG qualified persons), the data do not proportionately cover majority segment of Pakistani society. Additionally, poor awareness levels even among the highly qualified class in Pakistan suggests that the vast majority being lesser educated will have much poorer awareness about the advantages and benefits of RTS systems. Combining the information level and the willingness correlation with this assumption, awareness appears an important contributor to the poor adoption rates of RTS in Pakistan. In part, poor awareness reflects that information campaign, if any, has failed to attract consumers' interest to participate in the (energy) transition process.

IPS survey recorded only few awareness parameters, whereas the target population needs awareness covering all aspects of the RTS based socio-technical transition demanding their participation in, including but not limited to, 1) the PV technology, 2) governmental policies, 3) related regulations, 4) economic benefits, 5) job creation, 6), environmental benefits 7) available incentives, and 8) financial support mechanisms. Tailored survey questions covering all such aspects could lead to more realistic results about the impact of awareness on the participants' decision to become prosumers. Also, as the literature under review revealed, one particular type of questionnaire may not appropriately fit with the socioeconomic background of all segments of the society and pilot studies may be needed to design and develop separate surveys for different communities/ regions.

5.6 Epilogue

With promising prospects offered by solar PV technology, RTS has an important role in energy security with direct impact on the socioeconomic well-being of the households. This study established statistically significant correlation between target populace's awareness and their willingness to become prosumers. Future surveys and studies must cover all dimensions of solar PV/ RTS technology in the light of literature review on the subject. Notwithstanding the direct benefits of RTS systems, the indirect advantages of solar PV technology in the form of extended energy access, less air pollution, decreased GHGs, better climatic conditions, reduced health hazards, and improved energy security – all demand focused attention of the concerned government departments in fast proliferation of RTS to every household in Pakistan.

There is a need for re-evaluation of policies concerning adoption and promotion of RTS in Pakistan, with planning and resource allocation for tailored information sharing campaigns. The policy review merits reconciliation of the type and kind of information needed to change people's perceptions and attitudes about the RTS, as well. Further, policies may also be reviewed for identification and use of means and measures for result-oriented awareness, invoking prospective prosumers' proactive participation in adopting and promoting the RTS systems. Future work may cover suitable qualitative and quantitative survey elements to contribute new insights into the global literature on awareness of RTS and its relation to adoption in Pakistan.

CHAPTER 6

DISCUSSION

6.1 The Precursors

Literature on energy and development exhibits strong evidence on the correlation between electricity access and economic development as well as positive impacts of household based solar PV systems on the socioeconomic well-being. Additionally, research on the interaction between seventeen SDGs suggests there is a role of SDG-7 – sustainable energy for all – in achieving most SDGs and in many ways progress towards universal energy access is affected by the steps in the direction of other SDGs. Universal energy access is seen to have pronounced impact on the socioeconomic wellness of the populace. The achievement of 2030 Agenda for Sustainable Development demands attention on multifarious life-needs including but not limited to *energy*, *economy* and *environment* leading to *sustainability* in the society – the three aspects being explored in this dissertation.

6.2 Households and the Society

Living standards enjoyed by households indicate the quality of life in a society. Representing the lowest tier social component, households are the right choice for addressing the economic and energy poverty at grassroot level. The robust correlation between household energy and the income presented in Chapter 4 predicts the prospects of simultaneous solutions addressing energy poverty and economic deprivation. The impact of awareness on proliferation of solar PV technology discussed in Chapter 5 offers guidance on some practicable measures to accelerate the pace of RTS adoption. Thus, the two important aspects related to household energy scenarios highlighted in this dissertation are: establishing a strong association between household energy type and the people's socioeconomic conditions and highlighting the significance of information and awareness towards changing people's behavior and attitudes in accepting and adopting newer renewable, clean energy technologies like solar PV systems. Thus, this research effort explores and suggests workable measures on achieving sustainability in meeting the critical energy and economic needs through the involvement of common people.

6.3 Implications of Households' Energy Access

The penalty that the households with energy shortage and with low-density, poor-quality energy pay in terms of lost opportunities of better-quality life and higher education, merits urgent attention, identification, and suitable measures to remedy the situation. Provision of high quality, reliable domestic energy offers multifarious prospects for sustained socioeconomic development through improved health conditions, better education opportunities and learning environment for children, availability of time for relaxation, recoupment of energy and removal of drudgery – all leading to increased productivity and new opportunities for home-based businesses and cottage industries. Household energy also has a direct bearing on the economic well-being of the common populace. With clarity on this important aspect of energy access, the institutions can better focus on the attainment of the SE4All objectives and formulate customized awareness strategies for educating and persuading citizens to change their role from consumers – causing energy drain – to prosumers – contributing and benefitting from the production of energy. Energy innovations to benefit from abundant advancements in the renewable energy technologies are too scarce, especially in the developing countries. Energy technologists are not failing, and energy scientists are in pace with the need of the time – social scientists creeping behind need to catch up and catch up fast.

6.4 Correlation between Household Energy and Wellness

In line with Sovacool's hypothesis that 'key components of energy poverty are directly linked to economic deprivation and energy–poverty relationship can be better understood by untangling economic and technological aspects of energy poverty' [20], Chapter 4 provides evidence in favor of better income opportunities provided household energy access is improved. Chapter 4 also lays down the statistical foundation underpinning the correlation between household's energy services and socioeconomic wellness, opening venues to further explore the impacts of improved energy services on reducing economic poverty. It highlights the implications of poor-quality energy (lighting and cooking) versus the poverty trap. The woes of unreliable energy supply and electric breakdowns are well known to Pakistani citizens. This energy-cum-economic deprivation adversely impacts people's ability to think progressively for individual and societal development beyond the boundaries of limited economic prospects. This, coupled with ever worsening availability and resulting volatile fossil fuel prices, and the need for cutting down greenhouse gas emissions demand out-of-box thinking and solutions.

6.5 Sustainability Aspects

By now, it is well understood that renewable energy sources offer the potential to meet all global energy needs, with far lower carbon footprints. Countries world over have been identified possessing a mix of different renewable energy sources. Renewable energy is the fastest growing energy source as depicted in the 'International Energy Outlook (2021), with a predominant contribution from solar PV systems followed by wind [269]. Pakistan too has been blessed with enormous renewable and clean energy potential in the form of year-round sunshine and several wind corridors, besides hydro, biomass and geothermal sources. Pakistan's solar irradiance potential makes solar PV an ideal candidate as the main contributor to its sustainable energy future and, as the main source to its energy mix.

World Bank's Policy Research Working Paper on Pakistan in 2018 concluded that provision of electricity to the deprived population could increase its GDP by $113 million per million connections added to its households. This estimate comes to an annual GDP increase of $565 million if based on the conservative figure of 5 million (2016 survey statistics) and $5.7 billion if calculated with 2017 figures of electricity deprived households [138]. It is huge gain for Pakistan's struggling economy – that doesn't deserve to be ignored. As per the world bank, Pakistan's entire energy demand can be met by solar system technologies covering 0.071 percent of the country's entire area. Despite this massive solar potential coupled with vast wind corridors, Pakistan's installed solar and wind project is merely 4% of the total capacity as of November 2020 [164]. Both these assessments point to one fact that result-yielding measures can not only address the energy woes of the entire nation while meeting the GHGs' NDCs but will also aid fast retirement of international loans. Rapid addition of renewables in the national energy mix has never been as urgent as today in the face of over dependence on energy imports, highly volatile energy prices, soaring trade deficit, the geopolitical pressures, and adverse environmental consequences of fossil fuels.

6.6 Advantages and Disadvantages of Solar Energy

Notwithstanding the main disadvantages of intermittence and higher upfront costs, solar PV technology is characterized by many diverse advantages like free and abundant sunshine, almost year-round availability in most areas of Pakistan, suitability for distributed power generation, off grid utility, mini-grid applicability, coinciding availability with the cooling needs, economic viability, negligible operating costs, low carbon footprint, very low maintenance costs, noiseless power generation, and hardware portability. In household applications as RTS systems, solar PV technology offers added benefits such as no or negligible burden on scarce public resources, long-term cost-effectiveness, no demand for installation space, comparative ease in backup power storage and no interference with daily routines. Lifestyle changes can greatly help overcome solar energy's intermittence problems; the remaining can be handled through a combination of storage devices and alternate energy sources. Customized awareness campaigns on all these aspects can serve as catalyst in drawing the residents' attention towards acceptance and promotion of the RTS systems.

6.7 Invoking Participation

The success stories of faster renewable energy adoption show that keen interest and whole-hearted participation of the citizens made the main difference [188, 270]. With a clear understanding of long-term benefits of solar PV adoption for themselves, for the society, for the environment and for the nation, the 'awareness' can induce incredibly phenomenal pace in proliferating the RTS systems. It signifies that country-specific analysis, regional approach and involvement of the local populace and result-oriented strategies are essentials for promoting RTS adoption in Pakistan. Powerful public support can not only drive evolution in social acceptance of an initiative but also bring revolution in the society, overcoming multi-faceted barriers. Success of niche transitions necessitates alignment of interests and synergy in various sectoral programs and close interactive relationships between and willing involvement of all – public and private – stakeholders. Well chalked out joint programs by energy regulators and development sectors, based on customized research, with effective monitoring mechanisms can ensure the benefits reaching the targeted low-income population. Such a framework in place duly monitored by independent surveillance network for accountability and providing feedback to authorized higher position holders can ensure the attainment of desired results.

6.8 Niche Transitions and Bold Policy Measures

The radical new ideas and disruptive technologies need customized data collection followed by focused and result oriented research to formulate policies that can take roots in the society bringing benefits to all. To-be-considered policy options have to be realistic, yet it must be understood that no major gains can be expected if the policy measures are not radical. The top-down implementation approach dominating the policy formulation in Pakistani bureaucracy – apparently in the wake of traditional/ typical power based governmental structures – has to be abandoned. The bottom-up approach – engaging individuals and communities – is sure to pay rich dividends as seen in case of Chinese government's small hydro power (SHP) policy introduced in late 1970s, that had delivered over 47,000 SHP stations by 2014 [271].

Technology-led transitions bring about changes in institutional, economic, political, and sociocultural landscapes and demand policy support with regulatory mechanisms to take root. Rightly called the socio-technical transition, adoption of RETs/ RTS too has to progress on the shoulders of all stakeholders who must be correctly identified and fully involved for the ultimate success. Success stories in RETs adoption convey only one lesson: Transition to just, equitable, and inclusive energy solutions is only possible with whole-hearted involvement of the citizens and the community.

6.9 Current Scenario and Government's Role

Unfortunately, despite multifarious advantages the renewable energy adoption could not take roots in Pakistan as a matter of choice by the people as seen through the progress in installation of rooftop solar systems by even the affording Pakistani households. Chapter 5 highlights using evidence-based statistical results that the involvement of citizens can accelerate RTS adoption leading to energy equity and energy justice in Pakistan. We need to work more on what and how of the energy futures so that the citizens are intimately involved in renewable energy adoption. In niche transitions the government's role becomes more crucial in encompassing multiple undertakings such as offering financial incentives, educating and informing people, laying down and implementing price and quality control mechanisms, identifying and involving ambassadors of change, and establishing regulatory framework for markets and for finance. The diffusion of renewable energy technologies must be imagined and treated like the physical diffusion process. The confidence in technology among citizens satisfactorily using rooftop solar PV systems for their household needs can encourage them to switch to solar PV technology for most of their energy needs: agriculture, commercial, transportation and industrial etc.

Collaboration between diverse actors is critical to the attainment of SDG-7 alongside other SDGs but the challenge for developing countries is creating synergy between energy policies and other socio-economic development programs. In planning for the energy futures, there is a need to establish inter-disciplinary research mechanisms to ensure a clear understanding of complex interactions between energy, technologies, and sustainable development. The energy innovation research demands true appreciation of how different disciplines interact with each other and how integrated planning can advance achieving all SDGs simultaneously.

6.10 This Dissertation and its Contributions

Long-term development objectives can be achieved through clear understanding, right prioritization, wholesome approach, and effective coordination between different stakeholders. Sustainable energy transitions necessitate that the related institutions and departments realize the complex interactions between equitable energy futures and other SDGs – especially poverty eradication, health support, education, environment protection, and suitable earning opportunities. An endeavour has been made through this research to simultaneously address two important aspects related to sustainable energy transitions in Pakistan – one, the socio-economic dimensions of energy in Pakistani households and second the sociocultural need for creating awareness about the greater dividends of RTS adoption for the households, for the society and for the national economy. It is time the policy makers move beyond firefighting approach and sector-oriented policies and coordinate with their associates in other ministries and divisions to formulate policies, lay down regulatory mechanisms and establish governance structures for the programs that lead to simultaneous attainment of multiple socioeconomic development objectives. It is hypothesized that synergy between energy planning and poverty alleviation programs, as and when achieved, is enough to remove Pakistan's current energy woes and eliminate the abject poverty from its society.

Understanding what hurts the most, or what heals the best, guides us to the right directions and correct priorities. That reminds of the Sun Tzu's principle of winning the battles: Know yourself and know your enemy. Applying this principle to the current energy scenario in Pakistan, knowing ourselves implies clearly understanding the energy crisis Pakistan is confronting, and the energy sources it is abundantly blessed with, and knowing our enemy suggests consciousness of the disastrous economic, environmental, and geopolitical consequences of our dependence on the import of fossil fuels. In today's world a country's sovereignty depends upon the economic freedom and the economic freedom of Pakistan must propel it towards self-reliance in its energy needs. The central idea this dissertation underlines is the need for a clear understanding of the impact that household level RTS-based energy would have on sustainably meeting the energy needs of the lower- and middle-income groups, thereby contributing to poverty alleviation goals and cutting the country's energy import bill.

This dissertation establishes robust linkage and interplay between clean energy and the quality of life at household levels across breadth and width of Pakistan. While the studies referred to in this dissertation provide strong evidence on the importance of energy services and more-so the adoption of renewable energy technologies towards sustainability and social well-being, this dissertation accentuates the same correlation at household level through empirical results from the data disaggregated at district level across Pakistan. This exploration into the nexus between energy and income in Pakistan is first effort of its kind backed with solid statistical results. Viewing through the socioeconomic parameters, it offers reliable evidence on the likelihood of improvement in income if the households' energy access is improved. This research also provides the reasoning whether and how improvements in household energy can bring change at the grassroot level through equitable energy access among the struggling low-income communities in Pakistan. This research is unique in many aspects, in that: 1) it uses the data collected in one year, 2017 and not that spread over decades, 2) the data is aggregated at district level (and not at country or higher level), 3) the data covers districts across all four provinces, 4) it's the energy type being used as exploratory variable and not the amount of energy consumed and 5) it's the household (the lowest tier societal unit) level under study thus representing the energy-economy correlation at grassroot level.

Further, this research has identified some of the measures that can help overcome formidable challenges faced by Pakistan's energy sector. It highlights incentives for innovation and development strategies that may lead to energy equity, energy security and economic independence through sustainable energy transitions. Awareness can transform the way people think, remove the real and imaginary fears, and make the real value of change visible down to the lowest income group in the societies. Awareness has significant behavioral implications at individual as well as community level that need to be understood. Changing life-long dogmas affecting deep-rooted perceptions demands strong engagement of all stake holders. Focused efforts and dedicated campaigns must involve local volunteers, prayer leaders, community leaders, and academia. Clear understanding of the real consequences of delayed response to the call of the time and the long-term benefits of RTS adoption for the households and for the country is sure to invoke interest as well as participation. Beginning with a small number in each community, the information, knowledge, and awareness about RTS can be expanded outwards increasing the adoption rate with every new ‘ambassador of change’. Identification of energy enthusiasts, willing to pay as early adopters, can play a critical role in greater gains and faster results and such like strategy can take the program to farthest segment of society in much shorter period. The need is to widen the public participation in decision making process for resilient and sustainable energy futures. Inclusive participation can be invoked through well deliberated customized awareness campaigns, that may ultimately build consensus among the citizens leading to collective ownership of the energy transition initiatives.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 Conclusions

Households are the basic societal units for measuring socioeconomic well-being in a country. Affluence and/or deprivation at household levels depicts the quality of life in a society. First part of this dissertation highlights the robust correlation between energy and economy at households' level in Pakistan. To this end, chapter 4 of this dissertation has established the linkage between clean energy and the quality of life at household levels through empirical results from the data disaggregated at district level covering all provinces of Pakistan. This is the first ever attempt at exploring the nexus between energy and income in Pakistan that – within its socioeconomic context – provides evidence on the possible improvement in income given the type of household energy. This investigation also provides the reasoning whether and how improvements in household energy can bring change at the grassroot level through equitable energy access among the struggling middle and low-income communities in Pakistan.

The second part of this dissertation identifies a few strategies that may lead to sustainable energy solutions for the households. Chapter 5 of this work has brought out the importance of citizens' involvement in energy transitions through statistical analyses of citizens' inclination for RTS adoption based on their level of awareness about the technology and the associated economic-cum-policy parameters. That outcome has helped identify some of the measures that can greatly reduce energy poverty facing households through RTS proliferation.

Thus, the outcome of this research highlights the fact that though diffusion of solar PV technology in Pakistani households is confronted with multiple challenges, it holds a key to sustainable and equitable energy future for the society. And access to clean dependable energy services can advance the greater objectives of medium to long term socio-economic development alongside the environmental protection. The poverty and energy poverty challenges facing Pakistan are immense but equally extensive is Pakistan's solar energy potential. Bold and radical policy options are necessary to remove the yokes of energy and economic slavery. Multifarious directions and routes are available for a steady pace into adoption of RTS in Pakistan. A few result-oriented measures deduced from this research work are summarized below.

- Custom-designed research through academia with interdisciplinary research mechanisms aimed at: -
    - Accelerating the diffusion of solar energy technologies among different communities across Pakistan,
    - Identifying the routes to synergized planning between various development sectors, and
    - Determining and recommending development programs aimed at attainment of multiple SDGs through SSG-7.
- Clear understanding of energy-poverty nexus i.e., improved energy access can accelerate the pace of poverty alleviation and improved economic conditions can help all segments of the society attain clean and reliable energy access.
- Customised data collection based on local demographic and sociocultural dynamics, separately covering different segments of the society and each income group.
- Formulation and implementation of policies to achieve the critical SDGs through equitable and just energy transitions.
- Implementation of synergized development programs through close coordination between energy regulators and other development sectors with effective monitoring mechanisms.
- Innovative measures to seek supportive involvement of citizens in adoption and proliferation of rooftop solar energy, solar water heating, solar energy cooking and in increased domestic earning opportunities.
- Identification and recruitment of energy enthusiasts and ambassadors of technology to enhance wider public participation in RTS proliferation.
- Strategies and regulatory measures to ensure implementation of policies in letter and spirit.

7.2 Recommendations for Future Research

Based on the knowledge gained during the course of this Ph.D. undertaking, few identified areas meriting exploration are: -

1. Focused research through customized data collection to explore the need of each income-group that may impact the design of policies for successful implementation of rooftop solar PV adoption programs.

2. Exploring causal mechanisms that can affect the outcome of solar PV based poverty alleviation initiatives leading to policies tailored to suit respective regional contexts and socioeconomic cum socio-political peculiarities. 'One Size-Fit all' approach may not yield the desired outcome.

3. Examining the RTS option's potential for meeting all household energy needs that may include cooking, lighting, air circulation, refrigeration, vehicle battery charging etc.

4. Possibility of offsetting solar energy intermittence through a combination of lifestyle changes and energy storage devices.

5. Research design to explore the measures for promoting productive use of household energy through carefully tailored questionnaire.

6. Practicable options for addressing the solar energy's intermittence through other renewable energy sources.

7. Research on comparing the IPP based, community solar power and RTS based options covering pros and cons of each.

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APPENDICES

Appendix 1

31 Districts Randomly Selected for Regression Analysis

Ser	Districts
1.	Abbottabad
2.	Bahawal Nagar
3.	Bannu
4.	Dadu
5.	Dera Ghazi Khan
6.	Gawadar
7.	Ghotki
8.	Gujrat
9.	Hangu
10.	Hyderabad
11.	Kashmor
12.	Khanewal
13.	Kharan
14.	Khushab
15.	Kohat
16.	Lakki Marwat
17.	Larkana
18.	Nankana Sahb
19.	Noshki
20.	Pakpattan
21.	Peshawar
22.	Pishin
23.	Quetta
24.	Rahim Yar Khan
25.	Shaheed Benazir Abad
26.	Sahiwal
27.	Sanghar
28.	Sibi
29.	Tank
30.	Zhob
31.	Ziarat