LONG TERM INTEGRATED (MULTI-AGENT) MODELING OF POWER SECTOR UNDER SUSTAINABLE DEVELOPMENT PATHWAY

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In the name of Allah, the Most Merciful, the Most Beneficent!

Dedicated to my parents

With love and thanks for all they have done to support me throughout my life as well as during the life of this project.

DECLARATION CERTIFICATE

The thesis being submitted for the degree of PhD in the University of the Punjab does not contain any material which has been submitted for the award of PhD degree in any other University and to the best of my knowledge and belief, neither does this thesis contain any material published or written previously by another person, except when due reference is made to the source in the text of the thesis.

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CERTIFICATE OF APPROVAL

It is hereby certified that this thesis is based on the results of modeling work carried out by Ms. Sana Bashir under our supervision. We have personally gone through all the data/results/materials reported in the manuscript and certify their correctness/ authenticity. We further certify that the materials included in this thesis have not been used in part or full in a manuscript already submitted or in the process of submission in partial/complete fulfillment for the award of any other degree from any other institution. Ms. Sana Bashir has fulfilled all conditions established by the University for the submission of this dissertation and we endorse its evaluation for the award of PhD degree through the official procedures of the University.

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ABSTRACT

In the developing world, the energy needs of the household sector have grown manifold due to rapid urbanization and the introduction of affordable technology. However, constraints in the power supply and underutilization of renewable resources, coupled with inefficient fuel use and obsolete technology, have increased the average energy usage cost and emissions. With the aim to combat the current energy crisis and to manage excessive energy consumption in household sector, this study provides long-term integrated energy modeling for sustainability analysis of power sector of Pakistan through 2050. Pakistan was chosen as case study because of the characteristic energy crisis despite its highest electrification rate among developing countries. The data set used in the study represents socioeconomic and environmental conditions of a developing economy that is facing multiple challenges, including rapid urbanization, uncontrolled population growth, technological and financial constraints, capacity issues, energy security, and climate change vulnerability. These challenges account for shaping the future of world energy. The study involved a detailed analysis of existing energy models and uncertainties attached to the energy systems. To address energy security and climate change challenges, long-term energy plans for least cost electricity generation (OPT) and demand management for household sector (DSM) were devised. This includes sustainable policies that represent Nationally Determined Contributions (NDCs), mix of efficient and conventional technology and appliances, and targets for renewable energy. The power supply scenario (SSM) exhibits different energy supply policies with lowest socio-economic and environmental impacts. On the basis of analysis of current and historical policies and energy consumption patterns, macro-economic modeling was carried out for the period 2011-2050, using the Long-range Energy Alternative Planning modeling tool. Results indicate that electricity generation sector is expected to continue posing more global warming than any other sector if the current scenario prevails such that the environmental emissions will quadruple the current global warming potential in 2050. Therefore, the SSM alternatives were further compared to analyze their potential with and without externality cost of environmental emissions. Results of optimization of SSM show that wind, solar and hydel power plants are the most economic options with respect to their fuel inputs whereas residual oil based plants cost very high due to their consumption of expensive imported furnace oil. Though natural gas and coal are locally available, their mining and extraction charges are more costly than renewable resources.

For a holistic decision on the most suitable scenario, a cost benefit analysis of these scenarios was performed in terms of societal perspective. This sustainability evaluation lead to formulation of a least cost electricity generation mix (OPT) for Pakistan which included the supply target of 10% renewable electricity till 2025. Conventional market valuation and benefits transfer approaches were used for economic analysis of demand side policies. It was found that the "efficient water heating" scenario for demand management in household, offers the maximum energy-saving potential (up to 270 M.TOE) whereas "efficient space cooling" is the lowest-cost scenario. To achieve the best-fit mitigation scenario (MIT), targets for renewable energy supply were also incorporated. Findings were weighed against the reference scenario (REF), which reveals a huge GHG reduction under DSM. Moreover, the cost required to implement MIT is estimated to be US $ 3.4 billion/ton of carbon dioxide-equivalent, less than the REF. The resultant policy set features a best-fit sustainable management plan in terms of its energy saving potential, social cost, and environmental impacts. Hence, the findings of this study are extremely important for developing countries, in order to meet their energy related GHG targets, especially NDCs.

–Failing to plan is planning to fail.

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“I don’t expect that everyone who reads this book will be satisfied with anything which I write but I hope that everyone who reads this book will learn something or provoked to think.” –Marjorie Bouillon

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ABBREVIATIONS AND NOTATIONS

$/kW	Dollar per kilowatt-hour
A.O	Addition Order
ADB	Asian Development Bank
AEDB	Alternative Energy Development Board
AHP	Analytic Hierarchy Process
ASEAN	Association of Southeast Asian Nations
BCf	Billion Cubic Feet
C.A	Current Account
CCGOT	Combined Cycle Gas and Oil Thermal Power Plants
CFL	Compact Fluorescent Light
CHASHNUPP	Chashma Nuclear Power Plant
CHP	Combined Heat and Power plants
CO_2	Carbon dioxide
CT	Combustion Turbine
DISCOs	electricity distribution companies
DM	Decision Making
DSM	Demand Side Management Scenario
Eff.	Efficient
EIA	Energy Information Administration
FAHP	Fuzzy Analytic Hierarchy Process
Fig.	Figure
FTL	Fluorescent Tube Light
GDP	Gross Domestic Product
GENCOs	Thermal Electricity Generation Companies
GHGs	Green House Gases
GJ	gigajoule
GLPK	GNU Linear Programming Kit
GNU	GNU's Not Unix
GoP	Government of Pakistan
GWh	gigawatt-hour
GWP	Global Warming Potential
H.H	Household
HDIP	Hydrocarbon Development Institute of Pakistan
IAEA	International Atomic Energy Agency
IB	Incandescent Bulb
IEA	International Energy Agency
IEP	Integrated Energy Planning
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
KANUPP	Karachi Nuclear Power Plant
LCA	Life Cycle Assessment
LEAP	Long-range Energy Alternative Planning
LP	Linear Programming
LPG	Liquefied Petroleum Gas
M.T.CO_2Eq.	Million Tonnes of Carbon Dioxide Equivalent
M.TOE	Million Tonnes of Oil Equivalent
MCA	Multi-Criteria Analysis

MCDA	Multi-Criteria Decision Analysis
MCDA	Multiple Criteria Decision Aid
MCDM	Multi Criteria Decision Making
MESEDES	Multi-Objective, Multi-Area and Multistage Model
MIT	Mitigation Scenario
MoCC	Ministry of Climate Change
MSW	Municipal Solid Waste
MW	megawatt-hour
NDCs	Nationally Determined Contributions
NEPRA	National Electricity and Power Regulatory Authority
NGCC	Natural Gas and Coal Combined Cycle Power Plants
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NTDC	National Transmission and Dispatch Company Limited
O&M	Operation & Maintenance
OPT	Least Cost Electricity Generation Scenario/Optimization
OSeMOSYS	Open Source Energy Modeling System
PAEC	Pakistan Atomic Energy Commission
PEPCO	Pakistan Electric Company
PJ	petajoule
PP	Power plant
PPIB	Private Power Infrastructure Board
PRIME	Preference Ratio in Multi-attribute Evaluation
PV	Photo voltaic
REF	Reference Scenario
RES	Renewable Energy Source
RETs	Renewable Energy Technologies
RPS	Renewable Portfolio Standard
SEI	Stockholm Environment Institute
SSM	Supply Side Management
T&D	Transmission and Distribution
TED	Technology and Environmental Database
TOE	Tonnes of Oil Equivalent
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WAPDA	Water and Power Development Authority
WB	World Bank
WCED	World Commission on Environment and Development
WRI	World Resource Institute

Chapter One

INTRODUCTION

1.1. Background

Energy and electricity are the main driving force of an economy. The per capita energy consumed is directly reflected in the country’s GDP and nation’s prosperity. Excessive trend of urbanization followed by desire for adapting luxurious lifestyle has excessively increased energy demand, especially in household sector.

Such a situation is highly reflective of energy statistics of emerging economies where inadequate measures are taken to meet energy needs of rapidly growing population. Hence these nations, specifically within Asia and Sub-Saharan Africa, are expected to shape the global energy outlook (Bashir *et al.*, 2018).

Notwithstanding, as per global estimates by the World Bank (2018), one billion people still lack access to electricity. Where available, above eighty percent of the power supplied dissipates owing to irrational behavior of the consumer (Hafeez *et al.* 2018). Moreover, 3 billion people do not have access to safe cooking fuels.

Accordingly, less concern of developing countries towards induction of clean energy is directly featured in the overall global environmental quality. The effects of using dirty fuels on indoor air quality have been reported to cause an annual death toll of four million people (WB, 2018).

1.2. State of Energy Sustainability in Pakistan

Likewise Pakistan, the world's sixth largest nation with second fastest urbanization rate in South Asia, is facing significant growth in its energy demand. Besides boasting one of the highest electrification rates among developing countries, 28% population (i.e. 1.65 million people) are deprived of modern energy. Furthermore, access rate to clean cooking fuels and technologies is only 43.32% (WRI, 2017; WB, 2018).

Most recently, the installed power capacity reached to 29,573 MW, whereas electricity generation remained 69,956 GW/h. The chief shares of electricity and natural gas supplies are consumed by the household sector (GoP, 2017a, b, 2018). Yet it remains supply-constrained as a result of multiple reasons which have compromised energy system sustainability. The consequent energy crisis in Pakistan caused prolonged load-shedding that not only affected the economy but also increased average energy usage cost causing social anxiety and violence.

Additionally, a country-wide estimation of green house gases for the period 1994 to 2015 shows that Pakistan's energy sector is also the chief contributor of GHG in Pakistan, emitting 85.8 M.T.CO_2Eq. in 1994 to 185.97 M.T.CO_2Eq. in 2015 (MoCC, 2016). Currently, renewable energy represents only 4% of the overall energy mix of Pakistan whereas energy losses peaked to 18%. These economic, social and environmental impacts demonstrate un-sustainability of existing energy system.

1.3. Need for a Long-term Sustainable Integrated Energy Plan

With increasing socio-environmental consciousness and its connection with economy, the process of energy planning is expected to address all aspects of sustainability i.e. economical, social, environmental and institutional. The consideration of residential sector in the overall energy planning and environmental policies is generally vital for energy sustainability. It is well-recognized that energy efficiency and its saving in household sector can reduce up to an estimated fifteen percent of energy needs (WB, 2018).

Literature review also suggests that sustainable management of energy demand in residential sector can offer highest energy saving. (Ahmad *et al.* 2017; Hafeez *et al.* 2018; Awami, 2008; Chaudhry, 2010; Chaudhry, 2010; El-Fadel *et al.* 2001; Ghanadan and Koomey, 2005; McNeil and Letschert, 2005; Phdungsilp, 2010; Sheikh, 2010; Supasa *et al.* 2017). In order to address the prevailing shortfall of supply in Pakistan, some short-term actions were taken at the government level.

These steps were directed to enhance indigenous fuel capacities for power generation, diversification of fuel imports, and strengthening inter-regional alliances in form of China-Pakistan Economic Corridor for instance. This resulted in considerable cuts in the frequency of load-shedding in urban areas i.e., 6 hours during 2015–2016 compared to 16 to 18 hours in 2013 (Khokhar *et al.* 2015; PERI, 2017). Albeit, the goal of the National Power Policy-2013 regarding complete eradication of supply-demand gap by 2017 and a power surplus for regional-trading by the end of five-year could not be realized. In addition, there is no local or community level disaggregated plan for sustainable management of energy demand in household sector of Pakistan (Bashir *et al.* 2018).

Various national reports and policy researches confirm that reason for partial achievement of national policy targets is the absence of a fair and consistent long-term Integrated Energy Plan. By definition, “Integrated Energy Planning is the systematic analysis of all the factors that influence the evolution of energy systems. It facilitates problem solving and makes it possible to explore linkages, evaluate trade-offs and compare consequences, thereby helping countries to develop an effective energy strategy that supports national sustainable development goals” (IAEA, 2008).

However, no serious attempt has been undertaken to formulate a ‘Sustainable Integrated Energy Plan’ for Pakistan (Mirjat *et al.* 2018; Debnath and Mourshed, 2018). Most of the government studies focus on economic aspect alone to identify cheapest choices for electricity production. The consequent policies and plans are mainly ‘cost-centric’ with unsustainable outcomes in long-term.

Rehman *et al.* (2017) state that majority of energy-sector forecasting at government level is usually exaggerated. An example is the Energy Security Action Plan of Pakistan for the period 2005-2030 which projected the national energy demand to 120.18 M.TOE for the year 2015 contrary to the actual consumption of 70 M.TOE.

In light of preceding review, it is imperative to attain a sustainable energy demand and supply system that is efficient, cost effective, socially viable and environmentally feasible. Such system is indispensible against climate change challenges and recent global initiatives on environment that impose bigger implications on developing countries.

Although some studies have been carried out to assess future energy implications of Pakistan, there have been no attempts to appraise its energy-environment targets including NDCs. Hence, the necessity for a long-term integrated plan has been immensely felt more than ever. Such a plan is anticipated to address energy-poverty and narrow the supply-demand gap. Also, there is need to incorporate the aspects of energy security into climate and sustainable development programs. As reported by WRI (2017), this requirement has also been highlighted in the mitigation plan of Pakistan’s NDCs submitted to the UNFCCC.

This study proposes a long-term sustainable power generation and deliverance plan for Pakistan for the study period year 2012 to 2050. The modeling tool, LEAP, was applied to analyze sustainability of the anticipated policies, in view of socio-economic and emission potential of those policies. Subsequently, optimization of the findings was carried out to obtain a final policy set, termed as mitigation scenario. Consideration of socio-economic and climate change aspects in this study recommends its suitability for other developing countries with similar economic and energy situations.

1.4. Objectives of the Research Work

Objectives of this research work are:

- To review the power sector and energy policies of Pakistan in order to assess the present energy crisis and associated sustainability challenges,
- To appraise energy modeling techniques and existing computer based macro-economic modeling tools, and their limitations in meeting energy sustainability indicators,
- To build an integrated model with country details for the energy and electricity sector of Pakistan to evaluate its socio-economic and environmental impacts and future projection to the year 2050,
- To propose policy scenarios for management of electricity supply and its demand in the most intensive sector i.e. household, and their integration for modeling the impacts of suggested technological changes and investments,
- To propose a least cost electricity generation module for supply side management with the aim to enhance efficient use of indigenous fossil resources, encouraging production of cleaner energy and cutting down emissions from thermal electricity generation, specifically penetration of renewable energy share options in relation to eco-innovation,
- To model sustainable societal/consumer behavior of urban household sector with the feedback systems and interdependencies between societal, environmental and economic technologies and structures related to energy and power sector, and
- To explore and weigh the proposed policies to reach to a best fist scenario that could facilitate and accelerate transition towards green and sustainable power development and its adequate supply to meet the demands of household sector in a an efficient way.

Chapter Two

LITERATURE REVIEW

2.1. Background

One of the most important advances made in power sector studies is introduction of techniques and models to achieve energy sustainability through integrated planning. This chapter reviews the literature pertinent to modeling techniques and energy and power system analysis. Specific emphasis has been laid upon integrated energy planning and modeling carried out in Pakistan. Furthermore, the modern energy modeling software tools and their limitations in meeting energy sustainability indicators has also been discussed in this chapter.

2.2. Sustainable Energy Development

In the present day, the strong relation between quality of environment and sustainable development has reshaped energy development processes, their assessment and policy formulation. The importance of environmental aspect is backed with the historic highs of energy related emissions upto 32.5 Gigatons in 2017 (i.e., two-third of GHGs and 80% of CO_2 emissions). During this period, least contribution came from the United States due to high renewable input (WB, 2018).

In view of less consideration of clean energy development by developing world, it is estimated that CO_2 emissions from non-Annex I countries will exceed the Annex-I's by 61% in 2030 (IEA, 2008). Koh *et al.* (2011) reason it to some common contributing factors of developing economies. These include growing need for electricity, technical and technological barriers, financial limitations, fuel-mix based on cheap fuels with absence of renewable share.

Energy and environment are strongly linked to sustainable development. Hypothetically, sustainable development must be achieved with zero emission or no impacts on environment. Hence, this concept was integrated into energy planning in order to address energy-environment issues while involving the key stakeholders in decision making process (Shaaban *et al.* 2018). Rosen (2009) states that improved energy efficiency and environmental stewardship have ability to overcome potential impacts on environment.

The idea of "Sustainable Development" was first introduced in the WCED report (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". With the evolution of energy-environment-sustainability trio, aforementioned idea was extended into relevant terms of sustainable energy, energy sustainability, etc.

The term "Sustainable Energy" means "a safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative" (Brundtland, 1987). As per the United Nations (2016), report, "the seventh goal of 2030-Agenda for Sustainable Development, adopted at the UN Summit in year 2015, is to ensure access to affordable, reliable, sustainable and modern energy fostering the objectives of the Sustainable Energy for All initiative".

The other term "Energy Sustainability" has also been studied in different contexts by Ness *et al.* 2007; Terrapon-Pfaff *et al.* 2014; Stambouli *et al.* 2012; Tsai, 2010; Liu, 2014; Singh *et al.* 2009; Pohekar and Ramachandran, 2004; Wang *et al.* 2009; Abu Taha and Daim, 2013; Doukas *et al.* 2012; Chester, 2010; Winzer, 2012; Kruyt *et al.* 2009; Maull, 1984; Bohi and Toman, 1996, Sovacool and Brown, 2009; Awerbuch, 2006; Markandya, 2010; Hughes, 2009; Leung, 2011; Wang and Chen, 2012.

Literature review suggests that the concept of energy sustainability was first proposed by Chester (2010). Winzer (2012) described it as continuity of energy supply relative to energy demand. Maull (1984) put it as embodying the eco-environmental sustainability of energy and the economic sustainability of energy. An analysis performed by Sovacool and Brown (2009) found out that such a sustainability comprises up of usability, efficiency, affordability and management of environment.

Most recent studies by Shaaban *et al.* (2018) and Li and Li (2017) reviewed various descriptions of energy sustainability based on temporal and spatial usage of energy resources. Shaaban *et al.* (2018) found that energy sustainability is simply the application of the general definitions of sustainability to energy. In other ways, it is more complex and involves the provision of energy services in a sustainable manner, which in turn necessitates that energy services be provided for all people in ways that, now and in the future, are sufficient to provide basic necessities, affordable, not detrimental to the environment, and acceptable to communities and people.

Kruyt *et al.* (2009) investigated the aspects of energy sustainability. They assessed that energy usage of an economic entity, its availability, economic cost of supply sustainability, and environmental sustainability. Salameh (2003) investigated various features of energy sustainability to determine energy security prospects of America. Hughes (2009) suggested the 4Rs of energy security i.e. review, reduce, replace, restrict, and their inter-linkages.

Awerbuch (2006) studied efficient power supply portfolios and their deterministic characteristics including renewable share, production cost and consequent energy sustainability. Bohi and Toman (1996) proposed that policies to restrict excessive energy usage can also enhance energy sustainability. Markandya and Pemberton (2010) discussed such policies including energy-tax. With a view to achieve low-carbon societies, Shukla *et al.* (2008) studied policy implications under imposition of a carbon tax alone and its combination with sustainable options.

2.3. Integrated Energy Planning (IEP)

In order to address the cross-cutting aspects of sustainable development, the essence of ‘energy sustainability’ and ‘sustainable energy’ has been embedded within the concept of ‘integrated energy planning (IEP)’. The aim of IEP is also the availability of reliable, affordable, and environmentally feasible energy for sustainable development. Such a planning ensures that all sectors in an economy are integrated within the energy plan while considering the economic, social, environmental and institutional aspects of sustainable development.

Integrated energy planning is more than a detailed computer model or a one-time plan. It requires a robust structure for establishment and implementation of the plan, a process that includes all steps associated with planning, including stakeholder engagement and communication, and as well as analytical tools for assessing alternatives. Hence, it can be assumed that sustainable energy development seeks integrated energy planning to provide the best suitable strategic pathway in a most optimal mode. Figure 2.1 shows main objectives of the process.

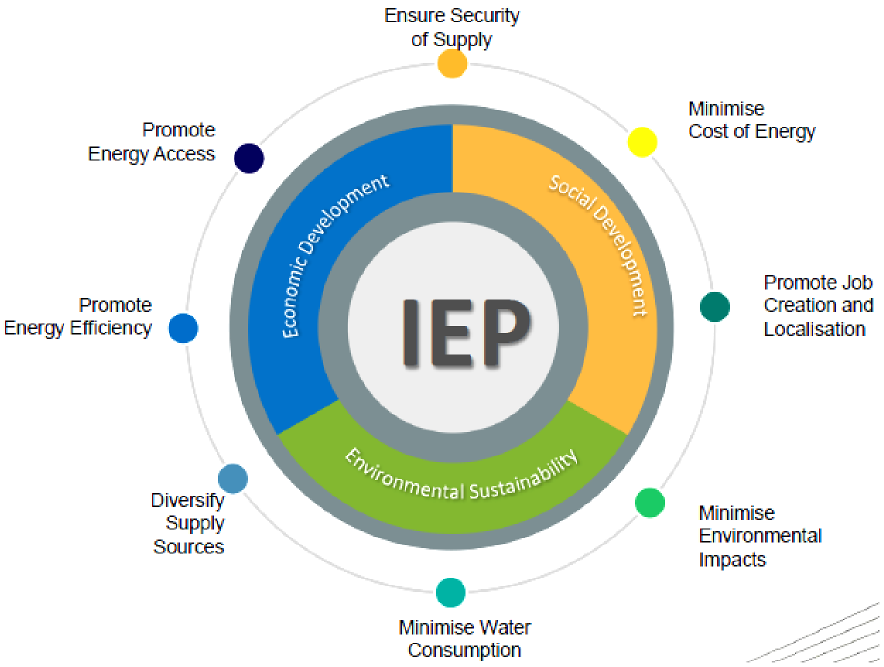


Fig. 2.1: Main Objectives of Energy Planning

In addition, sustainable energy planning ensures that the plan is long term, flexible against unexpected changes and consulted with all public and private stakeholders. This altogether reflects that generation, supply and utilization of energy is cost-effective, efficient, and induction of clean energy technologies, a decent renewable share and energy intensities are taken into account during planning process. Therefore, IEP is also believed as tool for investment and decision-making.

IEP has been used to evaluate a range of feasible options and develop an agreed-upon and implementable energy strategy. It supports decision making for clearly defined and prioritized objectives and a common vision for the energy sector and larger economy or society. Moreover, it considers risks and uncertainty about the future to ensure preferred energy strategy is wise, even if things do not work out the way we think they will. Ensure short-term actions consistent with long-term strategy.

Thus, the overall output of IEP is improved decision making with firm political commitment, financial guidance on infrastructure planning for energy and enhanced policy results. On the other hand, the World Resources Institute (2017) reports that energy-poverty and demand-supply gap are the major barriers in expansion of sustainable energy in Pakistan. Some other challenges are over-reliance on expensive imported oil, negligible share of renewable sources in energy mix, personal interests, poor government policies, energy security, poor management and circular debt.

An independent analysis assessed the causes of circular debt in Pakistan which represented 4% of GDP during peak load-shedding in 2012 (Planning Commission, 2013; GoP, 2018). During 1970s, most of the developing world initiated management and conservation of energy demand, along with efficient and renewable energy initiatives. From Pakistan, the only country initiative was formulation of the 2006-Renewable Energy Policy, with low level implementation.

2.4. Energy Modeling Tools and Techniques

International researches state that transition toward sustainable energy systems is complex and urge for new and efficient modeling techniques. It must include primary and secondary variations in markets, technologies, fuels, policies, infrastructure and institutions (Farooq *et al.* 2013; Cheema and Javid, 2015). Modeling is important for integrated energy planning but without process and structure, modeling is only a theoretical exercise without real tangible benefits. It must consider resource management plan for all resources, including energy efficiency, indigenous and renewable. Additionally, the integrated energy system models can be high-dimensional due to computation and data challenges.

An integrated energy model involves drivers and institutions to execute programs. Generally, its 3 main drivers are poverty, equity and environment. Whereas, energy specific drivers include energy security, high dependency on imported fossil fuels, price/ affordability, accessibility, reliability and other adverse impacts. The programs include all global, regional and national institutions including policy framework, development plans and legislations. Such an energy model, on the basis of performed simulations, should allow planners to classify the strength and weakness of available options, compare alternative scenarios, explore constraints, in terms of negative cost prospects, price optimization and long-term returns based on short-term investments, and weigh potential outcomes (Paˇsiˇcko *et al.* 2010; Zeng *et al.* 2011; Rehman *et al.* 2017).

Earlier, energy modeling was carried out through various economic theories and mathematical models. Van Beeck (1999; 2003) classified those energy models on the basis of a number of characteristics. Cormio *et al.* (2003) categorized energy planning levels into model-based, analogy-based and inquiry-based in accordance with the spatial and temporal requirements. With the integration of computer-based modeling tools in the energy planning process, the earlier classification was reviewed and later extended by Jebaraj and Iniyan (2006), Giatrakos (2009), Connolly *et al.* (2010), Nakata *et al.* (2011) and Van Beuzekom (2015). The improved classification generally considers concept, scope/ objective, data input, analytical capability and methodology employed by modeling tools (Mirjat *et al.* 2017).

From a literature review of the description of these models, it has been found out that these tools are accessible with or without charge or after obtaining license. User-friendliness of such models varies from high to low and in some cases training material is also provided. Energy modeling analysis uses top down or bottom up approach to meet the objectives of forecasting, exploring and back-casting of policies and scenarios (Connolly *et al.* 2010; Nakata *et al.* 2011).

Planning the level of such analysis range from community, local, national, regional and global for short, medium and long-term time scales. The data characteristics are mainly qualitative, quantitative, aggregated and disaggregated which depends upon the energy characteristics, i.e., energy services, demand sectors, generation and conversion/storage types. Different methodologies are used by these models including econometrics, macro-economic, economic equilibrium, optimization, simulation and multi-criteria using linear, mixed integer or dynamic mathematical programming.

With growing emphasis over technological innovations and clean and green energy, the advanced energy planning and modeling initiated to explore possibilities for shifting towards efficient means of energy production.

Nowadays, a range of modeling tools is used to explore sustainability of energy system. However, their relevance and results fluctuate among developed to developing economies, local to regional, time horizon, energy importers to producers, technique, data requirement and its level of disaggregation, validation and is largely influenced by targets set by planner and modeling uncertainties (Farhad, 2011; Sun *et al.* 2016; OECD/IEA, 2017). Table 2.1 exhibits a comprehensive review of the main energy models, their developers, scope and modeling methodologies.

Table 2.1: Main Features of some Integrated Energy Models (Source: SEI, 2011, 2017)

Name	Developer	Scope	Methodology	Type	Time-step & Spatial-Application	Additional Features
MARKAL	ETSAP	Nexus of energy and environment	Optimization operation	top-down bottom-up equilibrium	regional, national and state level	high user friendliness
TIMES	ETSAP	MARKAL and energy flow	Optimization operation	bottom-up top-down equilibrium	regional, national and state level	high user friendliness
LEAP	SEI	Nexus of energy and environment for accounting and cost minimization using economic variables of fuel price, capital costs, O&M, carbon tax, subsidies/quotas for electricity, heating, cooling non-e transport chemicals, all import & export demand sectors, all non-renewable & renewable generation, conversion & storage types	Accounting, Simulation, Optimization, scenario operational approach	bottom-up top-down	global, regional, national and state level hourly, yearly, 20-50years	high user friendliness, dedicated GUI, 3-4 days training Free for academics not open source
MESSAGE	IAEA	Energy demand projections	Optimization/ LP	bottom up	global/regional levels	high user friendliness
EnergyPLAN	Denmark-Aalborg University	Technology or economics of electricity heating cooling, e & non-e transport chemicals of	Simulation/ Optimization, operational planning	bottom up	regional, national and state level hourly to annual basis	high user friendliness, dedicated GUI, few days training

		residential, transportation, industry import & export sectors, all non-renewable & renewable generation, conversion/storage of batteries, pumped hydro heat storage, heat pump H2 storage, carbon capture and storage using economic parameters of fuel price, capital costs, O&M, carbon tax, subsidies/quotas	approach			Free not open source
ENPEP-BALANCE	USA-Argonne National Laboratory	Nexus of energy and environment/ GHG scenario building	market Simulation	top down	global/sectoral levels	high user friendliness
Energy Costing Tool	UNDP	Estimation of energy types and magnitudes to invest in targets of MDGoals	Accounting		global/sectoral/local levels	high user friendliness
GEMIS	Germany, Oeko-Institute	LCA of energy chains	Accounting		sectoral/local levels	high user friendliness
HOMER	USA-NREL	Designing on- and off-grid electrification using fuel price, capital costs and O&M for NPC minimization of electricity heating, cooling of only specified load types (primary, deferrable, thermal), generation of CHP, micro-turbines biomass, small hydro,	Optimization, scenario operational		local, island operation 1 hour, 1 year	high user friendliness, dedicated GUI, 1 day training 14-day free trial not open source

		wind, solar thermal, photovoltaic, and conversion/storage of batteries, H2 production & storage, fuel cells, AC/DC converter				
MAC Tool	World Bank (ESMAP)	Break-even carbon pricing calculation Constructing marginal abatement cost-curves	Accounting		global/sectoral	user friendliness
MAED	IAEA	Nexus of energy and environment	Accounting and Simulation			user friendliness
OSeMOSYS	KTH, SEI & other organizations	Long-run planning	Optimization/ LP		Long-run	user friendliness
REAP	SEI	End user based footprint assessment of ecology and emissions	Environment extended input-output		Regional Local authorities of UK	user friendliness
RETSCREEN	Canada-Natural Resource	Consideration of renewable energy technologies and enhancement of energy efficiency measures for generation, its cost and emission assessment	Accounting		state/regional/national	user friendliness
SUPER	OLADE	Energy demand & conservation, hydrology, planning under uncertainty, financial, and environmental analysis	Optimization and Simulation			user friendliness

TRACE	World Bank (ESMAP)	Identification of under-performing sectors, evaluation of financial savings and prioritization of energy efficiency policies	Accounting and Simulation	Decision-support	Cities	user friendliness
WEAP	SEI	Integrated policy planning and analysis for water sector	Accounting, Simulation, Optimization operations with GIS integration		Global, regional, national and state level	User friendly framework
CCP	Canada-Torrie-Smith Association	action plans and cataloging for climate	Accounting		Local (cities) and state level	user friendliness
EFFECT	WB (ESMAP)	Scenario-building of green house gases	Accounting			user friendliness
COMPOSE	Denmark-EnergiAnalyse	Cost-effectiveness toolbox for private & public decision-makers	Accounting			user friendliness
CO_2DB	Austria-IIASA	Development of energy technology data with respective CO_2 emission levels	Data inventory			user friendliness

Literature review suggests that a model has the capability to support an objective policy formulation process. Studies by Fragnière *et al.* (2017), Qudrat-Ullah (2015; 2016), Mischke (2014), Pfenninger (2014), Day (2013), Sahir (2007), Jebaraj and Iniyan (2006), Pina *et al.* (2011), Bhattacharyya and Timilsina (2010), Manne *et al.* (1979), Nilsson *et al.* (2008), Pina (2012), Herbst *et al.* (2012), Pandey (2002), Urban *et al.* (2007), Boulanger and Bréchet (2005) and Strachan *et al.* (2009) undertook this exercise to meet other developmental goals.

In addition to energy modeling, LEAP, MARKAL, AIM models were also used to assess national targets for GHG mitigation and other low-carbon policies in many countries studies including the UNEP-Balancing Energy, Sustainable Development and Climate Change Project (Nakata, 2011).

Siagian *et al.* (2017) and Ibrahim (2010) applied AIM/CGE model and MARKAL, respectively whereas Purwanto *et al.* (2015) used a multi-objective optimization model in their studies for Indonesia. Bappenas (2014) used MARKAL-ANSWER to appraise the benefits of low-emission technologies in Association of Southeast Asian Nations. Kannan (2011) used flexible-time-slicing to build up Temporal MARKAL model.

Sun *et al.* (2016) developed 8 renewable-based scenarios through EnergyPLAN to visualize effectiveness in meeting national intended contributions of China. Sithole *et al.* (2016) also carried out modeling to analyze emission reduction target. Shukla *et al.* (2008) used an integrated soft-linked model framework to realize the goals of low-carbon society.

Heaps (2002) and Connolly *et al.* (2010) commented on benefits of these tools in analyzing and interpreting large data sets belonging to different regions to serve different objectives with different technologies, in a systematic manner. Blarke (2005) found out that the energy models, namely MARKAL, ENPEP, LEAP, MESSAGE and EnergyPLAN, are best tools on basis of increasing applications, performance and capacity building through trainings.

Among the above motioned best energy tools, LEAP has been applied in several studies conducted in emerging economies. These studies aimed to explore energy transition pathways and the associated GHG estimation (Heaps, 2016). Mirjat *et al.* (2017) also compared these energy modeling softwares and concluded that the former two have wider user-base. He further recommended LEAP for its application in Pakistan with consideration of multi-agents.

In order to analyze and forecast energy demand of urban households, along with related emissions under alternative policy strategies, the LEAP model was used. This energy model has been applied by many countries to study energy transition and determine policies. Some of its applications in developing countries include India, Iran, Thailand, China, Mongolia, Panama, Korea, and nations in Africa (IGCS, 2014; Amirnekooei, 2012; Von Hippel and Tempest, 2014; McPherson and Karney, 2014; Phdungsilp and Wuttipornpun, 2011; Park, Yun, Chan, 2013; Nadia, 2017; Xing *et al.*, 2017).

LEAP has a long successful global experience of diverse applications. These applications include study for California wherein LEAP was used for energy forecasting and identifying alternative fuels (Ghanadan and Koomey, 2005). In Mexico, it was used to determine the feasibility of future scenarios based on moderate and high use of bio-fuels in the transportation and electricity generation sectors (Islas *et al.* 2007).

LEAP model has been incorporated into energy studies to find developments in supply and demand and energy sector prospects as in China (Wang *et al.* 2010). Also, it has been used for carbon dioxide emissions assessment in petroleum-refining sector of Korea (Park *et al.* 2010) and in carbon modeling for Bangkok city (Phdungsilp, 2010).

In Lebanon, mitigation options were assessed to reduce emissions from electricity generation with emphasis on the usage of renewable energy resources (El Fadel *et al.* 2001). The energy consumption and various types of emissions in consumption sectors in Iran were analyzed by using LEAP model (Awami and Farahmandour, 2008). From literature review, details of all such energy studies conducted in various parts of world, other than Pakistan, is presented in Table 2.2.

Table 2.2: World wide Applications of Energy Modeling Tools

#	**LEAP** Long Range Energy Alternatives Planning System	**MARKAL/TIMES** Market Allocation	**MESSEGE** Model for Energy Supply Systems and General Environmental Impact	**EnergyPLAN**	**ENPEP BALANCE** ENergy and Power Evaluation Program
1.	IGCS (2014) performed long-term energy and development pathways for India	Chen and Wu (2001) studied China's future sustainable energy development	Herdinie and Sartono (2003) assessed the role of nuclear power and other electricity generation options in Indonesia	Connolly *et al.* (2009) modeled the Irish energy system	Bouille (2000) studied electric power options in Argentina
2.	Ghanadan (2005) used LEAP to create multi-sector end-ues model of energy supply and demand in California	Akinbami (2001) assessed renewable energy resources and technologies and policy framework for Nigeria		Porubova *et al.* (2010) analyzed long-term plan for energy supply system for Latvia on indigenous Latvia	Conzelman and Koritarov (2002) reviewed energy and environment for Turkey
3.	Roinioti *et al.* (2012) studied future energy scenario while focusing upon Greek electricity production system	Bappenas (2014) focused not only on Indonesia but also on the ASEAN region to clarify the implications of low-carbon power technology options	Saradhi *et al.* (2009) analyzed Indian energy supply, demand and related environmental aspects	Bhattacharyya (2011) studied integration of wind power into the British system in 2020	IEA (2005) carried out comparative assessment of energy options and strategies in Mexico
4.	Amirnekooei *et al.* (2012) carried out integrated resource planning for energy system-Iran	Ibrahim (2010) studied Indonesian energy scenario to 2050 while projecting the consumption, supply option and primary energy mix scenarios	Hainoun *et al.* (2010) developed long term energy supply strategy for Syria	Franco and Salza (2011) studied strategies for optimal penetration of intermittent renewables in complex energy systems based on techno-operational objectives for Italy	Mirsagedis *et al.* (2004) carried out long term GHG emissions outlook-Greece

5.	von Hippel *et al.* (2014) developed green energy strategies-Mangolia	Tsai and Chang (2015) examined low carbon energy pathways-Taiwan	Fairuz (2013) studied long term strategy for electricity generation-analysis of cost and carbon foot print-Malaysia	Ćosić *et al.* (2011) assessed GHG reduction potential due to renewable electricity in Macedonia	
6.	McPherson (2014) examined long-term scenario alternative and their implications in electricity sector-Panama	García-Gusano (2015) carried out energy optimization modeling for environmental policies in Spain	Kichonge *et al.* (2015) modeled energy supply options for electricity generation in Tanzania	Fernandes *et al.* (2014) studied renewable energy scenarios in the Portuguese electricity system	
7.	Huang *et al.* (2011) examined energy demand and supply of Taiwan during 2008-2030	Krakowski *et al.* (2016) assessed renewable share in overall energy mix of France	Kumar *et al.* (2011) studied energy sector development for 2010–2050 Malaysia	Palzer and Henning (2014) modeled German electricity and heat sector in a future energy system	
8.		Mondal *et al.* (2014) evaluated future energy-supply strategies for UAE power sector	Pereira *et al.* (2008) used MIPE and MESSAGE for developing National Energy Outlook of Brazil		

In case of Pakistan, despite severe energy crisis, only a few energy assessment and forecasting studies were carried out and even fewer used IEP modeling tools. Sahir (2007) and Harijan (2008) employed Linear Regression to determine sustainable energy alternatives and renewable resources potential in Pakistan. Uqaili (1996) studied 4 scenarios to assess their projected results till year 2018 using modified econometric models. Anwar (2010) used partial-equilibrium model to analyze energy security.

Literature review of energy studies of Pakistan further suggests that LEAP model was used in majority of the studies (Gul and Qureshi, 2012; Mengal *et al.* 2014; Syed *et al.* 2014; Perwez *et al.* 2015). It was also used for city level studies for the Islamabad Industrial Area by Erum and Ahmad (2010). In another study by Shabbir and Ahmad (2010), LEAP was used for air quality monitoring for urban transport of Rawalpindi. Recently, Bashir *et al* (2018) also deployed LEAP to study demand side modeling of urban household and associated GHG emissions. In addition, the IEA's MARKAL/TIMES model was applied by Farooq *et al.* (2013), IRG (Pak-IEM, 2010) and Valasai *et al.* (2017 b; c) in their energy studies for Pakistan. Scope of these energy modeling applications is briefly presented in Table 2.3.

Table 2.3: Energy Modeling Applications in Pakistan

	LEAP	MARKAL/TIMES
1.	Gul and Qureshi (2012) performed a range of energy-scenarios analysis	IRG (2009) modeled an integrated country level energy model "Pak-IEM"
2.	Mengal *et al.* (2014) studied energy scenarios to analyze demand and emissions	Farooq *et al.* (2013) studied energy-environment-economic impacts of RPS for developing state
3.	Syed *et al.* (2014) carried out energy scenarios forecasting for decentralized planning	Valasai *et al.* (2017 b) studied carbon-free electricity production, supply and consumption
4.	Erum and Ahmad (2010) analyzed city level industrial energy consumption for Islamabad	Valasai *et al.* (2017 c) considered options for renewable-based power generation in their study
5.	Perwez *et al.* (2015) modeled long-term demand and supply of electrical energy	
6.	Shabbir and Ahmad (2010) examined urban transport air pollution in Rawalpindi	
7.	Bashir *et al.* (2018) performed energy demand modeling of urban household	
8.	Rehman *et al.* (2017) compared ARIMA, LEAP and Holt winter	

Veit *et al.* (2004) found out that integration of more than a single model in multi-agent energy modeling enhances its multi-purpose function under a centralized decision making process. Hong *et al.*, (2013) stated that multi-criteria assessment approach has the ability to deal with a variety of uncertainties and input information. The purpose of optimization operation is provision of an optimal cost-effective solution under set constraints. Table 2.4 provides a detailed review of applications of decision aids for sustainable energy modeling.

Mathematical models like Multiple Criteria Decision Aid-MCDA, Preference Ratio in Multi-attribute Evaluation-PRIME are among the numerous optimization models with high user base. Multiple criteria has been used in energy assessment studies by Atilgan and Azapagic (2017), Strantzali *et al.* (2017), Volkart *et al.* (2017), Brand and Missaoui (2014), and Baležentis and Streimikiene (2017).

Furthermore, Saaty (1980; 1990) studied the importance of Analytic Hierarchy Process-AHP which is an extension of attribute level MCDM (Keeney and Raiffa, 1976). AHP has been observed as one of the most applied methods to resolve the multi-dimensional energy-environment issues. The technique was also applied by Ligus (2017) to determine GHG dependency on technology. Mirjat *et al.* (2018) used it with several criteria and sensitivity to analyze sustainable options for electricity production.

Multi-agent modeling and decision-aid have also been practiced in many renewable energy studies to develop desired levels of Renewable Portfolio Standards at country level (Sadorsky, 2011; EIA, 2003, 2011; Uyterlinde *et al.* 2005; Palmer and Burtraw, 2005; Kydes, 2007; Urban *et al.* 2009; Demirtas, 2013; Ahmad *et al.* 2017; Haddad *et al.* 2017; Malkawi *et al.* 2017; Katal and Fazelpour, 2018).

In view of which, MCDM was also done in conjunction with GIS tools for resource identification and its potential assessment in different studies conducted for Columbia (Quijano and Domínguez, 2008), Colorado (Janke, 2010), Bangladesh (Mondal and Denich, 2010), Colombia (Quijano *et al.* 2012), offshore wind farms allocation (Punt *et al.* 2009), site-selection of wind turbines and hybrid wind solar-PV (Aydin *et al.* 2010; 2013), modeling with ordered weighted averaging for study of Oman (Charabi and Gastli, 2011), modeling with fuzzy set theory (Chang *et al.* 2008; Chen *et al.* 2011; Tavares *et al.*

2011) and further combining it with ordered weighted averaging (Makropoulos and Butler, 2004; Jiang and Eastman, 2000; Gorsevski *et al.* 2012).

For consideration of socio-economic variables, most of the available energy demand forecasting studies employed co-integration, multivariate models, abductive and neural networking, uni-variate time-series analysis. Kankal *et al.* (2011) used ANN and regression analysis, Pao and Tsai (2011) used grey prediction model for Brazil, whereas Lee and Tong (2011) coupled it with genetic programming for China. Galli (1998) used log-linear and quadratic models to determine energy demand in some ASEAN countries, Hyndman and Fan (2010) used semi-parametric additive in their study of South Australia.

Another such technique is ARMA (Autoregressive Moving Average) which is a combination of two models, namely Auto Regressive and Moving Average. This has been used to assess energy demand in many county level studies by Saab *et al.* (2001), Ediger and Akar (2007), Erdogdu (2007; 2010). Another study of China used Group Auto-Regressive and Group Method of Data Handling (Xiao *et al.* 2015).

The ARMA model was also combined with various analytical operations and models including i.e., ANN and neuro-fuzzy system (Kaynar *et al.* 2011), ANN and regression analysis (Deka *et al.* 2015), neural networks (Voronin and Partanen, 2014), SARIMA model (Pan *et al.* 2012), ETS model for Nigeria (Asumadu-Sarkodie and Owusu, 2016), and ETS and multiple regression models for China (Chai *et al.* 2016).

In terms of application of decision aids for energy modeling studies in Pakistan, Hussain *et al.* (2016) applied Holt-Winter and ARIMA. In a similar study for Turkey, Akpinar and Yumusak (2016) also combined ARIMA with Holt-Witner in addition to time-series decomposition and exponential-smoothing. The results of ARIMA were also compared with GM (1,1) by Yuan *et al.* (2016), and with Holt-Witner and LEAP models by Rehman *et al.* (2017).

Unsihuay-Vila *et al.* (2011) devised a multi-dimensional multi-objective, multi-area and multistage model to long-term expansion planning (MESEDES) for power generation and transformation. Dementjeva and Siirde (2009) suggested that due to continuous updating and improved versions of these tools by their developers, it is wiser to apply already available tools rather than devising new models.

Table 2.4: Applications of Decision Aids for Sustainable Energy Modeling

	Scope of Study	Decision Aids
1.	Mirjat *et al.* (2018) assessed power generation scenarios under sustainability criteria for Pakistan	MCDM-AHP/Sensitivity/ Sensitivity Criteria
2.	Sahabmanesh and Saboohi (2017) modeled energy system for Hamadan, Iran	SESM-AHP
3.	Promjiraprawat and Limmeechokchai (2013) performed electricity development planning with CO_2 avoidance for Thailand	MCDM
4.	Janke (2010) applied multi-criteria GIS modeling for study of Colorado	GIS-based MCDM
5.	Quijano *et al.* (2012) modeled renewable energy plans under sustainability criteria	MODERGIS/ Sensibility Criteria
6.	Punt *et al.* (2009) proposed model for offshore wind power site while keeping into account maximization of economic factor, reducing affects on environment and natural habitat	Integrated economic-ecological models
7.	Aydin *et al.* (2010) studied spatial identification for harnessing wind energy keeping in view its environment and energy generation capability	GIS-based MCDM applications
8.	Aydin *et al.* (2013) later extended their study to economical & environmentally feasible siting hybrid wind solar-PV systems	GIS-based MCDM applications
9.	Chang *et al.* (2008) modeled urban landfill site selection	GIS-based MCDM with Fuzzy Set Theory
10	Tavares *et al.* (2011) modeled site selection for incineration of municipal waste	GIS-based MCDM with Fuzzy Set Theory
11	Chen *et al.* (2011) modeled for Best-Environment-Watershed-Plan selection	GIS-based MCDM with Fuzzy Set Theory
12	Makropoulos and Butler (2004) carried out location -specific planning for management of water consumption	Fuzzy Set Theory, Ordered weighted averaging in GIS
13	Jiang and Eastman (2000) studied functions of fuzzy measures in multi-criteria	Fuzzy Set, Ordered weighted averaging in GIS
14	Gorsevski *et al.* (2012) studied evaluation for siting of landfill	Multi-criteria evaluation, Fuzzy Set Theory, ordered weighted averaging in GIS
15	Charabi and Gastli (2011) studied siting-suitability in Oman for vast Photo-Voltic parks	ordered weighted averaging in Arc GIS
16	Mourmouri *et al.* (2012) for developing Renewable Energy Computer Model	MCDM
17	Stewart *et al.* (2013) Integrating MCDA and scenario planning-Review Paper	MCDA
18	Ligus (2017) evaluated Social- Economic-Environmental impacts for development of low-emission energy technologies in Poland	MCA, FAHP, Delphi method
19	Unsihuay-Vila *et al.* (2011) devised a bottom up multi-objective, multi-area and multistage model	MESEDES

	to long-term expansion planning	
20	Ferreira and Araújo (2012) proposed integrated power planning framework for Portugal	LEAP and MCDM
21	Phdungsilp and Wuttipornpun (2011) performed analysis and projections of energy and carbon emissions of Thailand	LEAP and DM
22	Giatrakos *et al.* (2009) performed power planning for Crete Island, Greece	RES LEAP and RETscreen
23	Mirakyan *et al.* (2009) carried out energy planning for France region	LEAP and DAM
24	Quijano and Domínguez (2008) performed energy planning for Columbia, USA	LEAP, ARCGIS, LCA, and MCDA
25	Park *et al.* (2013) examined the impacts of Korean electrical energy scenarios till year 2050	LEAP and Sensitivity Analysis
26	Makowski *et al.* (2006) examined potential of energy policies of European Union (2004-2008)	MARKAL, LCA and MCDA
27	Heinrich *et al.* (2007) studied power transformation, grading and assortment of its expansion alternative in South Africa	MARKAL and MCDA
28	Pereira *et al.* (2008) performed energy sector modeling for Brazil	MIPE and MESSAGE
29	Kumar and Radhakrishna (2008) analyzed energy sector potential of India till 2030	ENPEP and MAED
30	Deshmukh *et al.* (2014) carried out rural domestic energy-demand study for India	Decision support system with a graphical user interface (GUI)

2.5 Study Gaps

In the backdrop of energy crisis in Pakistan, some energy forecasting studies were conducted at academic level in Pakistan by Valasai *et al.* (2017 b; c), Uqaili (1996), Sahir (2007), Hussain *et al.* (2015; 2016), Perwez *et al.* (2015), Perwez and Sohail (2014), Anwar (2010; 2016), Rehman *et al.* (2017), Gul and Qureshi (2012), Farooq *et al.* (2013), Mengal *et al.* (2014), Syed *et al.* (2014) and Rauf *et al.* (2015).

Meanwhile, the studies conducted by government focused upon ‘economic aspect’ alone in order to identify cheapest options for electricity production. The consequent government policies and plans are mainly ‘cost-centric’ with unsustainable outcomes in long-term. Rehman *et al.* (2017) remarked that majority of energy-sector forecasting at government level is usually exaggerated.

On such example of government studies for energy sector is the Energy Security Action Plan of Pakistan for the period 2005-2030 which projected the national energy demand to 120.18 M.TOE for the year 2015 contrary to the actual consumption of 70

M.TOE. In view of which the USAID and Planning Commission of Pakistan (2013) also observed that absence of government strategy to deal short-fall is responsible for crisis. The only notable contribution by governmnet in this regard is the Pak-IEM (IRG, 2009) which used TIMES model.Unfortunately, its findings remained unutilized also and thus could not benefit the energy system of Pakistan.

In order to assess challenges in harnessing renewable energy potential in Pakistan, some energy forecasting studies were also conducted by academic researchers in this regard by Bhutto *et al.* (2011; 2012 a and b; 2013), Abbas *et al.* (2014), Rafique and Rehman (2017), Sheikh (2009; 2010), Shah *et al.* (2011), Nayyar *et al.* (2014), Rauf *et al.* (2015), Shaikh (2015), Siddique and Wazir (2016) Khan *et al.* (2007), Harijan *et al.* (2011), Yazdanie *et al.* (2010), Asif (2009), Khan *et al.*(2009), Khan *et al.* (2003; 2008 a, b; 2009b), and Farooq *et al.* (2013).

Out of the multiple challenges identified in above cited studies, some major barriers included intermittent nature of renewable resources, location confinement, weather dependency, technological, institutional and capacity limitations, high initial investment, market variations, cultural and social perceptions, etc. Other than Pakistani researchers, Painuly (2001), Vaitheeswaran (2003), Aydin *et al.* (2013), Schilling and Esmundo (2010) and Weyant (2011) also discussed the issues which have limited the benefits of renewable energy exploitation in renewable-rich regions. However, the necessary technical and financial support to overcome those barriers is missing.

These high priority issues and underlying gaps were also identified and highlighted in various studies conducted in Pakistan at government and academia level. Among the few energy studies carried out in Pakistan, modeling tools were deployed in even fewer studies as detailed at Table 2.3. Literature review also suggests that causes of these issues are lack of requisite authentic data and problems in data collection. Moreover, absence of sub-sectoral studies and decentralized data is also a huge obstacle in generating realistic energy system analysis of Pakistan.

Qazi and Jahanzaib (2018) further connected its cause to subjective policy making, inappropriate institutional developments and instability of administrative setup. Hence, they proposed an integrated framework for strategic support and improvement of the sector, organization and government. Mirjat *et al.* (2017) and Rehman *et al.* (2017)

also emphasized upon the need to address these issues through a rational and long term integrated energy plan for Pakistan.

The importance of considering household sector in overall energy planning and emissions policies is evident from literature review. It is well-recognized that energy efficiency and its saving in household sector can reduce up to an estimated fifteen percent of energy needs (WB, 2018). Furthermore, sustainable management of energy demand in residential sector can offer highest energy saving including 10% energy conservation through efficient appliances (Ahmad *et al.* 2017; Hafeez *et al.* 2018; Awami, 2008; Chaudhry, 2010; Chaudhry, 2010; El-Fadel *et al.* 2001; Ghanadan and Koomey, 2005; McNeil and Letschert, 2005; Phdungsilp, 2010; Sheikh, 2010; Supasa *et al.* 2017).

However, there is no local or community level disaggregated plan to address excessive energy demand of household sector in Pakistan till yet. In practice, very few efforts have been made towards integrated planning for energy sector and its modeling in Pakistan. Hence, the current research work is of huge significance as it is the first study carried out in Pakistan to examine potential of energy-saving in residential sector. The results of this study are based upon mathematical operations of extrapolation, growth rate method or interpolation of LEAP model, to analyze and forecast energy demand of urban households, along with related emissions under alternative policy strategies.

However, formulation of such a plan takes time and is not easy. This requires an agreed upon process for collecting, reviewing and agreeing on data and developing a strategy for filling data gaps. Hence, rational and reliable IEPM is not a cheap and effortless choice. These limitations altogether result in provision of misleading information to policy makers. Therefore, this necessary requirement for reassessment of energy models for transition towards sustainable energy development is also considered in this study at section 2.6.

2.6. Modeling Challenges and Limitations

Challenges and limitations in sustainable energy planning and modeling through conventional approaches have been identified in literature. It had been argued that the main purpose of conventional approaches was forecasting of energy use, demand and supply for least cost planning. However, sustainable planning seeks to consider all aspects of economy, environment, social and institutional all together (Olerup, 2000; Ferreira, 2007).

Paˇsiˇcko *et al.* (2010) reviewed energy modeling and their suitability to address technical and technological advancements. They concluded that modeling of the present day electrical energy systems is more challenging as they have altogether transformed under the decentralized, liberalized and consequently more competitive energy markets.

Few studies have been conducted to identify uncertainties arising due to structure of model and data base. Those uncertainties are both quantifiable and unquantifiable which pose direct and indirect effects on decision making process. Zheng *et al.* (2011) reviewed methods of optimization modeling to address such uncertainties and their interactions, and the decision aid tools.

In this regard, Zheng *et al.* (2011) and Paˇsiˇcko *et al.* (2010) investigated certain areas which require further improvements. It was recommended that more research can be done for integration of multiple sectors, resources and technologies in a model. He further proposed to resolve issues in handling data diversity and inconsistency, and emphasized upon evaluation of modeling results and their applications

Various studies confirmed that the model should not be relied upon as the ultimate decision maker rather it assists the user in evaluating all available options to reach a decision in a planned and logical way. Van Ruijven *et al.* (2008) and Urban *et al.* (2007) assessed various energy models used in IPCC Scenarios Report for scenario building of emission reduction in energy use. Shukla (1995) also examined limitations of these models on the basis of income, electrification, household fuel share and its exhaustion, structural economic variations, and informal markets.

Ramos and Adler (2007), Dyner and Larsen (2001), Kagiannas *et al.* (2003), Botterud *et al.* (2007) and Pasicko *et al.* (2007) observed that in order to satisfy the additional constraints from emissions reduction and efficiency improvement targets, volatility and price insecurities regarding energy resources and long run investment preferences, etc, optimization of energy systems is necessary.

Laitner *et al.* (2003) discussed that projections of existing macro-economic models, under the usual case, generate biased estimations. Biswas (1990) and Van Beeck

(2003) determined that such evaluation offers partial reality of a system that represents quantifiable variables only while the qualitative features are largely ignored. In addition to overly-optimistic economic projections of these models, Farhad (2011) found out that the environmental cost incurred in resource extraction/ depletion or invested as eco-innovation is also not considered in the system’s production function.

Rath-Nagel and Voss (1981) emphasized that even if the modern modeling tools consider environmental and economic constraints, these generally fail to address all aspects of energy sector simultaneously. Hence, integration of one more than one model is required to serve linked purposes of an energy plan or policy. Thörnqvist (1980), Wene and Rydén (1988), and Olerup (2000) observed that conventional energy models have usually short term perspective and less focus upon local or community level. Hence, they are not open to technological development and unable to reflect the direct long-term future consequences on human welfare from environmental quality and ecosystem goods and services.

It was also argued that conventional models are inflexible and their results can easily be influenced by any unpredicted change or external variables. However, energy systems are open to change and absence of the associated influences both internally and with its environment is also reflected as deviation from reality (Farhad, 2008).

In terms of necessary stakeholder engagement, Ivner *et al.* (2010) states that all involved should be involved within the planning process from the beginning. According to Webler and Tuler (2006), the process must be open, transparent and be capable of determining the investor’s interests to propose the best suitable pathway.

However, Rydin and Pennington (2000) and Healey (1992) argued that this proposition is not always justified instead the results may delude policy makers and subsequent policy failure. The reasons of unintended outcomes of public participations were identified as differences in stakeholders’ knowledge, opinion, stakes and interests.

Moreover, an agreed upon process is required for collecting, reviewing and agreeing on data and developing a strategy for filling data gaps. This takes time and is not easy. Hence, rational and reliable IEP modeling is not a cheap and effortless choice (Sahir and Qureshi, 2006). These limitations altogether result in provision of misleading information to policy makers. Therefore, reassessment of energy models is necessary for transition towards sustainable energy development.

Generally, the long term models are designed to consider high capacity factors relating to non-renewable power generation for which annual flows are measured. Kannan (2011) and Connolly *et al.* (2010) stated that this might not work in case of renewables due to their intermittent nature. Although H2RES, EnergyPLAN, MesapPlaNet and SimREN generate results upto hourly or even finer time resolutions, yet these models differ in other factors (Sun *et al.* 2016).

Chapter Three

METHODOLOGY

3.1 General Introduction

Current approaches and models for energy system analysis join the features of physical accounting, simulation and optimization, embedded within a general equilibrium system. But sustainability modeling requires much more than mathematical calculations. In order to cover all aspects of sustainability challenges in energy and power system, the present study carried out long range scenario analysis using the LEAP modeling tool in the proposed model. The resultant system has an adaptable and transparent data structure where energy related uncertainties and barriers are integrated as constraints.

Future policy study approach was used for forecasting and back-casting. The results of such prospective studies can either present a mix of policy options directed to achieve the set objectives or package of future scenarios representing various options. The importance of considering the household sector in overall energy planning and emissions policies is evident from literature review. In Pakistan, most of the population belongs to the middle income level. Therefore, the energy demand of a common middle-income urban household was chosen in this study to represent the energy needs of the highest proportion of households

The results of this study will be determined in terms of global warming potential of GHG emissions from energy supply and consumption activities in urban household sector, social cost of the activity, energy saving potential, etc. The net present value will be determined as a result of cost benefit analysis among alternative scenarios, from societal perspectives. Also, environmental constraints will be added as externality costs.

3.2 Data Requirements

The crucial first step in developing a credible integrated energy planning model for Pakistan is acquiring and assembling the detailed data needed for a comprehensive national model. This begins with a methodical review of the nature of the existing economic, financial, and technical data related to the Pakistan energy system from resources (domestic and imports) through end-use demands that is necessary for the model.

A detailed review of energy policies, international energy sector reports, and analysis of power sector of Pakistan form basis of this study. For this purpose, relevant literature was reviewed and discussions held with energy and environment experts. In light of which, the country's energy mix was analyzed in detail in chapter 4, in terms of fuel composition, renewable energy share, supply-demand pattern with focus on household sector, clean energy potential and overall GHG emissions of energy sector. Accordingly, frameworks for demand and supply sides will be devised for scenarios development in chapter 5.

The most recent year, 2011, is chosen as baseline year of the study in order to have the most updated baseline, whereas 2050 is selected as end year. Database acquired for energy modeling (table 3.1) was statistically aligned and converted to time-series data;

Table 3.1: Database used for Energy Modeling

	Sectoral variables	Demand side	Supply Side	Technological Options
1.	GDP\value added	Sector and subsector totals	Characteristics of energy supply and conversion facilities	Performance and price of technology
2.	Population	End use and technology	Exogenous or endogenous capacity additions	Proportion of annual replacement of available and new stock
3.	No. of households	Characteristics by sector and subsector	Resources and prices	Emission factors
4.	Household size	Fuel use by sector or subsector	Performance factors of power plants	Penetration rates
5.		Disaggregation of energy usage into service and appliance, (available versus new appliances), type of appliance stock	Renewable potential Fossil fuel reserves	Power plants performance factors Capital and O&M costs Foreign exchange
6.		Performance and price of technology	Fixed and variable Capital and O&M costs	Ratio of GHGs emitted from energy generation, transformation and use
7.			Characteristics, costs and online date of new capacities	
8.			Energy supply plans	

For the latest scenario development, statistical data for calculation of power plants performance characteristics was extracted from government reports including Energy Yearbook and DISCOs websites. Data sources for provision of historical and current energy supply data for this study are elaborated in chapter 4. The acquired data was then updated to base year 2011 to generate an up-to-date picture of the Pakistan energy sector.

Due to problems in extensive data collection for demand side energy consumption of the country, the information was collected from national census and previous household surveys. For determination of existing trend of household energy consumption in Pakistan, data was used from the national website of the Pakistan Bureau of Statistics and Pakistan Social and Living Standards Measurement (PSLM) survey reports.

However, it is agreed that there is lack of time-based energy consumption and energy cost based data of end-use and appliance. The number of urban households in Pakistan was estimated in the study by the urbanization patterns, number of urban population and average household size.

3.3. Development of Modeling Framework

3.3.1. Structure of energy model

The Long Range Energy and Alternative Planning (LEAP) software which uses quantitative analysis approach, was applied to simulate how energy development might build up in Pakistan. Mathematical operations of extrapolation, growth rate method or interpolation were used to analyze energy supply-demand patterns and GHG emissions.

In this model, its in-built ‘Technology and Environmental Database-TED module’ is linked to all fuel categories in order to perform analysis of emissions of existing and future household devices and technologies. Nature and concentration of the emissions are assumed as environmental effects of the characteristic fuel composition.

Equation (1) presents calculation of fuel-based emissions of household devices:

$$C = \sum_{h} \sum_{m} \sum_{f} A_{f,m,h} \times EI_{f,m,h} \times EF_{f,m,h} \qquad (1)$$

where, “C” denotes “carbon emissions”, “A” is “activity level”, “E” denotes “final energy demand”, “I” represents “energy intensity”, “EF” is “carbon emissions factor”, “*f”* is “fuel type”, “*h”* is “sector” and “*m”* is “household appliance or device”.

On conceptual basis, this model drives upon an energy-services based scenario analysis. Its operations are based upon sectoral characteristics and wider environmental and socio-economic factors which are incorporated into the model. The model structure is elaborated in Figure 3.1.

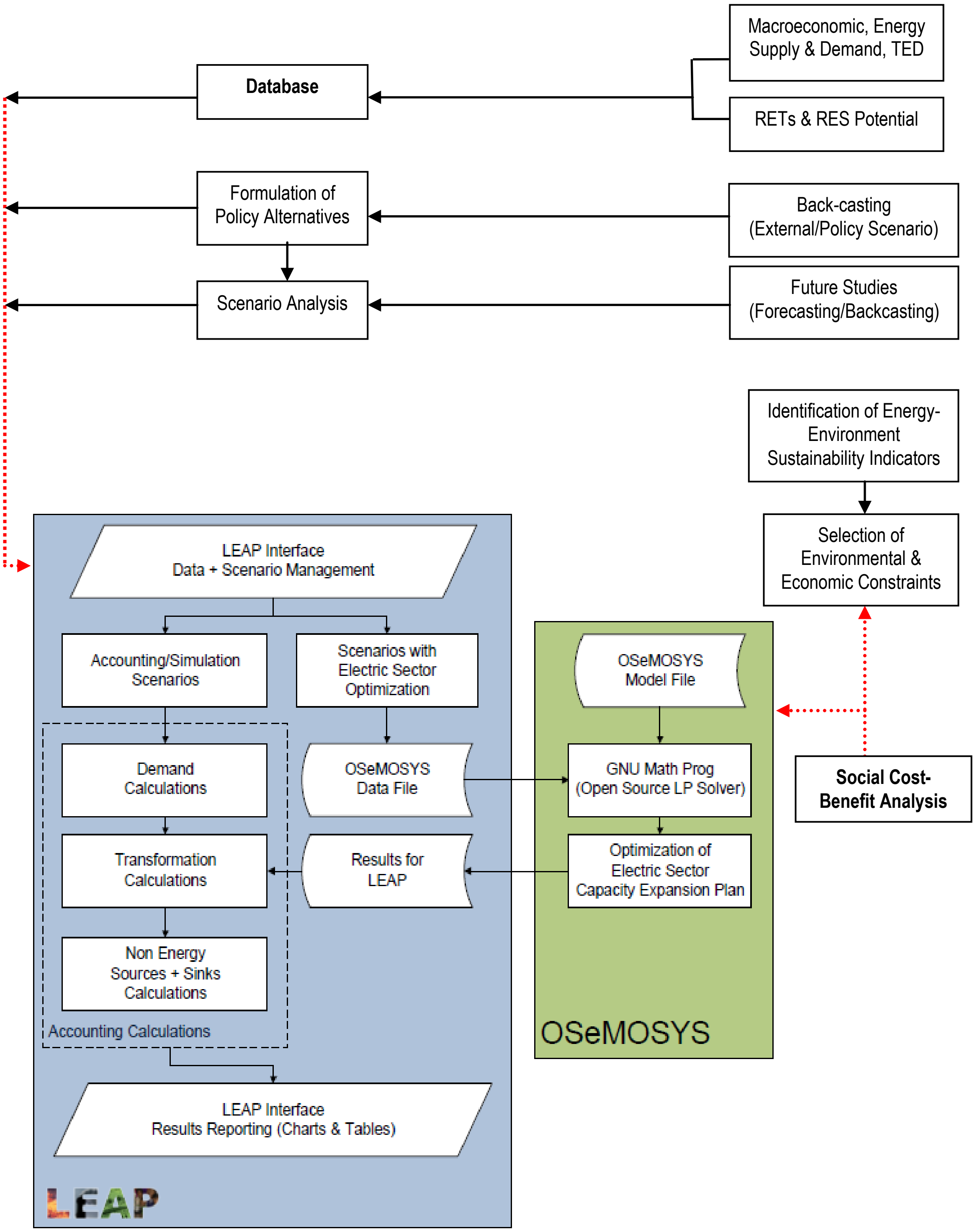


Fig. 3.1: Framework of the Proposed Long Range Sustainability model for Energy and Electricity Sector of Pakistan

3.3.2. Demand side framework

The demand side study framework is presented in figure 3.2. in this framework, energy services are disaggregated into 6 attributes, namely ‘lighting’ (IBs, FTLs, CFLs and kerosene lamp), ‘cooking’ (electric stove, natural gas stove, LPG stove, biomass stove), ‘cooling’ (fan, air-conditioner and refrigerator), ‘heating’ (space heaters, water geysers, biomass usage for heating), and ‘general appliances’ (iron, TV, washing machine, others). The percentage share of energy consumption at device or appliance level is further disaggregated into conventional and more efficient ones, being used or expected to be introduced soon.

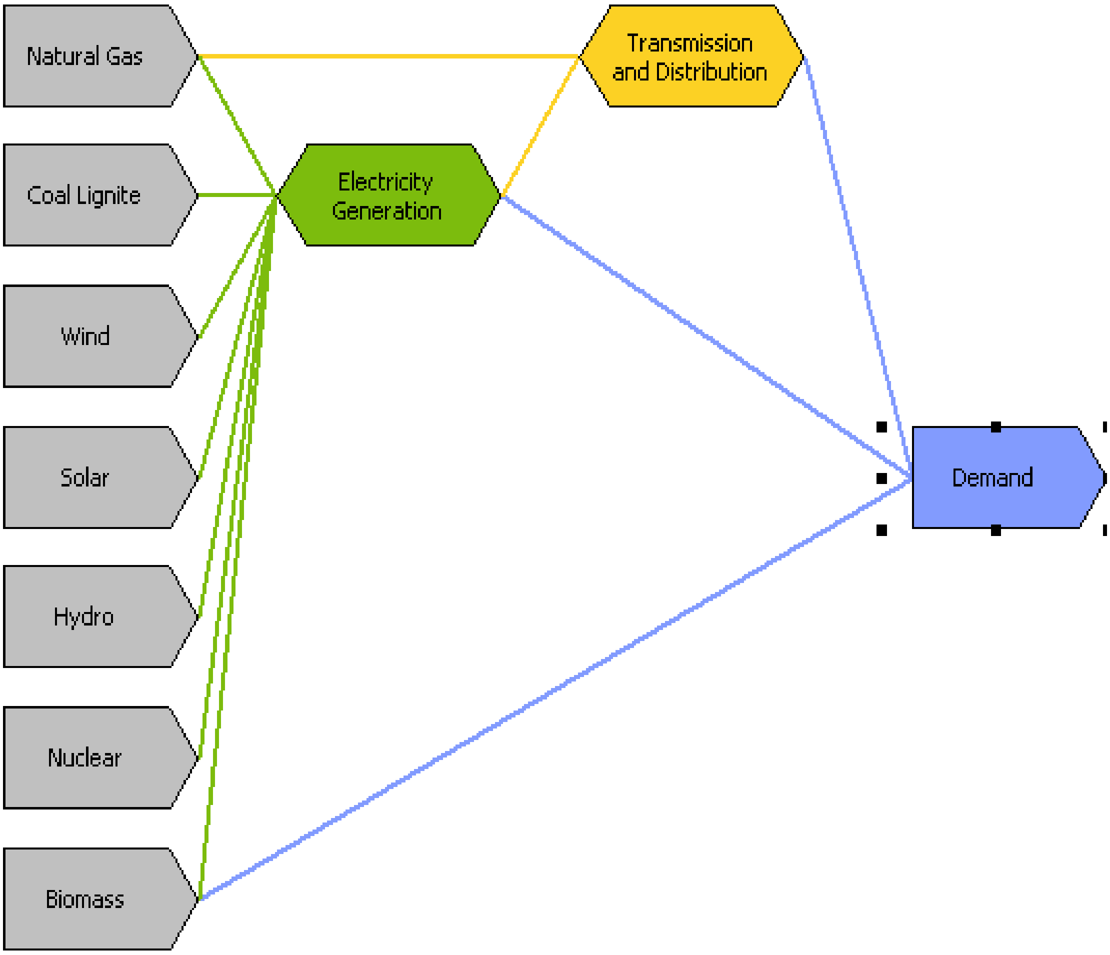


Fig. 3.2: Demand Side Energy Model

The “energy intensity” of household appliance (I), is calculated as the function of number of appliances, capacity of appliances and average usage hours. For lighting end-use, the data on average number of appliances per household and usage hours per day were acquired from the household energy survey report. The average capacity of conventional and high efficiency appliances/ devices was also obtained from the PEPCO website and company profiles of those devices.

The "annual energy consumption of a given technology" was determined for an urban middle income, average household as number of urban households, saturation of the end-use in the household, share of the end-use, and efficiency of the end-use and unit energy consumption of the given technology. Hence, "total energy consumption" is sum of different technology categories. Accordingly, equation (2) presents calculation of annual energy demand of existing and proposed energy technologies in household as below:

$$E_f = \sum_h \sum_m A_{m,h,f} \times I_{m,h,f} \tag{2}$$

here, "E" denotes "final energy demand", "A" is "activity level", "I" represents "energy intensity", "*f*" is "fuel type", "*h*" is "sector" and "*m*" is "household appliance or device".

3.3.3. Supply side framework

This supply framework is broken down into sector, module, process, output fuels, feedstock fuels and auxiliary consumption for each branch. Electricity and natural gas losses due to T&D were quoted from the yearly energy books and put at respective module level in the framework**.** Electricity generation, represented within the transformation module, relies upon mathematical operations of demand-side. Diagram for supply side study is shown in Figure 3.3.

In the electricity generating sector, power plants are categorized on the basis of a range of their performance factors. For output fuel properties i.e. electricity, the goal is to decline the deficit for which fuel import is allocated as the shortfall-rule. Whereas, the surplus-rule is set to export the surplus electricity.

The electricity generation module modeled in this study provides a transparent and comprehensive framework to determine the make-up and potential of power generation during the study period. It also assists in implementation of green scenarios for electrical energy generation.

In this framework, both primary and secondary fuels for power generation are further divided into imported and exported fuels. The price and reserves of these fuels is obtained from energy year book and economical survey. Growth rate was set for fuel prices to reveal future trends.

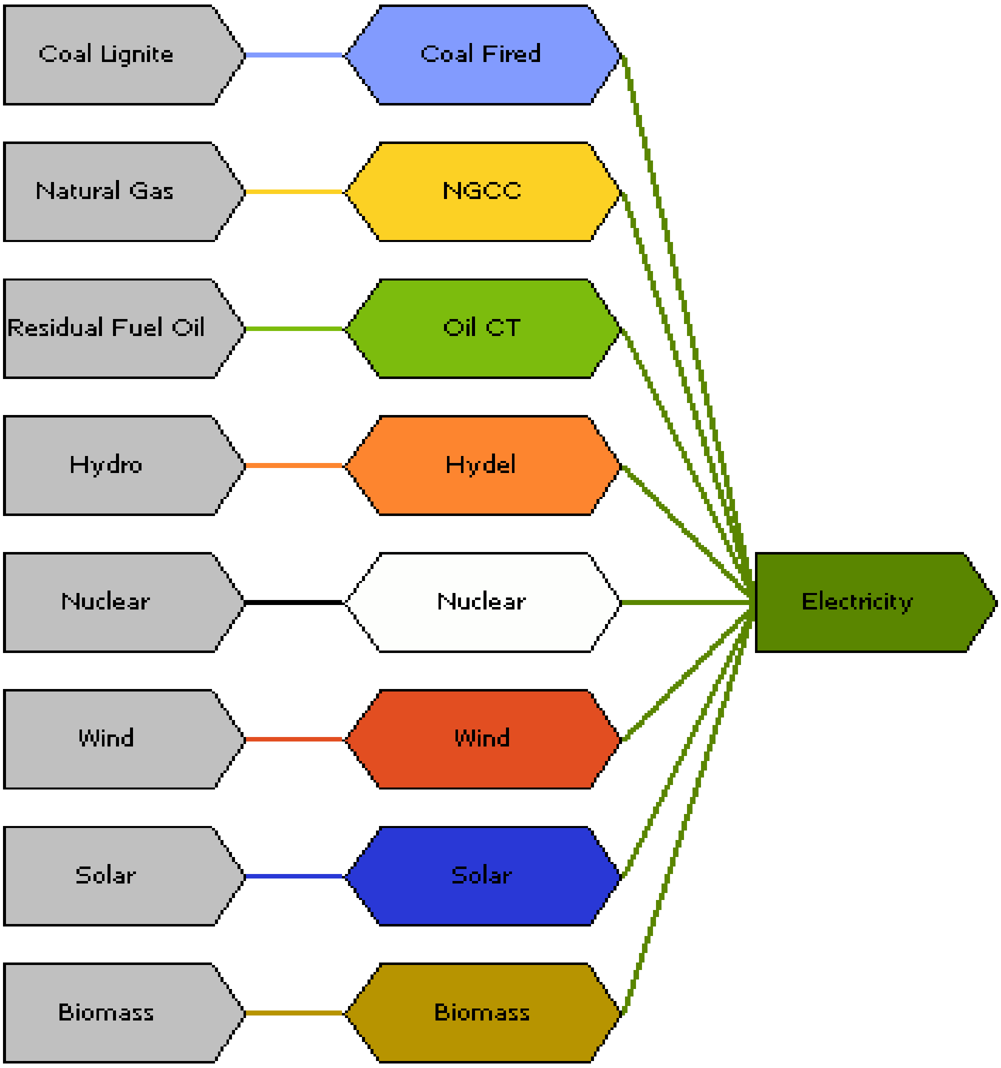


Fig. 3.3: Electricity Generation Model

All cost data used in the base-year of model i.e. device cost, investment, operating and fuel costs is first converted to US dollars with Pakistan conversion factors cited from GoP (2011). The default discount rate was set at 5% and planning reserve margin to 30%. Data on historical energy production was used to dispatch power generation processes in the study before the first simulation year, 2011(Table 3.2).

Table 3.2: Base-year (2011) data to Dispatch future Power Generation (GWh)

Power Plants	**Electricity Generation (**GWh**)**
Coal fired PP	116.40
NGCC	10307.7
Oil CT	17167.6
Diesel CT	0.1
CCGOT	36779.3
Hydel PP	28093.1
Nuclear PP	2894
Total	95358.2

In the software, exogenous capacity additions were built-in to the supply side model to show current and future committed capacities of power plants. Also, endogenous capacities were added into the model which is detailed in sections of respective scenarios.

3.4. Construction of Energy Policy Scenarios

In the present study, policy alternatives are suggested for Pakistan to assess their capabilities to drive energy development. The planning period for the study used in this model starts from year 2012 and completes in year 2050, with 2011 as base year. The scenarios are detailed in following sub-sections.

3.4.1. Reference scenario (REF)

Once the initial year data was gathered and prepared, the data collection process shifted its focus to the requirements for development of the reference scenario. Following hypotheses were proposed for simulation of the current and historical database which was projected from the base year of study (2011) to the end year (2050), using extrapolation and growth rate functions. Detailed simulation activity is also reflected in the next chapter of baseline development.

- Rapid urbanization and excessive population growth in developing countries has resulted in haphazard and unplanned growth of big-city settlements. Under the usual scenario, the urban households are expected to increase at an annual growth rate of 3%.

- Increased access to electricity and natural gas will gradually decrease biomass and LPG consumption.
- With increasing income levels and government incentives for energy-efficient devices, people will shift toward less energy-intensive devices. This is interpreted as reduced energy intensities of existing devices per household.
- T&D losses will decrease.
- The existing power plants have already completed their shelf life or not working to full capacity. In case of no new built, these plants are expected to retire till 2030
- The increasing burden of oil import on national economy will decrease its option for power generation by 10% per year
- Similarly, diesel combustion turbines are expected to be replaced 5% in 2015 and 10% in 2025 with biomass alternatives
- Unavailability of resources for natural gas extraction is assumed to decrease its potential for power generation by 5% per year
- In case of no new nuclear power plants, the existing KANUPP-I (PHWR) of 137 MW installed capacity, is operating at power level 90 MWe on an extended lifetime till 2017. C-I (PWR) of 325 MW installed capacity has operated its 10 years of life time till 2010.

Keeping these policies in view, new power plant additions are proposed in the study to maintain the planning reserve margin of 30% (Table 3.3). Some new capacity additions are being planned under governmental policies which were considered for exogenous capacity additions under reference scenario in next chapter.

Table 3.3: Endogenous Additions of Power Plants Capacities under REF

New Capacity Addition	Addition Order	Add. Size Expression (MW)
New Coal fired PP	1	2250
New Hydel PP	2	2481
New Nuclear PP	3	680
New CCGOT	4	4860

3.4.2. Alternative policy scenarios development

In these scenarios, alternative policies were introduced into the model to explore their potential in comparison with the findings of the REF. These policies are in line with the NDCs of Pakistan for mitigation across the energy sector.

3.4.2.1. Supply side management scenario (SSM)

In this study, a supply side management scenario is proposed which consist of a combination of different options as power generation alternatives. These options include coal, natural gas, oil, hydel, nuclear, wind, solar and biomass resources. This scenario aims to reach to a least cost electricity generation mix for supply side management in Pakistan. Capacity additions for these alternatives were interpolated to future years in light of various governmental policies for which the cost factor is still questionable. Following are the anticipated policies under SSM:

- In Integrated Energy Plan-2022, PPIB and public sector plans to induce a minimal ten thousand megawatt of power from local coal whereas three thousand megawatt by year 2022 from imported coal for base-load units.

- Cogeneration and LNG based power generation is planned to produce 9000 MW by 2022.

- If 10% of diesel consumed by Pakistan is switched to biodiesel, country’s annual import bill can decline by approx. US $ 1 Billion. ECC has already set indicative target of substituting five percent of annual consumption of petroleum diesel fuels by 2015 with biodiesel, and 10% substitution by year 2025. National Biodiesel Program with Pakistan State Oil (PSO) is operational under which 18,000 tons commercial biodiesel will be annually produced in Karachi.

- A Biogas Project has been initiated with New Zealand assistance to generate 50 MW of electricity. Similarly, 10 MW power will be available from a waste to energy study being conducted in Karachi. In this study, it is interpolated to reach 60 MW in 2050.

- PPIB and public sector plans to induce hydro capacity of 17,392 MW. WAPDA plans to raise the hydro generation capacity to 33,030 MW by small and big hydel plants under its vision 2025. For the purpose of this study, it is interpolated to reach 17,392 MW in 2022 and 32,733 MW in 2050.

- Government authorized PAEC for installing 8,800 MWe capacity of nuclear power by 2030. A new C-2 nuclear plant of 340 MW capacities is connected to national grid in 2011. Construction work has been started on another C-3 (PWR) plant of 340 MWe (Khan *et al.* 2011). This will add 4400 megawatt to national grid nuclear by 2022 as planned in Economic Advisory Council report (2009).

- Under the Power Development Programme 2030, WAPDA has planned to add an expected cumulative capacity of 106656 MW till 2030 (Economic Adviser’s Wing, 2011). So, thermal and nuclear capacities alone will contribute to an estimated 285586 MW by 2050. Combined oil and gas thermal unit capacities are interpolated in this study to generate power at 177460.4 MW installed capacity in 2050.

- AEDB (2009) has planned to induce 17400 MW through wind by 2022 which is interpolated to reach 17400 MW in 2022 and 20000 MW in 2050 in this study.

- Due to excessive solar potential in Pakistan, the solar power generation capacity is interpolated to reach 19,000 MW in 2050 (Alternate Energy Development Board, 2009).

3.4.2.2. Least cost electricity generation scenario (OPT)

To bridge the energy gap, major indigenous supply options were considered to reach to a least cost electricity generation scenario. Following steps were followed:

- Investigating various technology options for power generation

- Comparing cost of generating electricity from those technologies
- Performing sensitivity analysis to examine the cheapest adoptable option while considering externality-cost of local air pollution, included or excluded.
- Exploring the consequences of a cap on CO_2 emissions to see how it influences the proposed technology options and the implantation cost of the scenario.

For calculation of process capacity values consistent with minimizing costs while meeting demands, LEAP's optimization operation was utilized. Optimization calculations were performed in the model through Open Source Energy Modeling System **OSeMOSYS**. This system relies upon **GNU Linear programming Kit** (GLPK software tool). The GLPK intends to solve large scale linear programming problems by means of the revised simplex method. Emissions constraints were also added to the model to achieve a power supply set which consumes least cost and is environmentally favorable.

Eight simulation scenarios exhibiting independent fuel resources for power generation (Coal Only, NGCC Only, Oil Only, Hydel Only, Nuclear Only, Wind Only, Solar Only and Biomass Only) were created. Costs and emissions associated with different technologies proposed in these scenarios will be explored. Here, exogenous capacity variables were all set to zero and dispatch rule was set to running cost. Endogenous capacity variable set for each scenario is presented in Table 3.4.

Table 3.4: Endogenous Additions of Power Plants Capacities under OPT

Process	Addition Size Expression (MW)
Coal Only	100
NGCC Only	100
Oil Only	100
Hydel Only	100
Nuclear Only	100
Wind Only	100
Solar Only	100
Biomass Only	100

Consequently, a new scenario, Least Cost Electricity Generation/ Optimization (OPT) was created through in-built decision preferences of LEAP tool. Emissions constraints were also added to the model to achieve a power supply set which consumes least cost and is environmentally favorable.

3.4.2.3. Demand side management scenario (DSM)

In order to reduce energy consumption in urban household sector, different policy alternatives were proposed for future implementation. These policies assumptions are elaborated in Table 3.5.

Table 3.5: Alternative Energy Policies for DSM

Policy Measure	Description
Efficient Lighting	• Modern lighting standards will cut down 1% of existing energy intensity annually. The remaining share of existing lighting devices targeted for IBs and FTLs is 15% and 30%, respectively, by 2050.
Efficient Cooking	• Introduction of retrofits for stoves is already in place by natural gas transmission and distribution companies in the country. This is expected to reduce the energy intensity of cooking per household by 70% in 2050. • Increased access to natural gas will also decrease the household share of LPG and bio-fuel cooking devices by 20% and 10%, resp. • Increased future adoption of electric stoves is assumed to increase the household energy intensity at 0.3% per year.
Efficient Space Heating	• Household efficiency standards will lower biomass consumption for space heating through reducing its share to 7% of households by 2050.
Efficient Water Geysers	• High-efficiency heating appliances will be promoted to replace 40% of household shares of existing natural gas geysers by 2050. It will reduce major energy consumption of household by 70% in 2025 and 90% in 2050.
Efficient Cooling	• Efficient-energy labels will reduce average intensity to 5% in 2020 and 20% in 2050, and 20% for air conditioners. • Conventional refrigerators and air-conditioners will be replaced with high-efficiency ones by 75% and 40% respectively, by 2050.
T&D Loss Reduction	• Power losses will decline up to 18% by 2025 and 14% by 2050. In addition, natural gas pipeline losses will be reduced to 2%.

3.4.2.4. Mitigation scenario (MIT)

The final "mitigation scenario" is constructed by integrating the outcomes of proposed policies into sector-wise combinations and subsequently bringing under an all-policy MIT scenario. Here, the supply side exhibits usual-case along with the "10% target of electricity generation from renewable resources by the year 2025" (Table 3.6).

Table 3.6: Endogenous Additions of Power Plants Capacities under MIT

Process	**Renewable Electricity Scenario**		**Mitigation Scenario**	
	A.O	**Addition Size (MW)**	**A.O**	**Addition Size (MW)**
New Coal fired PP	1	2250		
New Hydel PP	1	4000	1	4000
Wind	2	2100	2	2100
New Nuclear PP	3	680	3	680
Solar	3	2100		
New CCGOT	4	4860		
Biomass	4	2071	4	2071

In short, 'MIT' is a combination of energy-efficient household devices and renewable energy options from hydel, solar, wind, and biomass. This infusion of renewable energy options to meet the target of 10% electricity generation by 2025 can also be visualized in the supply side model to reach the Mitigation Scenario depicted in Figure 3.4.

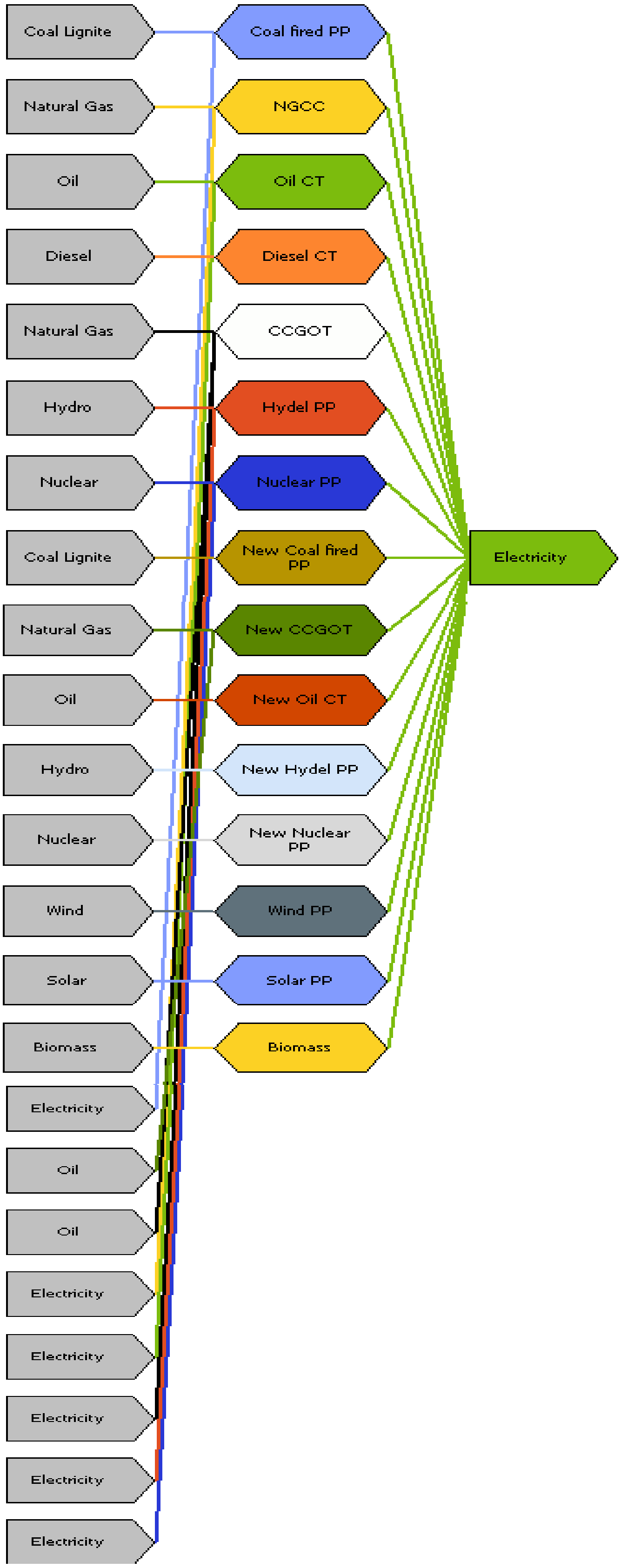


Fig. 3.4: Supply Side Model to reach Mitigation Scenario

3.4.2.5. Cost benefit analysis of scenarios

Keeping in view the perspective of socio-economic impacts transformation and consumption, an integrated cost benefit analysis was done through societal lens. This involved a comprehensive cost comparison among proposed technologies for demand, supply, optimization and mitigation scenarios.

Again, the LEAP software was used for economic valuation of proposed scenarios. Factors considered for the cost benefit analysis of the demand side policies included penetration, performance and cost of the energy efficient technologies. Data on device costs was gathered from market survey. Activity cost method was used to calculate annualized demand cost of efficient devices per household over their lifetime. It employs a standard mortgage formula.

For the supply-side, the target of 10% renewable based electricity generation by year 2025 was also considered. Cost benefit analysis of renewable options was carried out by the software on the basis of plant performance characteristics provided in the model.

Chapter Four

ENERGY POLICY REVIEW

4.1. General Introduction

In this chapter, power sector of Pakistan has been reviewed in order to describe the study area and identify gaps in existing energy system. It begins with a brief introduction of administrative and policy framework of the sector. Detailed review of challenges in achieving energy sustainability has already been done in chapter 2. On the basis of literature review and discussions held with energy and environment experts, the country’s energy mix has been analyzed in terms of fuel composition, renewable energy share, supply-demand pattern with focus on household sector, clean energy potential and overall GHG emissions of energy sector. Accordingly, frameworks for demand and supply sides were devised in this chapter for scenarios development in next chapter.

4.2. Description of Study Area

Pakistan is located in South Asia, sharing border with China, India, Iran and Afghanistan. It occupies an area of 803,940 km^2 of which 97% is land and rest is water. Due to its highly diverse physiographic and climatic conditions, it is classified into 11 geographical, ten agro-ecological and 9 major ecological zones. With a population of 177.10 million, it is the sixth largest in world and second highest urbanizing nation in South Asia (GoP, 2017a).

Pakistan is challenged with an excessive vulnerability to climate change due to characteristic demography, geography and geology. This situation is augmented due to presence of huge glacial reserves in the north which melt and flow supplying more than 70% of the river flows (Khan *et al.* 2011). Its world’s sixth largest reserves of coal along with the untapped hydel potential alone can fulfill its growing energy needs.

4.2.1. Administrative framework of power sector

With the privatization of Karachi Electricity Corporation (KESC) in 2005 and privatization and restructuring of Water and Power Development Authority (WAPDA) since 1998, electricity sector setup changed. The GENCOs of WAPDA work under PEPCO. In practice, WAPDA is still a vertically integrated utility and restructuring has not been worked out properly (Malik, 2007; NEPRA, 2010). Administrative structure of the Pakistan power sector is designed in Figure 4.1.

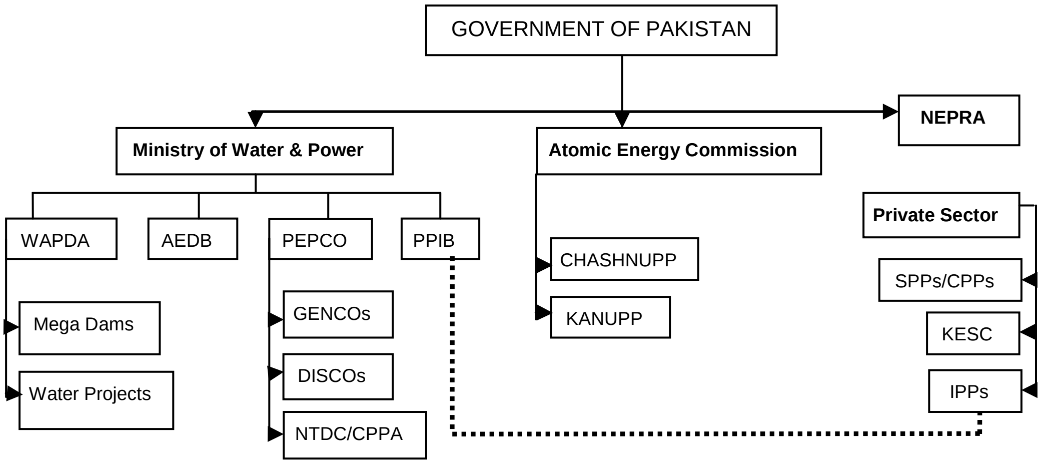


Fig. 4.1: Administrative Layout of Pakistan Power Sector

4.3. International Obligations and National Commitments on Energy Environment

With the endeavor to meet its global pledge, Pakistan has adopted the Sustainable Development Goal (2030) regarding “access to affordable, reliable, sustainable and modern energy for all” as country’s priority. The Pakistan Vision-2025 also identifies “Energy Food and Water Security” as one of the seven pillars of national development. Such energy system is indispensible in view of climate change challenges and recent global initiatives on environment that impose bigger implications on developing countries.

One such multilateral agreement is the UNFCCC and Kyoto Protocol-Paris Agreement, 2015 which aims to limit the rising global average temperature to two degrees centigrade by mid of this century. This binds developing nations to lessen their carbon foot print by introducing clean technologies and reducing fossil dependency especially in power sector. Supporting financial mechanisms are also provided to governments and entities through Global Environmental Facility (GEF), Green Climate Fund (GCF) and Clean Development Mechanism (CDM) which encourage expansion of carbon markets (Nakata *et al.* 2011; Li and Li, 2017).

Various energy-environment policies and plans have been formulated. Relevant sections of these policies are mentioned below:

4.3.1. Power plan, 1994:

Government declared various steps to promote the private power sector role. This is also reflected in the subsequent policies devised for power sector in Pakistan. The 1994-plan aimed for load forecast, generation planning and transmission expansion planning for the period from 1992 to 2018. It was later modified in years 1995, 1996, 1998, 2003, 2008, 2011, 2012 and 2014 to pace with the growing energy needs.

4.3.2. Policy for power generation projects, 2002:

The 2002-Policy includes private, public-private and public sector projects. Its objectives consist of provision of sufficient capacity for power generation at the least cost and to avoid capacity shortfalls, encouragement and ensuring exploitation of indigenous resources which include renewable energy resources, human resources, participation of local engineering and manufacturing capabilities to ensure that all stakeholders are looked after in the process, i.e. a win-win situation for all and to be attuned to safeguarding the environment.

Its Section 9 address the need for environmental compliance of energy projects as, "all requirements of the PEPA Act (1997), inter alia, relating to environmental protection, environmental impact and social soundness assessment, shall have to be met".

4.3.3. National energy conservation policy, 2005:

It provides guidelines and possible actions that can enhance end-use efficiency for various energy-consuming sectors of the economy and also for addressing various cross-sectoral issues that continue to retard promotion of energy conservation. Its main objectives are, "fostering energy conservation through stimulation of resources and regularizing total energy management programs in all sectors of economy, development of energy conservation market and facilitate commercialization by creating awareness and launching nation-wide demonstration projects, maximization of the demand for energy from indigenous resources, and creation of an enabling environment to reduce energy intensity of different energy consuming sectors through appropriate technological and policy measures, so as to promote sustainable growth".

4.3.4. National energy security action plan (2005-2030):

This national plan also included in “MTDF 2005-10” was devised with the aim to meeting the requirements of Pakistan’s Vision 2030 for reliable and quality energy supplies. Its objective is “to enhance energy supply through an optimal mix of all resources including hydropower, oil, gas, coal, nuclear and renewable energy such as wind and solar”. It also offers optimum use of indigenous fuel resource in order to cut reliance on expensive imported fuel.

4.3.5. Integrated energy plan (2009-2022):

Its aim is to provide a road map for Pakistan to achieve greater energy self-sufficiency by pursuing policies that are sustainable, provide for energy security and conservation, and are environment friendly. The plan emphasizes upon greater self-reliance on indigenous resources and renewables, energy diversity and energy security.

4.3.6. National environmental policy, 2005:

The main federal policy on environment aims to promote protection of environment, honoring of international obligations, sustainable management of resources, and economic growth. It calls for setting of standards and regulations for ambient and indoor air quality, vehicle emissions and manufacture, energy conservation, fuel specification and building codes. It aims to promote mass transit and non-motorized transport as well as cleaner technologies, including natural gas (LPG), solar, hydroelectric, biogas and cogeneration with waste, and offering tax incentives for efficient products.

4.3.7. Power development program (2010-2030):

In accordance with existing and future needs, WAPDA put forward this program for power expansion by 106656 MW at national level through capacity additions of 34,040 MW till 2030.

4.3.8. National power policy, 2013:

This most recent policy aims to develop the most efficient and consumer centric power generation, transmission, and distribution system that meets the needs of its population and boosts its economy in a sustainable and affordable manner. It has been devised upon principles of "efficiency, competition and sustainability to achieve reduction in supply demand gap (from 4500 - 5000 MW to 0 by 2017), affordability (decrease cost of generation from 12c / unit to ~10c / unit by 2017), efficiency (decrease T&D losses from ~23-25% to ~16% by 2017), financial viability and collections (increase collection from ~85% to 95% by 2017), and governance (decrease decision making processing time at the ministry, related departments and regulators from long to short durations)".

4.3.9. Pakistan vision 2025 one nation-one vision:

The goal is doubling the power generation upto 42,000 MW to provide uninterrupted and affordable electricity, and increase electricity access from 67% to over 90% of the population by 2025. The sub-goals include reduction of average cost per unit by over 25% by improving generation mix (15%) and reducing distribution losses (10%), increase percentage of indigenous sources of power generation to over 50%, and address demand management by increasing usage of energy efficient appliances/products to 80%.

4.3.10. Renewable energy plans/ RPS policy:

The 2006 Policy for Development of Renewable Energy for Power Generation was country's first ever initiative towards inclusion of small-hydro, solar and wind technology in the power mix. It goals are to "increase the deployment of renewable energy technologies in Pakistan, provide additional power supplies to help meet increasing national demand, introduce investment-friendly incentives, and facilitate renewable energy markets to attract private sector interest in renewable energy projects and devise measures to support the private sector in mobilizing, financing and enabling public sector investment in renewable energy projects".

Recently, the AEDB constituted under Board's Act-2010, laid down the (Certification) Regulations, 2018 as a framework for safe, secure and quality-assured supply of solar and wind energy generation products and installation and servicing for small industrial, commercial, agricultural and residential installations. Other policy initiatives in this regard are the Policy Recommendations for Use of Biodiesel as an Alternative Fuel-2008, Scheme for Financing Renewable Projects-Soft Loans-2009 (amended 2016), Alternative and Renewable Energy Policy-2011 (Medium term Policy), and Framework for Power Cogeneration-2013 Bagasse and Biomass.

All above obligations call for immediate response from Pakistan to reduce its energy sector emissions. Hence, in its NDCs submitted to UNFCCC, Pakistan has committed to reduce 20% GHG emissions against the projected value in 2030. In order to achieve this target, priority has been allocated to mitigation efforts in energy sector. Induction of efficient technology has been proposed for generation, supply, conservation and promotion of clean energy. However, positive outcomes of these commitments rely upon an integrated plan which must address all aspects of sustainability.

4.4. Energy Composition of Pakistan

4.4.1. Energy supply and demand status

Currently, there is approximately sixty-two percent access to electricity and twenty-five percent access to natural gas in Pakistan. Although approximate 3500 megawatt efficiency potential exists in electrical energy sector however, the efficiency ratio currently in operation is unsatisfactory.

On the Pakistan’s independence year 1947, a sixty megawatt capacity of electricity production was available with per capita utilization of 4.5 units for a total 31.5 million people. With major increase up to 79% in nuclear generation, electricity generation peaked to 95,608 gigawatt-hour, accounting 249 gigawatt-hour imported from Iran, during 2009-10.

The face of Pakistan’s energy sector has seen a variety of fuel-based eras starting from thermal dominancy during the period 1947-1959, shift to hydropower from 1960 to 1963, back to thermal during 1964 to 1968, return of hydropower era during 1969–1975 followed by one year thermal dominancy in 1976, revival of hydropower in 1977–1988 and subsequently thermal during 1989-2012, leading to the present era of efficient and alternative energy sources starting from 2013.

Despite the fact the country is provided with sixth largest global coal reserves, yet the two-third of overall power generated is based on natural gas and imported oil fuels. Furthermore, during base year of this study, almost 70% of total installed capacity of public sector thermal generation companies was above over fifteen years older. This was also reasoned to the inefficient and limited supply capacity. Recently, six coal thermal stations of 4,290 MW cumulative capacities were installed. It was further planned to run 5,201 megawatt capacity of seven units on imported coal instead of indigenous coal.

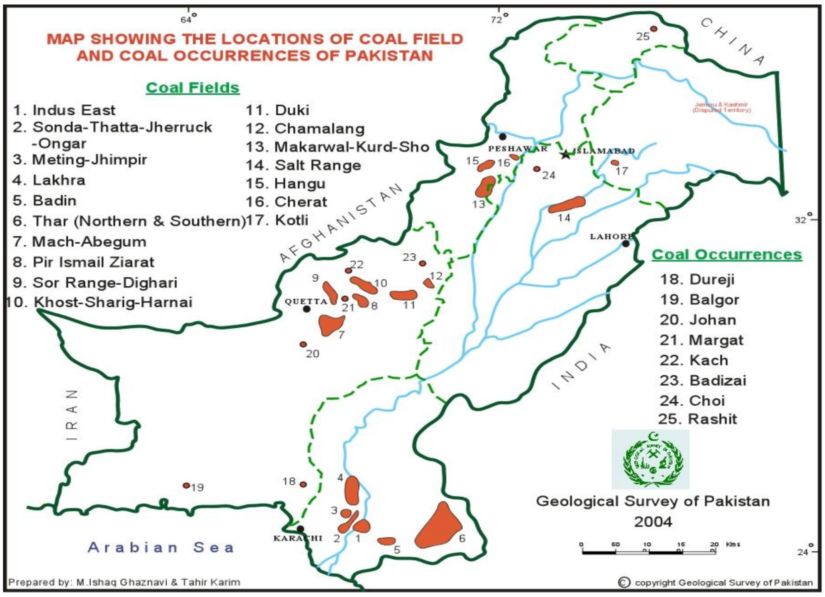


Fig. 4.2: Map of Pakistan showing Coal Reserves (Source: Geological Survey of Pakistan, 2004)

In terms of nuclear based electricity generation, the PAEC operates, plans and constructs of nuclear power generation stations. The GoP (2017b) states that currently 02 nuclear fuel-based stations i.e. K-1, C-1, C-2 and last addition of C-3 in 2016 are running on a total 1,090 megawatt capacity. Operationalization of C-4 in 2017 and K-2/K-3 is expected to achieve the target of 8,800 MW by 2030.

During base year of this study, 2011, Pakistan's primary commercial energy supplies were 63.1 MTOE with continued dependence upon natural gas fuel (at 48.8%), and oil fuel (at 31.4%) starting from year 1992. Whereas, electrical energy represented lesser share of the total energy mix, comprising up of hydro electricity 10.6%, coal 7.3%, nuclear electricity 1.1%, LPG 0.6% and imported electricity 0.1%. Figure 4.3 exhibits this continued dependence upon thermal fuel based power in Pakistan.

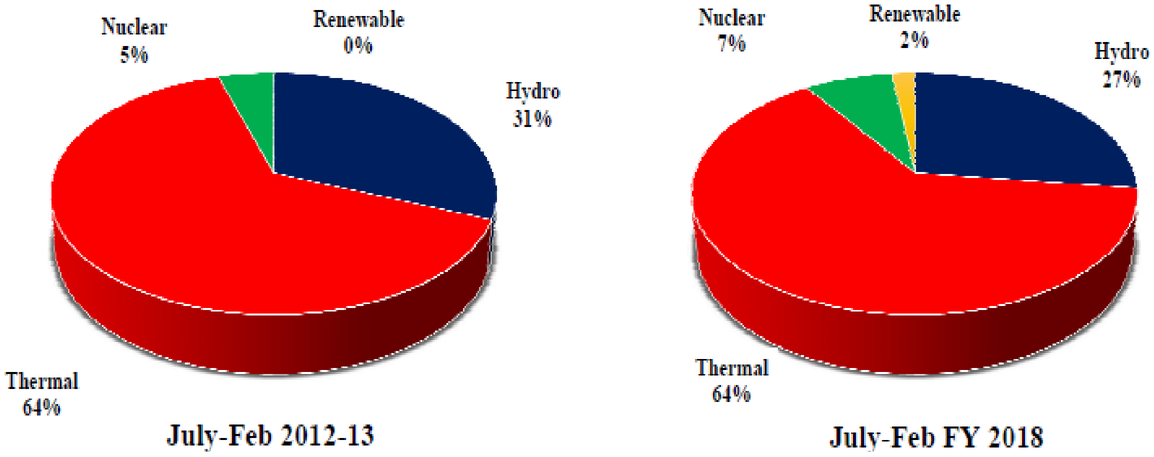


Fig. 4.3: Fuel Share in Electricity Generation (Source: GoP, 2018)

During recent years, the increasing trend in population and urbanization has exhausted this inefficient, limited capacity. As per estimates of GoP (2017), the installed electricity capacity of Pakistan faces world's highest rates of T&D losses causing shortfall peaks to 7000 MW (Fig. 4.4).

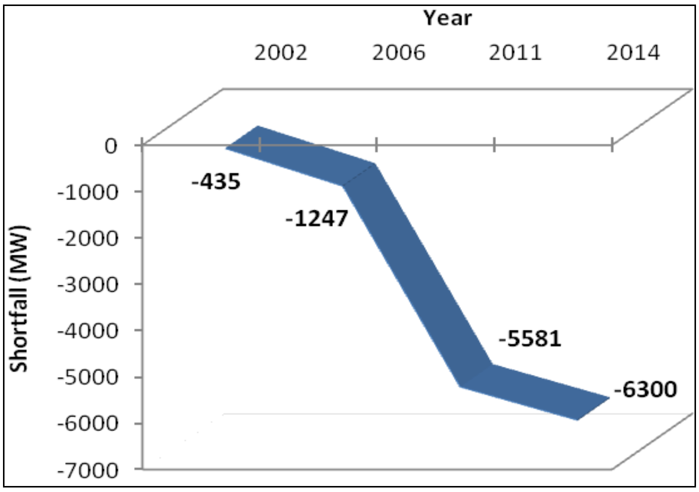


Fig. 4.4: Electricity Shortfall in Pakistan during 2001-2016 (Source: NEPRA, 2017)

In terms of electricity and natural gas consumption from the total supply, past trend continued in year 2017-18 (HDIP, 2018) as reflected in Figures 4.5 and 4.6. This unmet energy demand badly affected domestic sector. This situation worsened with domestic and industrial sector reliance upon inefficient electricity generators and illegal compressors for natural gas. Consequently, the usual cost of energy-usage and level of sectoral greenhouse gases shot-up which indicates a deeper crisis in energy policy making, governance, and regulation.

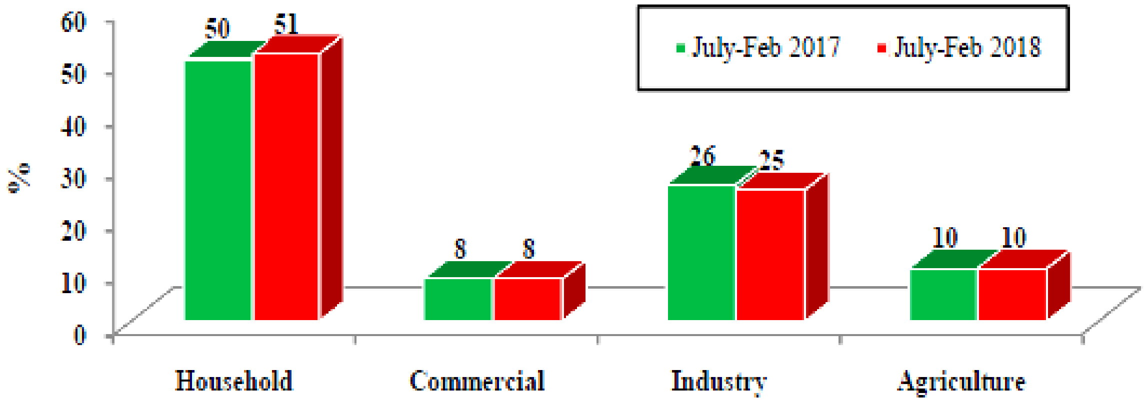


Fig. 4.5: Share in Electricity Consumption (%) (Source: HDIP, 2018)

According to the findings of an independent analysis by USAID and Planning Commission of Pakistan (2013), administrative flaws are responsible for the crisis. These include absence of government strategy to deal short-fall, delays and inaccuracies in tariffs with weak terms and conditions by NEPRA, unsettled arrears, inadequate fuel-price method, slow disbursement of contracts, court stays on fuel-price adjustments, T&D losses, inefficient thermal plants and energy mix by GENCOs, inadequate, delayed budgeting, disbursements and revenue collection to and from DISCOs.

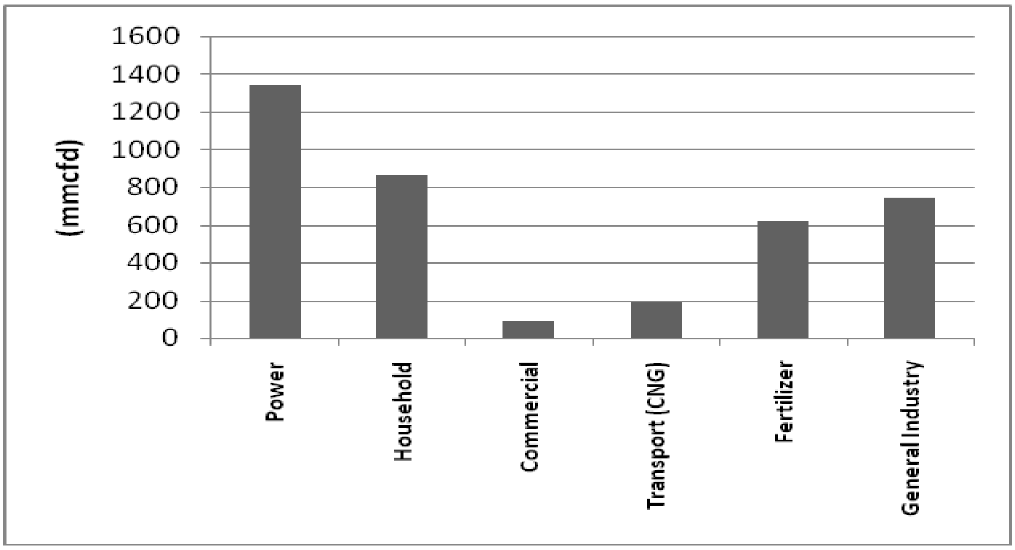


Fig. 4.6: Sectoral Consumption of Natural Gas Fuel (mmcdf) in year 2018
(Source: GoP, 2018)

Arshad *et al.* (2016), Ahmed *et al.* (2015), Mirjat *et al.* (2017) and Valasai *et al.* (2017a,b) identified other such causes as absence of a reliable strategy for demand-side management, non-consideration of renewable energy share, energy efficiency and its conservation. A study conducted by Asian Development Bank (2012) found that Pakistan has to enhance its domestic energy resources (hydro, gas, and coal) in order to meet demand and liberation from expensive oil imports.

4.4.2. Share of renewable energy in power mix

Currently in year 2018, the renewable-based capacity of 1,568 megawatt is operational in Pakistan. Excessive stress on conventional fuel sources and lack of technological advancements for mining and exploration calls for maximum induction of renewable energy sources. However, a limited number of household or community level renewable energy projects are being implemented to benefit from this source.

4.4.2.1. Hydro power generation

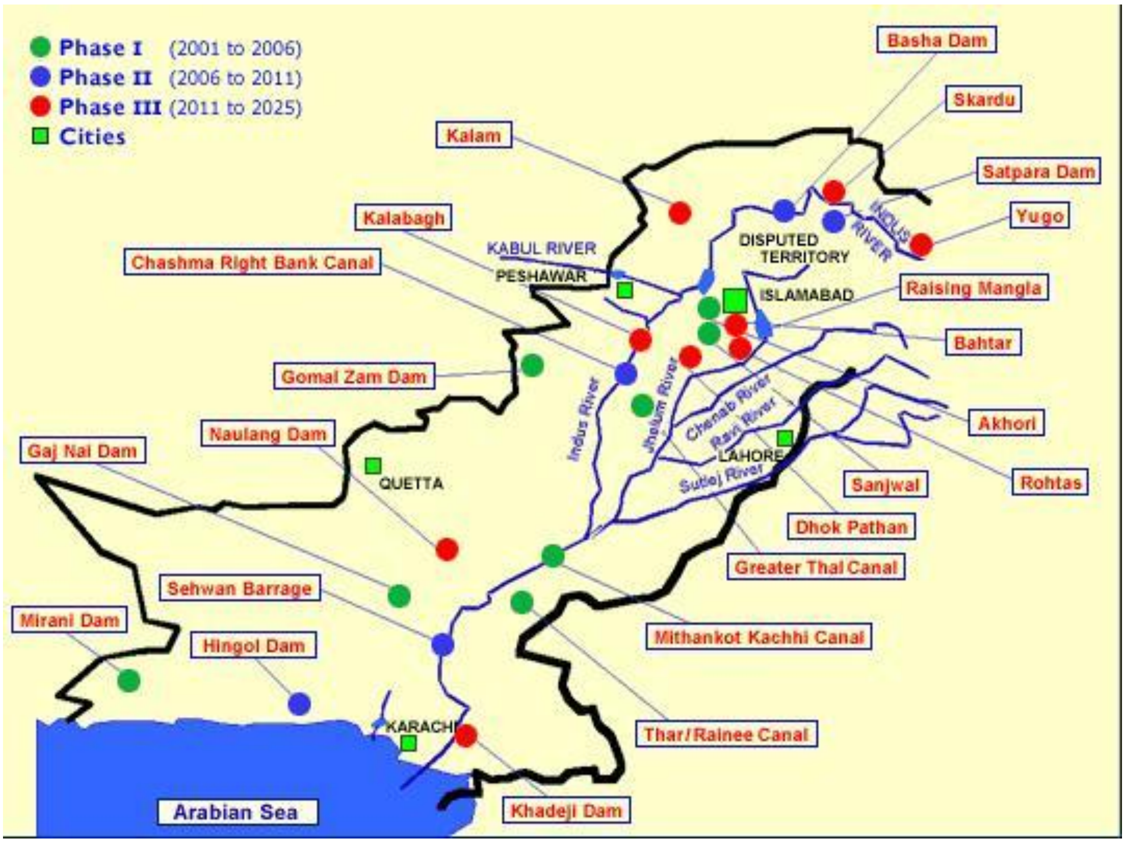
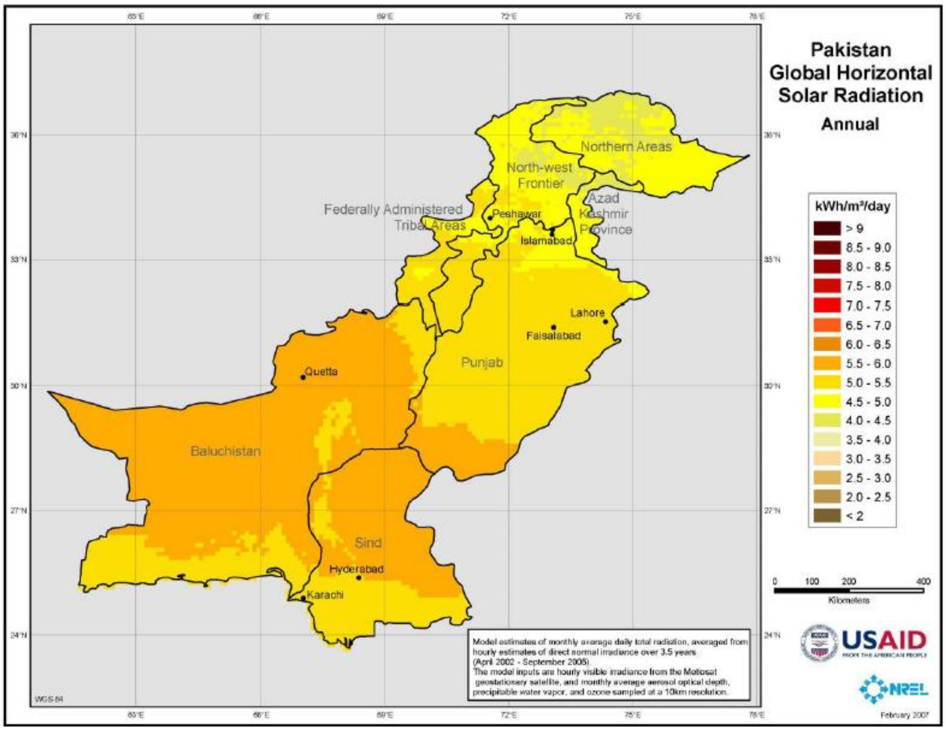


Fig. 4.7: Map of Pakistan showing WAPDA Vision-2025 (Source: WAPDA, 2004)

Hydropower currently contributes the biggest share of renewable energy generation in Pakistan. There has been a noticeable decline in hydel power over the last five years mainly due to less water availability. According to AEDB estimates, more than 1200 MW micro/mini hydropower potential is available in country while including power generation at northern mountainous region and southern plane region including energy generation through canal fall also. Out of this potential, less than 5% is being developed. For micro hydro power plants with capacities 100 and 500 kW each, an estimated potential of 300 MW and more than 400 MW, respectively exists in northern areas only.

4.4.2.2. Solar energy

Pakistan has been bestowed with an oscillating daily solar irradiation exceeding 5-6 kWh/m². According to AEDB, solar wind potential is estimated to be 2.0 million MW which is feasible for technical and financially viable both solar PV and thermal projects, on-grid or off-grid. Baluchistan receives highest solar potential followed by the potential in E-Sindh and S-Punjab. A total four hundred megawatt capacity of 4 solar farms under the Quaid-e-Azam Solar Park project were initiated during the base year of this study. Recently, seven IPPs and seventeen solar projects of 72.52 MW and 484 MW capacities, respectively are at different stages of completion.



Model estimates of monthly average daily total radiation, averaged from hourly estimates of direct normal irradiance over 3.5 years (April 2002 - September 2005). The model inputs are hourly visible irradiance from the Meteosat geostationary satellite, and monthly average aerosol optical depth, precipitable water vapor, and ozone sampled at a 10km resolution.

Fig. 4.8: Map of Pakistan showing Solar Irradiation (Source: http://www.nrel.gov/international/pdfs/pak)

4.4.2.3. Wind energy

At the coast of Sindh and Baluchistan and in valleys of KPK province, wind speed up to 5 to 7 m/second exists. The 60 km wide “Gharo–Kati Bandar wind corridor” has utilizable electricity generation potential of 50,000 megawatt. Technically the grid can take up to 30-40% of wind energy. Most of the remote villages in the south can be electrified through micro-wind turbines. But the lack of proper planning, cost analysis, availability of wind data and provision of adequate incentives to investors are perhaps major obstacles. The present installed generation capacity of wind power projects is 938.5MW. Twenty four wind power projects having a cumulative capacity of 1397.6 MW are at different stages of development/ operation (GoP, 2017, 2018).

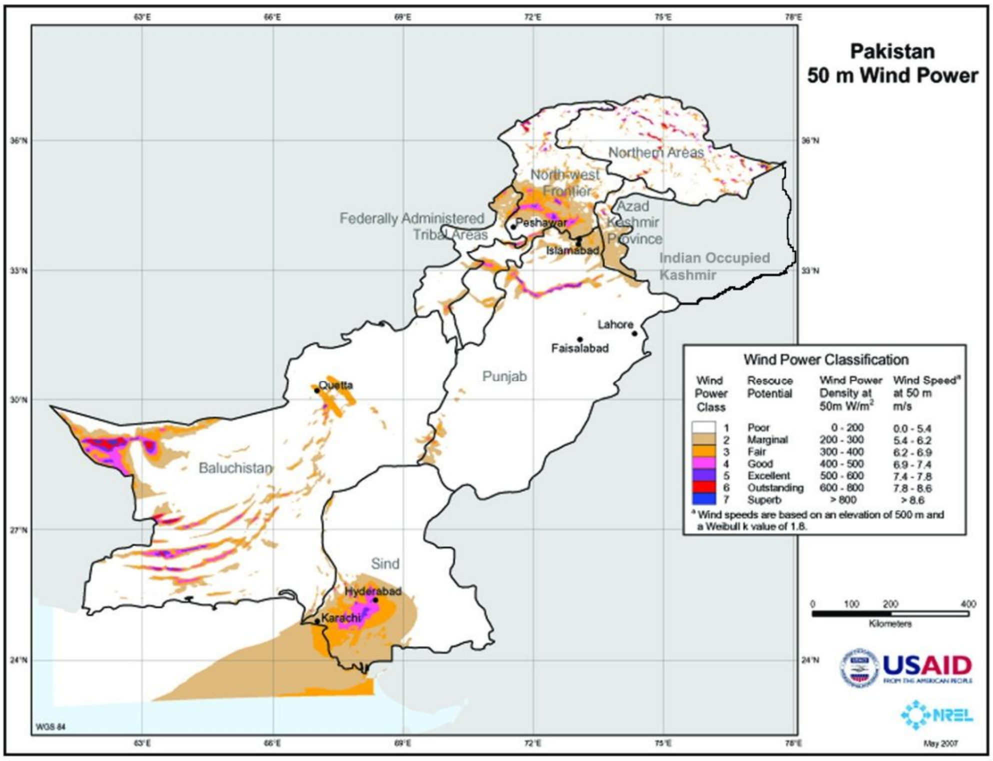


Fig. 4.9: Map of Pakistan showing Wind Power Potential (Source: *http://www.nrel.gov/international/pdfs/pak*)

4.4.2.4. Biogas

Pakistan is already heavily dependent on renewables, with a very high percentage of population using biomass energy, particularly in rural areas. The rural population meets more than 95% of their domestic energy needs by burning bio-fuels. Total biogas generation potential of 14.25 mm^3/day is available in the country. The life of these plants is being estimated up to 5 years. It is strongly being felt that high technology digesters generating more gas with capability of sustaining internal temperature under adverse environmental conditions and better life span should be installed (Sheikh, 2010). Biogas plants are gaining high popularity among the farmers of S. Punjab (Bahawalpur area). Under the Framework for Power Co-Generation 2013 (Bagasse/Biomass), 24 companies / sugar mills of 817.5 MW cumulative capacity are in process of development.

4.4.2.5. Geothermal energy

Although there are numerous hot springs with temperature ranging from 30º-170 ºC in various parts of Pakistan for example in the vicinity of Karachi and in the Pakistani part of the Himalayas but there has been no attempt to make use of geothermal energy in Pakistan yet (Sheikh, 2010).

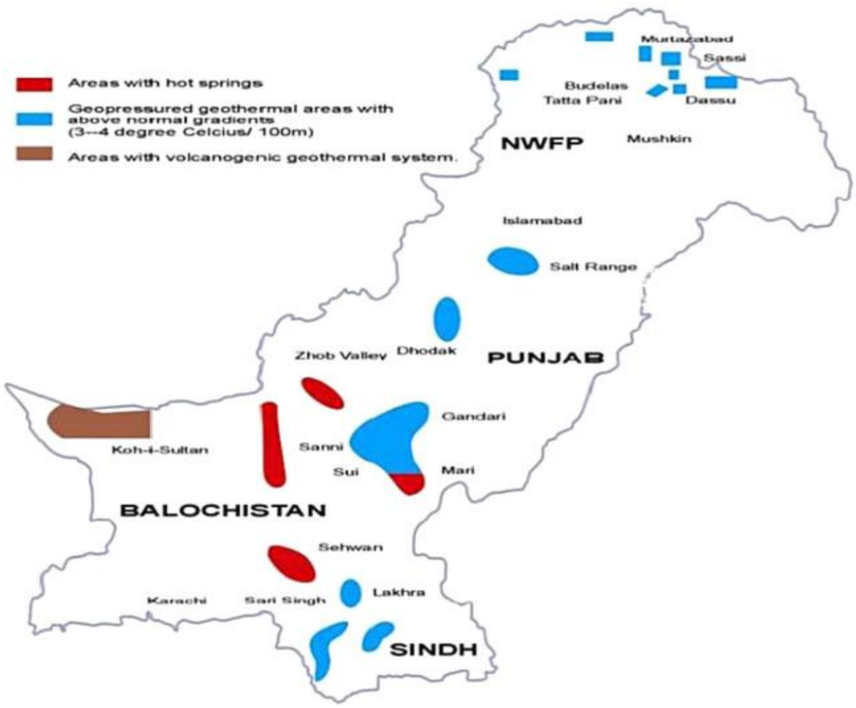


Fig. 4.10: Map of Pakistan showing Geothermal Potential

4.5. Energy Sector Emissions

Among the countries in South-Asia, the urbanization trend in Pakistan is ranked as the second fastest. Whereas, the country’s Environmental Performance standing in the Yale’s 2018 ranking is at 169th position among one hundred and eighty countries.

Moreover, on the criteria of environmental health sub-index, the country ranks at 177th position (Yale University, 2018).

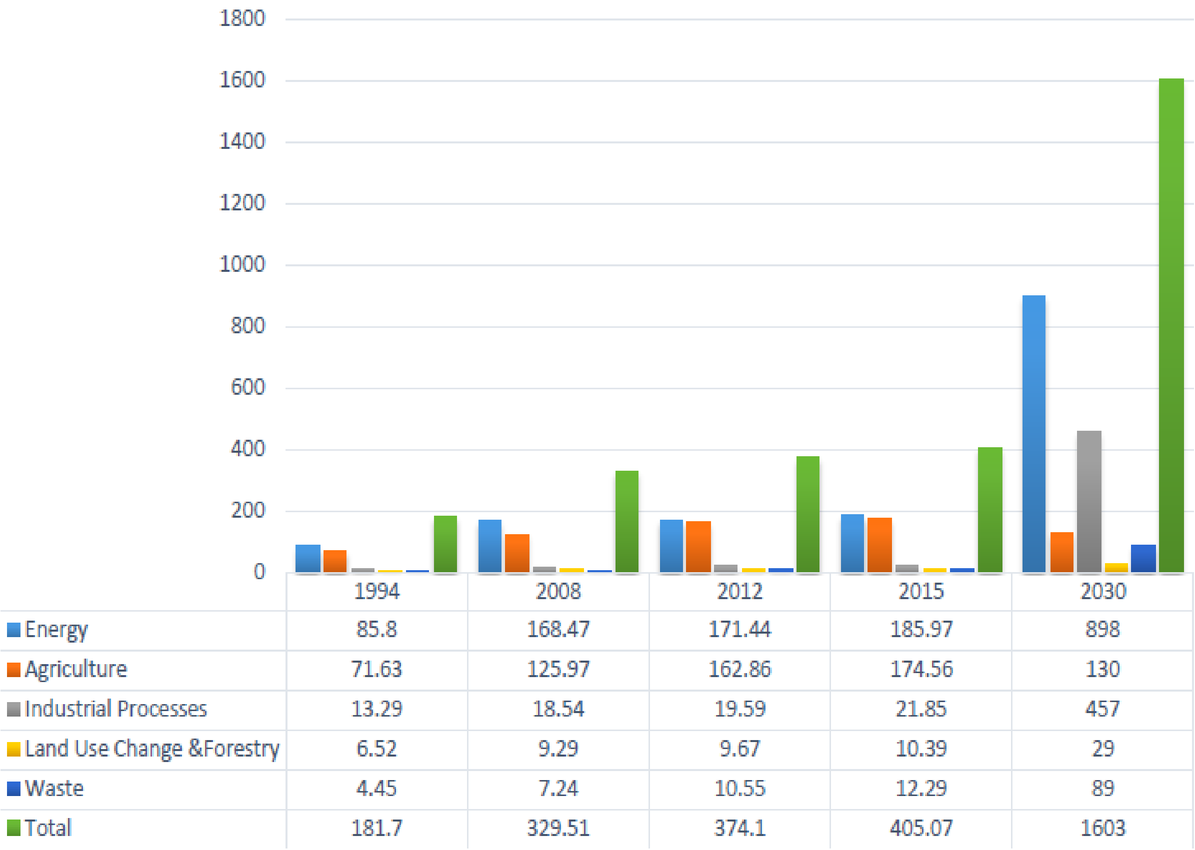
In view of the long-term risks from climate change, Pakistan ranks eighth globally with regard to fatal consequences due to extreme vulnerability. Air pollution alone is accountable for one-fourth of the annual death toll in the country, in addition to associated welfare losses and forgone labor.

While being at the receiving end of climate impacts, the country is one of the lowest global contributors to the problem. At present, Pakistan contributes 0.8% of the total global GHG emission and ranks 135th on a per capita basis. Although, Pakistan's per capita energy consumption and cumulative CO_2 emissions are extremely low, the CO_2 emissions per unit of energy consumption are relatively high. (Khan *et al.* 2011; https://germanwatch.org/en/download/16411.pdf)

However, in terms of sectoral distribution, energy sector is the largest GHG emissions contributor than any other sector in Pakistan. PAEC (2009) reported that country's total GHG emissions were 310 M.T.CO_2Eq. in year 2008. These emissions comprised of carbon dioxide (54%), methane (36%), nitrous oxide (9%), carbon monoxide (1%) and non-methane volatile organic compounds (0.3%). Almost 90% of these emissions came from the energy (and agriculture-livestock) sector and, subsequently, this is the area where the thrust of Pakistan's mitigation efforts needs to be focused.

As per assessment of the Pakistan's Ministry of Climate Change (2016), energy sector contributed 46 percent of total emissions, followed by agriculture (43 percent) and industrial processes (5 percent), with growth expected in both energy and industrial processes.

Below are two figures showing potential of GHG emissions (M.T.CO_2Eq.) from various sectors of Pakistan under business as usual. The cited sources of these figures made GHG projections on the basis of historical trend from 1994 to 2015 and a GDP growth rate of 4%.



	1994	2008	2012	2015	2030
🟦 Energy	85.8	168.47	171.44	185.97	898
🟧 Agriculture	71.63	125.97	162.86	174.56	130
⬜ Industrial Processes	13.29	18.54	19.59	21.85	457
🟨 Land Use Change &Forestry	6.52	9.29	9.67	10.39	29
🟦 Waste	4.45	7.24	10.55	12.29	89
🟩 Total	181.7	329.51	374.1	405.07	1603

(a)

Sector	1994	2008	2012	2020	2050
Energy	86	157	169	358	2,685
Agriculture	72	120	165	245	1,395
Industrial processes	13	18	14	26	67
Land use change and forestry	7	9	10	14	38
Wastes	4	6	10	7	15
Total national emissions	182	309	369	650	4,200

(b)

Fig. 4.11: Inventory of GHG Emissions of Pakistan under BAU (in M.T.CO$_2$Eq.) (a) GHG projections till 2030 (Source: Janjua *et al.* 2017) **(b**) GHG projections till 2020 and 2050 (Source: Chaudhry, 2017)

Chapter Five

RESULTS AND DISCUSSION

5.1. General Introduction

Rapid urbanization and the desire for luxurious lifestyles have increased energy demand in the household. The situation is most apparent in the developing world, due to growing energy needs of an increasing population. Despite rapid urbanization and accessibility to modern technologies, about 1.3 billion people in the developing world still lack access to electricity. Additionally, 2.5 billion people lack access to safe cooking fuels (Saxenaa and Bhattacharya, 2018). However, more than 80% of the power generated dissipates due to irresponsible consumer behavior (Hafeez *et al.* 2018).

The future of world energy hence relies upon developing countries, especially those in Sub-Saharan Africa and Asia. Among these countries, Pakistan has one of the highest electrification rates (International Energy Agency, 2017). However, more than a quarter of its population does not have access to modern energy. Moreover, the rate of access to clean cooking fuels and technologies is only 43.32% (World Bank, 2018).

The past several years of planned and unplanned electricity and gas load-shedding has affected the economy and society of Pakistan. The major share of the electricity and natural gas supply is consumed by urban households, however these fuel resources remain supply-constrained due to multiple factors that have compromised the sustainability of energy systems. The prevailing energy crisis has severely affected this sector (GoP, 2017; Chaudhry, 2017).

This calls for immediate measures to meet the energy needs of the urban household sector. However, such measures must be sustainable, and recognize all aspects of residential energy demand. Accordingly, this study was carried out with the help of bottom-up energy modeling software LEAP due to its strong accounting and evaluation capabilities required for simulation and optimization functions.

5.2. Baseline Development

Assessment and evaluation of energy sustainability at local, national and regional levels has also been the subject of modeling. The idea of sustainability indicators was offered in Agenda 21 to keep track of the effectiveness of policies and implementation plans. IAEA and IEA (2005) used energy-evaluation-index-system to determine energy sustainability.

This study conducted extensive review of various policies and reports while taking into account maximum possible variables from the energy supply and demand, for which data is available. List of these policies and reports is annexed at Annex-A.

World Bank (2018) reported the improving trends in ratio of population availing service attributes of energy and electricity as envisioned in the goal seven of SDG. It was found that ‘access to electricity’ is driven by socio-economic indicators of household-welfare, expenditure and gender of head of household. Whereas, the determinants of ‘affordability’ vary between tropical and temperate regions as per the fraction of residential electricity consumption cost in the total monthly expense.

These attributes have been further investigated and categorized into their respective economic, social, ecological, environmental, institutional/ technical and psychological/ behavioral indicators of energy systems (Frederiks *et al.* 2015; Blázquez *et al.* 2013; Clark *et al.* 2013; Yamamoto *et al.* 2008; Larsen and Nesbakken, 2004; Farhad, 2011; Shaaban *et al.* 2018).

Bashir *et al.* (2018) reviewed various studies of developing countries and identified energy sustainability indicators for this study which are particularly affecting energy demand in households. These factors include agro-climatic set-up, socio-economic conditions, literacy, gender roles, religion, and psychological factors. Xing *et al.* (2017) discussed energy stack and energy ladder models for possible energy shift in households due to income factor.

In addition to above, other such factors are consumer choice, lack of efficiency standards for electric goods, employment, safety risks, social acceptability, reliability, and resource potential, policy design and governmental roles which also contribute vital role in determining fuel inequity and equipment availability among different income groups (Bashir *et al.* 2018).

Studies from Pakistan that accentuated upon economic indicators include Aqeel and Butt (2001), Shahbaz *et al.* (2012), Khan and Ahmad (2008), Siddiqui (2004), Shahbaz and Lean (2012), Hye and Riaz (2008), Zaman *et al.* (2012), Raza *et al.* (2015), Cheema and Javid (2015), Ahmed *et al.* (2015), Komal and Abbas (2015), Shahbaz *et al.* (2013), Shahbaz *et al.* (2015), and Arshad *et al.* (2016).

Relationship among energy demand, energy-efficiency, environmental quality, financial growth and market variation has been studied worldwide (Cheema and Javid, 2015; Frankel and Romer, 1999; Dasgupta *et al.* 2001; Sadorsky, 2010; Zhang, 2011, Tamazian *et al.* 2009; Claessens and Feijen, 2007) and for Pakistan also (Alam *et al.* 2007; Ali and Abbas, 2013; Nasir and Ur Rehman, 2011).

Li and Li (2017) developed a model for quantitative evaluation of energy sustainability for Shandong Province using DPSIR in conjunction with variation co-efficient and matter-element extension approaches. The PSR model was also applied in a study by Hu *et al.* (2016) using nine indices.

Other studies conducted in this regard used Herfindahl-Hirschman Index (Lefevremarton and Blyth, 2005; Li, 2005), Shannon-Wiener Index based property-stack method (Jansen, 2004; Grubb *et al.* 2006) which are non-linear functions, in addition to studies by Wang and Chen (2012), Cohen (2011), Salameh (2003), Willrich (1975), Wang and Chen (2015), Sinton and Fridley (2000), Liu *et al.* (2012), Wang and Li (2017), Wang *et al.* (2017), etc.

The in depth policy review and insight on energy developments lead to identification of causes and effects of the issue and subsequent formulation of alternative policies. The identified causes and effects for this study are presented in Figure 5.1.

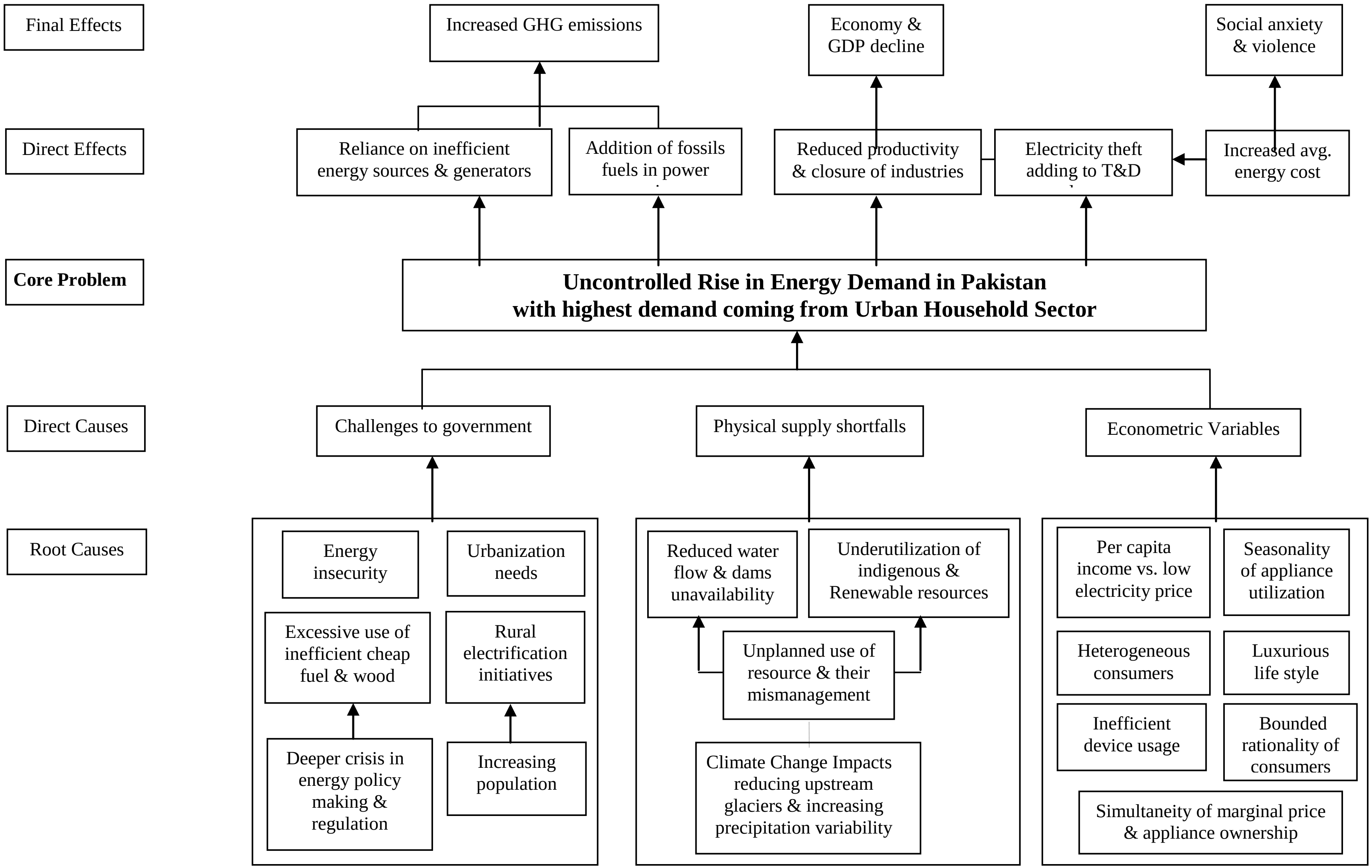


Fig. 5.1: Problem Tree of the Study

Accordingly, current study was carried out to propose an effective and efficient integrated long term management plan to address power demand and supply and its subsequent adoption in the national policy framework. The supply and demand-side frameworks of the current energy study are presented in Figures 5.2 and 5.3, respectively.

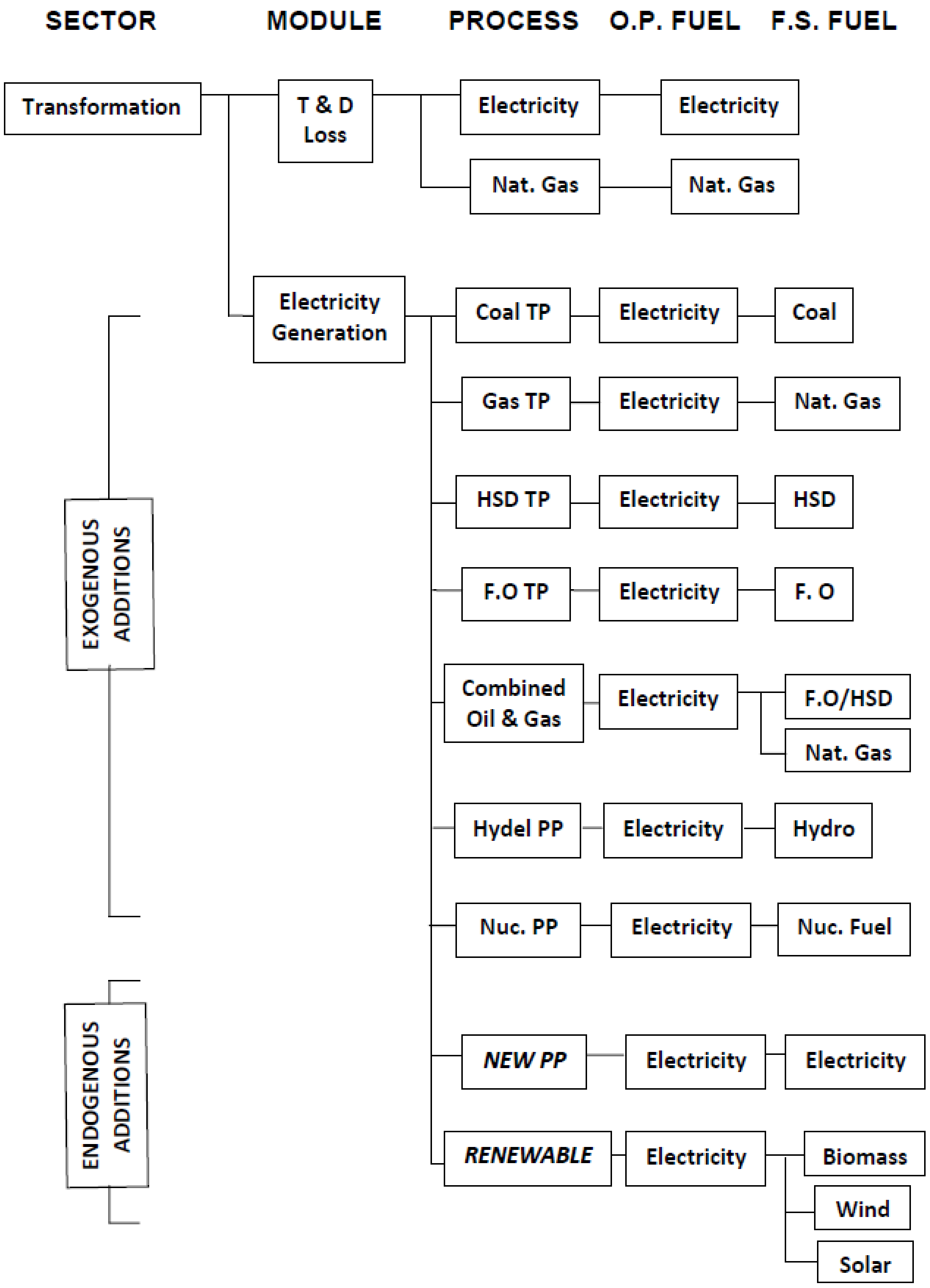


Fig. 5.2: Framework for Energy and Power Supply Sector of Pakistan

From assessment of household surveys, it is observed that demand for electrical energy is primarily driven by end-use services, namely lighting, cooling and electrical goods. Whereas, residential energy services of cooking and heating use natural gas and LPG fuels.

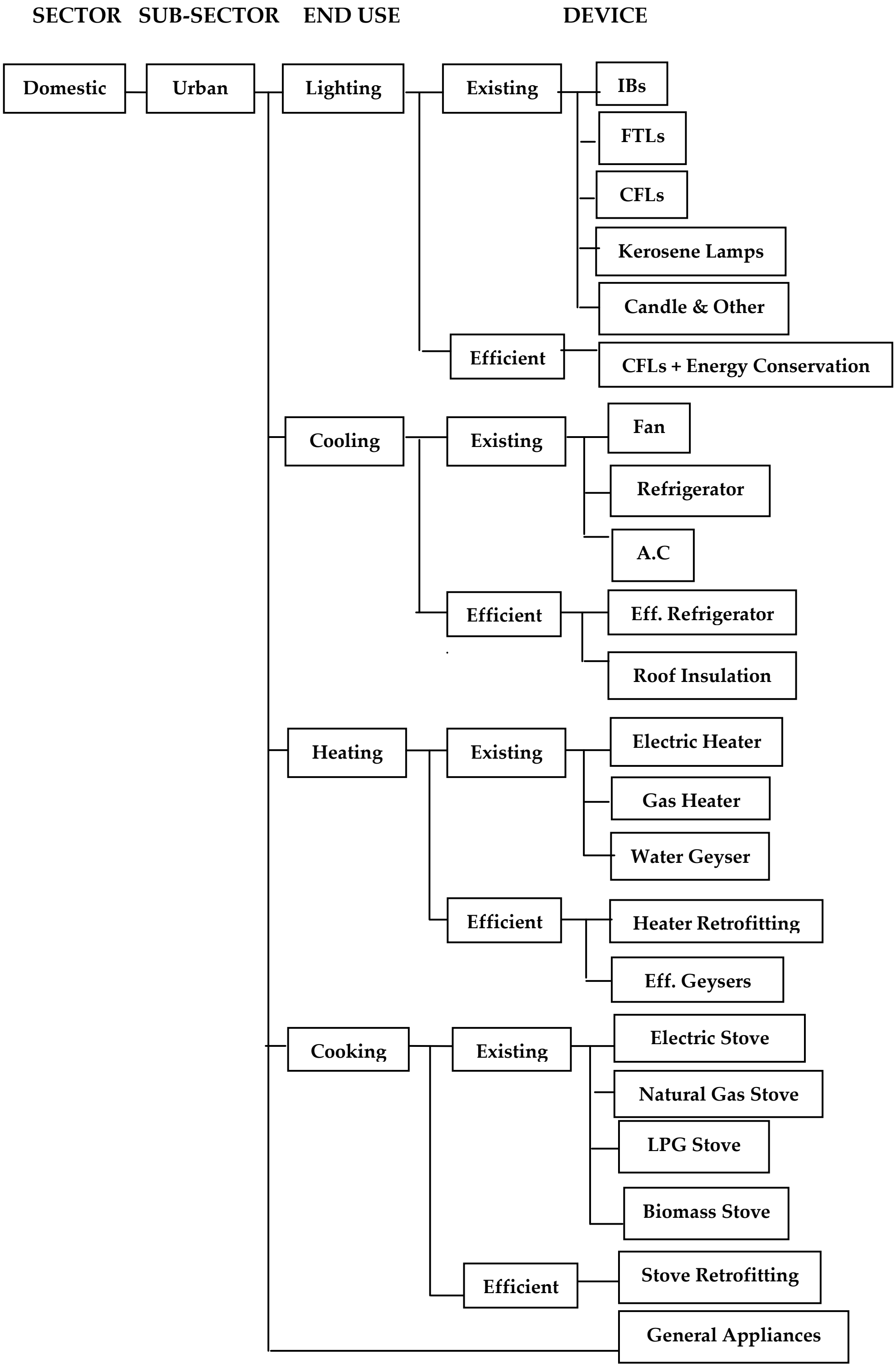


Fig. 5.3: Framework for Energy Demand Management in Urban Household Sector of Pakistan

The baseline development for simulation of macro-economic variables of energy demand, share of domestic energy devices and their final intensity under REF and DSM are presented at tables 5.1 to 5.3. Results of this study are based upon the estimations and calculations made in the light of available data. Larsen and Nesbakken (2004) also found out that successful analysis of residential power demand to determine its pattern and policy, must consider efficiency and usage of electrical appliances.

Monthly estimates of household electricity consumption in different income levels is detailed at Annex-B. These estimates are based upon electricity consumption based upon the energy intensity (Watts), usage (hrs/day) and number of devices used in low, middle and high income level households. The findings of these estimates suggest that annual electricity consumption in urban households was calculated to be 83 GWh for low income level, 23,946 GWh for middle and 3,480 GWh for high income level consumers.

In this study, an average middle income household is taken as a standard model to reflect the largest fraction of urban population. Annual electricity consumption is calculated to be 2,795.63 kWh, including 998 kWh consumed by lightening devices, 1014.8 kWh by space cooling devices and 782.78 kWh by general appliances making 35.7%, 36.3% and 28% share respectively in the base year, 2011.

A quantification analysis of household survey statistics regarding the saturation of end-use attribute of energy services apprised that in case of lighting end-use, a total 117.4 million residential light points existed in the base year of this study, of which IBs were present in 76.9% households, FTLs in 48.6%, CFLs in 2.94%, whereas 3.6% households used other/ miscellaneous devices.

In case of household cooling appliances, fans make the largest share whereas air conditioners and refrigerators are present in upper middle income households, respectively. General appliances are estimated to increase by 2.5% each year, with a raise from 7.7 million to 9.8 million within the period 2006-2009. It has been further estimated that during the base year of this study, an average 180,000 urban households consumed kerosene at an annual rate of 10 liter/ household. Additionally, candle, petroleum product, was also used by an estimated six thousand households.

Approximately, 4.70 million urban consumers used 4.18 M.TOE of natural gas fuel. In view of its consumption status in a middle-income urban dwelling, usually 0.88

TOE is consumed on annual basis. The findings further suggest the fuel-based consumption of natural gas by different end-use services in household. It has been observed that cooking requires least fuel intake. Meanwhile, higher shares come from space heaters present in 3.10 million houses, in addition to 1.60 million houses that use water geysers in winters.

These assessments were calculated from the residential gas bills of middle income urban households. According to these calculation, a 4-hours cooking on a daily basis extracts 380 Hm^3 (0.3 TOE) natural gas fuel. Meanwhile, a 4-hours daily use of two space heaters (1-burner), during three months of winters, extracts 4.664 mcft (0.11 TOE) of same fuel. For calculating natural gas consumption due to 10-hours usage of water heating devices during four months of winter on daily basis, an estimated 13.2 Hm^3 (1.1 TOE) gas is burnt by a 35-gallons conventional water geyser and 6.16 Hm^3 (0.52 TOE) by the new efficient geyser with conical baffle.

An approximate 3.60 million urban houses consumed LPG, as the fuel substitute, for cooking end-use. Apart from its wide consumption in hilly areas, an urban house usually consumes a typical sixty kg of this fuel during four months of the winter gas shortfall. Apart from local development and easy reach to basic fuel, an estimated 0.24 million houses used dung-cake biofuel whereas, 1.5 million used charcoal and firewood for cooking and heating end-uses in homes. This accounts for an estimated utilization of 787.5 million kg biomass each year by the urban fraction of Pakistani population.

From power supply side, this study considered possible power generation options including Thar coal power project, combined cycle gas turbines, hydel generation potential, renewables, etc. However, the investment and operational cost of these options is huge. Performance and cost factors of these future capacities are put into the model.

Table 5.1: Simulation of macro-economic/ sectoral variables of Energy Demand for REF and DSM

Variables	Activity Level		
	Current Activity (C.A)	**REF**	**DSM**
Population (in Millions)	2010, 173.5, 2011, 177.1	Growth 2.05%	Growth 2.05%
Household No. (in Millions)	27.24	Growth(3%)	Growth(3%)
Household (in Millions)	6.5		
Domestic Electricity Consumers (in Millions)	20	Growth(3%)	Growth(3%)
Domestic Gas Consumers (in Millions)	5.9	Growth(6.9%)	
GDP (in Billion US $)	2010,174.866, 2011,202.831	Growth(2.4%, 2012,3.8%, 2015,4.7%, 2020, 6.0%, 2030,6.5%, 2040,6.9%, 2050,7.1%)	
GDP Growth Rate (%)	2011,2.4, 2050,7.1	2015,4.7, 2020,6.0, 2030,6.5, 2040,6.9, 2050,7.1	
Income Bill (US $)	2010,1008, 2011,1145		
Energy Demand in Urban Household	1998,6.03, 2011,10.04	Growth(3%)	
Lighting		100	
Cooling		100	
Space Heater		100	
Water Geyser		100	
Cooking	100		
General Appliances	45	(2050,70)	

Table 5.2: Simulation of saturation (%) of Household Devices for REF and DSM

Device	% saturation		
	Current Activity (C.A)	**REF**	**DSM**
Lighting			
Electric Lamps	98.1	98.1	2,050,100
IBS	76.9	76.9	(2050,15)
FTLs	48.6	48.6	(2050,30)
CFLs	2.94	2.94	(2050,65)
Kerosene Lamps	1.9	(2050,0)	
Cooling			
Fan	98	Interp(2050,100)	
Refrigerator	32.1	(2050,60.4)	(2050,75)
Air Conditioner	24.9	(2050,26.7)	(2050,40)
Space Heater			
Gas heater	60	60	(2050,70)
Biomass heater	15.93	15.93	Interp(2050,7)
Water Geyser			
Gas	36		Interp(2050,55)
Biomass	15.93		Interp(2050,5)
Efficient Geyser	5		Interp(2050,40)
Cooking			
Electric stove	0.07		Interp(2050,5)
Natural gas stove	47.8		Interp(2050,65)
LPG stove	36.2		Interp(2050,20)
Bio-fuel stove	15.93		Interp(2050,10)
General Appliances			

Table 5.3: Simulation of Final Energy Intensity of Household Devices for REF and DSM

Device	**Final Energy Intensity**		
	Current Activity (C.A)	**REF**	**DSM**
Lighting Electric Lamps (kWh\H.H)			
IBS	324	324	Growth(-0.5%)
FTLs	132	132	Growth(-0.5%)
CFLs	72	72	72
Lighting Kerosene Lamps (TOE\H.H)	0.0000002	Growth(-0.1%)	Growth(-0.1%)
Cooling (kWh\H.H)			
Fan	464	Growth(15%)	
Ref	1728	Growth(10%)	(2020,1728*0.95, 2050,1728*0.8)
A.C	1200	Growth(4.8%)	(2050,1200*0.2)
Space Heater			
Gas heater (TOE\H.H)	0.11	Growth(-1%)	
Biomass heater (GJ\H.H)	0.188		
Water Geyser			
Gas (TOE\H.H)	45.71		(2025, 45.718*0.3, 2050,45.71*0.1)
Biomass (GJ\H.H)	5.6272086		
Efficient Geysers (TOE\H.H)	0.52		
Cooking			
Electric stove (kWh\H.H)	43200		Growth(0.3%)
Natural gas stove (TOE\H.H)	0.3	Growth(-0.5%)	Interp(2050,0.3*0.3)
LPG stove (TOE\H.H)	0.12		
Bio-fuel stove (GJ\H.H)	40.015706		
General Appliances (kWh\H.H)	782.78	Growth(2.5%)	Growth(2.5%)

5.3. Simulation Results of REF

Current trends in energy development scenarios explore the implication of future energy consumption and emissions. The findings of the household energy survey were also compared and aligned with the national reports.

5.3.1. Demand side results

The simulation results of macro-economic variables used in this study to analyze future energy demand are shown in Figures 5.4 through 5.7. These future projections have been constructed upon the policy supposition for REF.

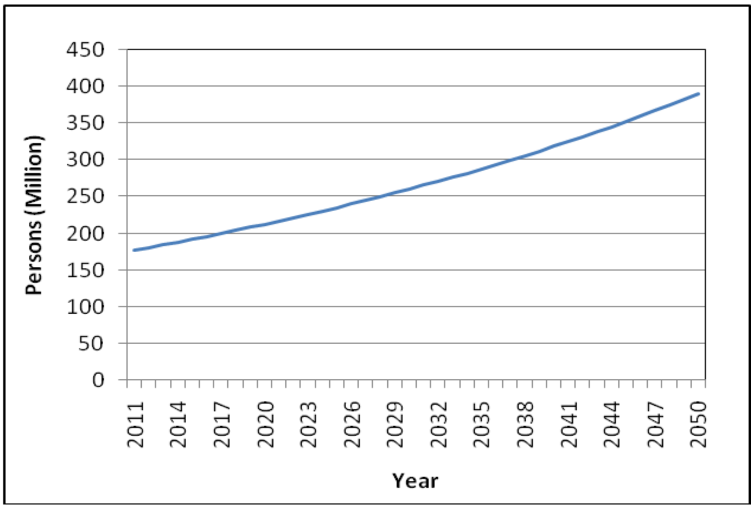


Fig. 5.4: Population growth projection under REF (2011–2050)

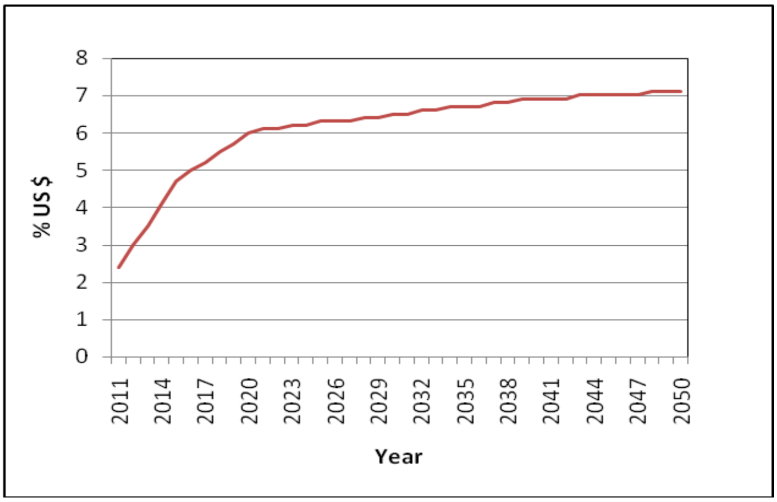


Fig. 5.5: GDP growth rate projection under REF (2011–2050)

As per the most recent household survey statistics (GoP, 2017 a), out of a total 32.205 million households in Pakistan, 12.192 million are urban which are expanding at an annual growth rate of 2.4% with average size of 6.45 persons. Although rise in consumption of energy reflects economic development, however the associated impact on environmental quality must not be neglected.

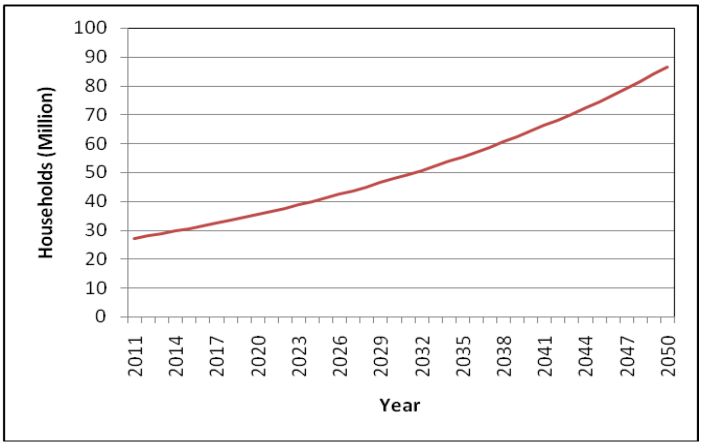


Fig. 5.6: Increase in household number under REF (2011–2050)

During the base year 2010-11of this study, the number of urban households in the country was 10.04 million. In the same year, the electrified consumers were estimated to be 9.84 million which were taking up 27,509 GWh from the national grid. It has been observed that access to electricity in country is exceptionally high. However, the share of consumers who acquire less than 50 units of electricity/month is consistently high. Hence, the current circumstances represent disproportion of consumption pattern which is based upon income level of the consumer.

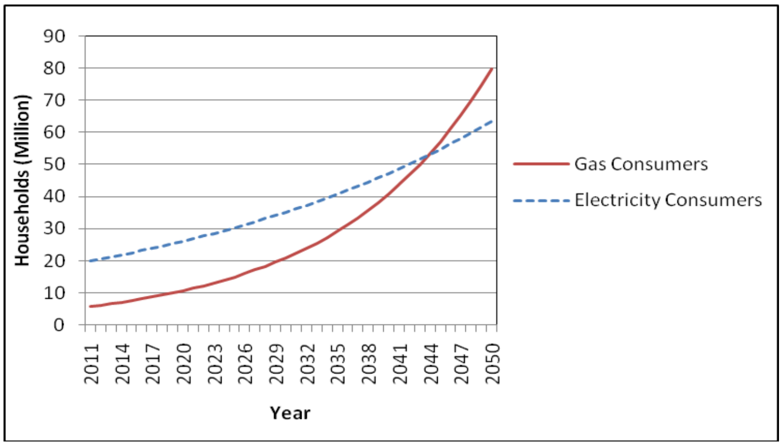


Fig. 5.7: Increase in household consumers of electricity and natural gas fuel under REF (2011–2050)

Table 5.4: Simulation of key Parameters for the study period 2011-2050

Parameters	**2011**	**2015**	**2018**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**Avg. Annual Growth (%)**
Electricity Consumers	20	22.5	24.6	26.1	30.3	35.1	40.7	47.1	54.6	63.3	3.00%
Gas Consumers	5.9	7.7	9.4	10.8	15	21	29.3	40.9	57	79.6	6.90%
Population	177.1	192.1	204.1	212.6	235.3	260.4	288.2	319	353.1	390.8	2.00%
Household	27.2	30.7	33.5	35.5	41.2	47.8	55.4	64.2	74.4	86.3	3.00%

During the base year of this study, total energy consumption of domestic sector in Pakistan was 836,0016 TOE (HDIP, 2011) out of which 27,9112 TOE (or 34,272 GWh) was electricity, 513,3540 TOE was natural gas, 34,2207 TOE was LPG and oil products consumption was 93,157 TOE. Data on biomass consumption is missing which makes a big proportion of fuel use in areas where other resources have not been provided by national authorities or available at no cost.

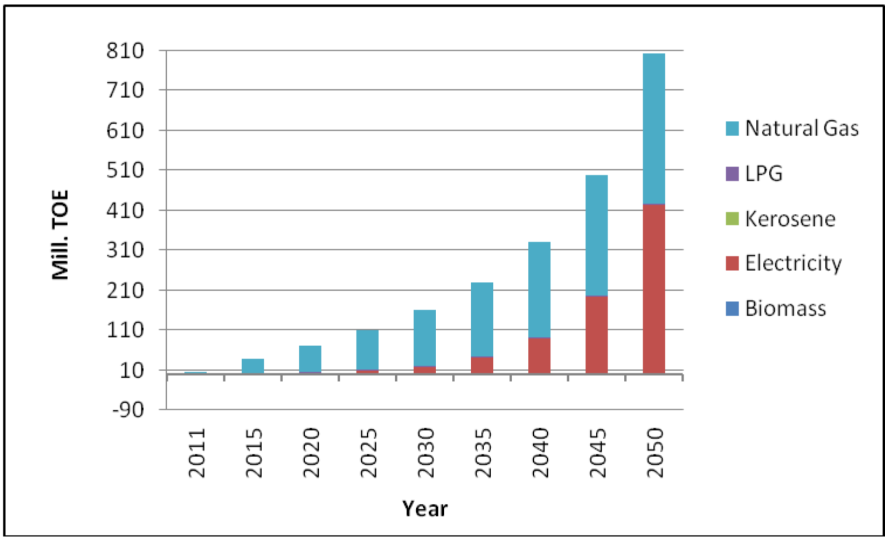


Fig. 5.8: Energy Demand by Fuel Type in REF (M.TOE)

Results for the demand side energy consumption in reference scenario reveal the increasing household energy demand by 4.5% each year which is estimated to be about 801.89 M.TOE in 2050. The remaining share of domestic energy is taken up by rural households which make low proportion of the actual use in terms of biomass exploitation.

Table 5.5 shows results for the future energy consumption pattern in urban households. Heavy reliance on indigenous natural gas is expected to remain steady at 3% annual growth. Thus accounting for a total 374.87 M.TOE of natural gas consumption in 2050. Electricity usage grows to 423.2 M.TOE making its largest proportion of energy utilization. LPG usage increases by 3% during 2011 to 2050. Whereas, increased access to electricity is expected to decline the share of biomass and oil products

With reference to the annual average growth of residential urban energy intensity through 2050, the energy consumed for lighting increases to 3%, 16.4% for cooling devices, 6.8% for general appliances, 2% for gas heaters, 3% for water geysers and 2.8% for cooking.

Table 5.5: Energy Demand by Fuel Type (M.TOE) in REF

FUEL	2011	2015	2020	2025	2030	2035	2040	2045	2050	Avg. Annual Growth (%)
Biomass	0.1	0.4	0.7	1	1.3	1.6	1.9	2.2	2.5	3
Electricity	0.22	2.52	4.82	9.62	19.82	41.52	89	192.8	423.2	15.2
Kerosene	0.0000002	0	0	0	0	0	0	0	0	2.9
LPG	0.12	0.32	0.42	0.52	0.62	0.72	0.92	1.12	1.32	3
Natural Gas	4.117	34.12	64.117	98.87	139.07	185.67	239.77	302.37	374.87	3
Total	4.557	37.36	70.06	110.01	160.81	229.51	331.59	498.49	801.89	4.5

The results of reference scenario exhibit that the social cost of domestic energy appliances is expected to reach 34 billion US dollars in 2050 with the highest usage by space cooling devices. Figure 5.9 shows the detailed preview at device level. Also, in comparison to the base year 2011, this cost is expected to decrease to 8.5 billion US dollars if various improvement steps are taken which were assumed for the construction of reference scenario. The largest saving up to 4.3 billion US dollars can be contributed by cooling appliances and 2 billion US dollars by lighting. Due to the increasing usage of electricity stoves, household cooking is expected to consume more energy than the base year of this study, 2011.

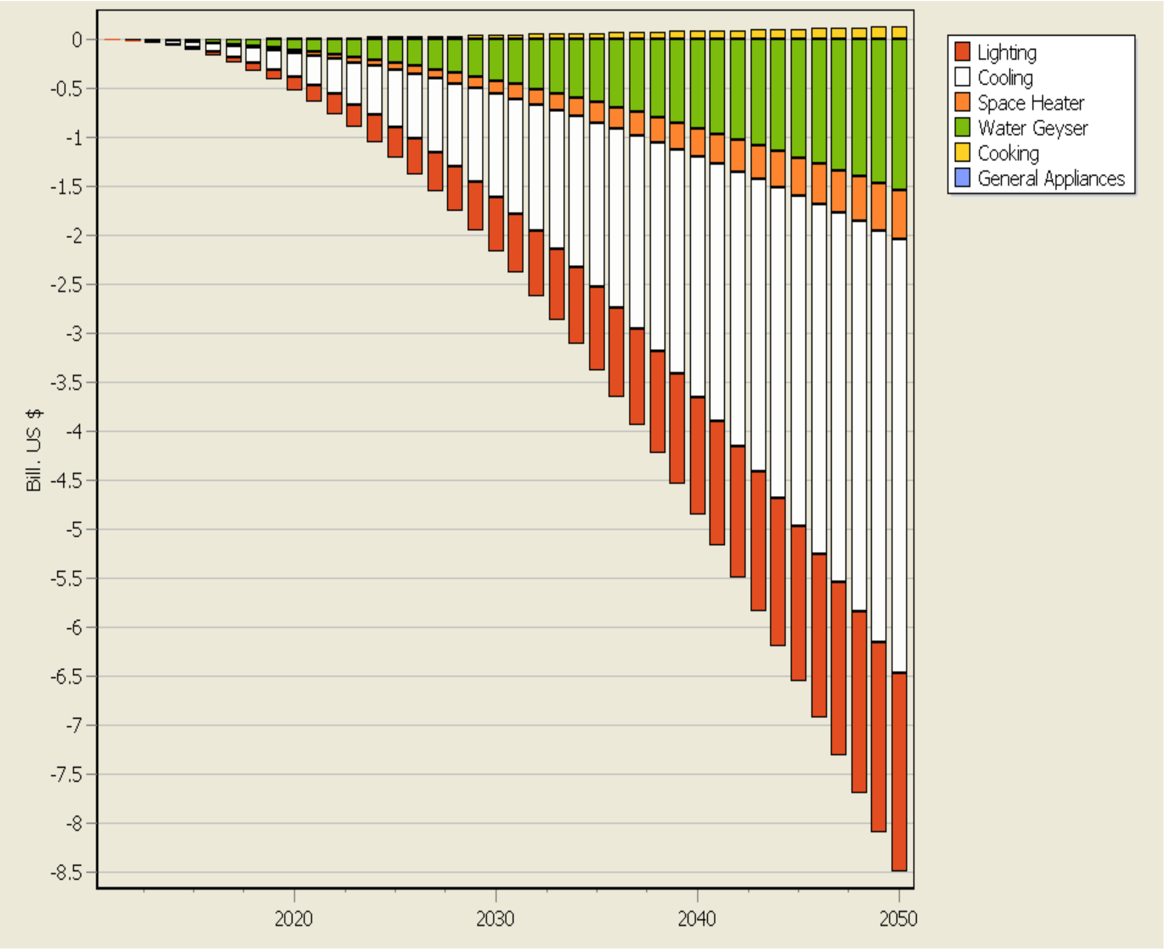


Fig. 5.9: Comparison of Social Cost of Household Energy Consumption

(REF vs. Base Year, 2011)

5.3.2. Supply side results

The power generation and distribution sector of Pakistan has been modeled for the study period of 2011-50, with individual power plants characterized based on their historic operating characteristics. Impacts of existing and future situation of power sector were analyzed to reveal the socio-economic and environmental impacts in successive years.

The presently operational power plants of the country are expected to retire no longer than 2035. For the purpose of this study, new endogenous and exogenous capacities were added into already running system from the year 2020 to generate a stable future supply. Simulation results of exogenous additions are presented in Table 5.6.

The supply side results at Figure 5.10 and its details at Table 5.7, reveal that in case of no-change in existing policy situation, Pakistan future power supply is under serious risk which would worsen the current picture. This is evident from the noticeable jump in electricity outputs from the year 2030 to 2035 in Figure 5.11.

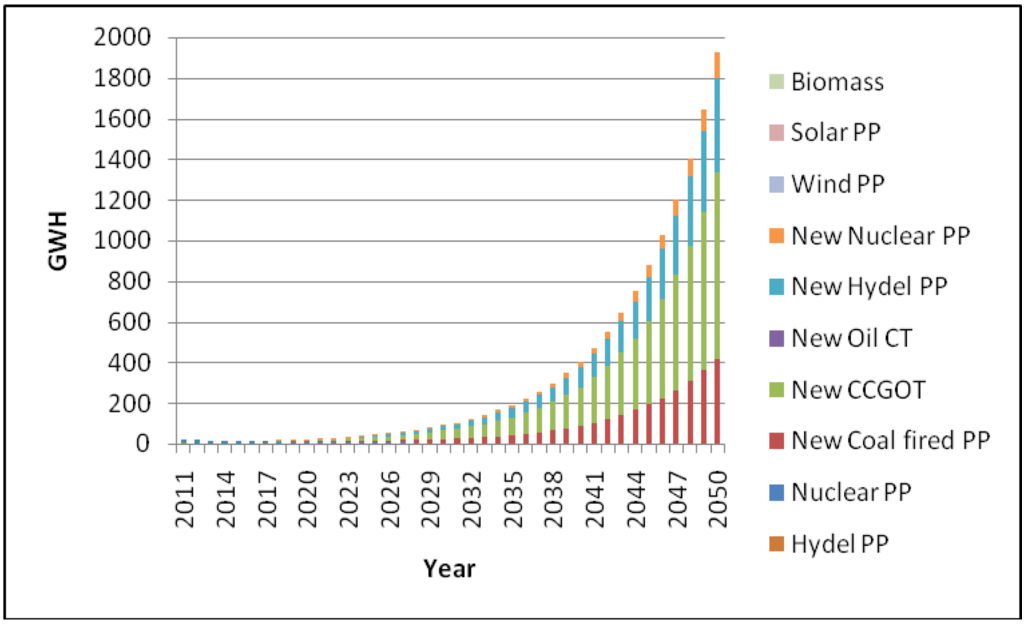


Fig. 5.10: Projected Electricity Capacity (GWh) in REF

Table 5.6: Exogenous Additions of Power Plants Capacities under REF (MW)

Power Plant	**2011**	**2013**	**2015**	**2017**	**2020**	**2023**	**2025**	**2027**	**2030**	**2033**	**2035**	**2037**	**2040**	**2043**	**2045**	**2047**	**2050**
Coal fired	150	134.2	118.4	102.6	78.9	55.3	39.5	23.7	0	0	0	0	0	0	0	0	0
NGCC	2528	2281.5	2059.1	1858.3	1593.3	1366	1232.8	1112.6	953.9	817.9	738.1	666.2	571.2	489.7	442	398.9	342
Oil CT	3096	2507.8	2031.3	1645.3	1199.5	874.4	708.3	573.7	418.2	304.9	247	200	145.8	106.3	86.1	69.7	50.8
Diesel CT	39	39	37	37	37	37	35.1	35.1	35.1	35.1	35.1	35.1	0	0	0	0	0
CCGOT	8164.6	7305.2	6445.7	5586.3	4297.2	3008	2148.6	1289.1	0	0	0	0	0	0	0	0	0
Hydel	6481.2	6034.2	5587.2	5140.3	4469.8	3799.3	3352.3	2905.4	2234.9	1564.4	1117.4	670.5	0	0	0	0	0
Nuclear	462	462	462	325	325	325	325	325	0	0	0	0	0	0	0	0	0
Total	20920.8	18763.9	16740.8	14694.9	12000.7	9465.1	7841.6	6264.6	3642.2	2722.3	2137.7	1571.8	717	596	528.1	468.6	392.8

Table 5.7: Electricity Installed Capacity in REF (GWh)

Power Plant	2011	2015	2018	2020	2025	2030	2035	2040	2045	2050	Growth (%)
Coal fired	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0
NGCC	2.5	2.1	1.8	1.6	1.2	1	0.7	0.6	0.4	0.3	-5
Oil CT	3.1	2	1.5	1.2	0.7	0.4	0.2	0.1	0.1	0.1	-10
Diesel CT	0	0	0	0	0	0	0	0	0	0	0
CCGOT	8.2	6.4	5.2	4.3	2.1	0	0	0	0	0	0
Hydel	6.5	5.6	4.9	4.5	3.4	2.2	1.1	0	0	0	0
Nuclear	0.5	0.5	0.3	0.3	0.3	0	0	0	0	0	0
New Coal	-	-	2.3	4.5	9	20.3	42.8	90	193.5	420.8	-
New CCGOT	-	-	0	4.9	19.4	43.7	87.5	189.5	413.1	913.7	-
New Oil CT	-	-	0	0	0	0	0	0	0	0	-
New Hydel	-	-	2.5	2.5	9.9	22.3	47.1	99.2	213.4	466.4	-
New Nuclear	-	-	0.7	0.7	2.7	6.1	12.2	26.5	58.5	127.8	-
Wind	-	-	0	0	0	0	0	0	0	0	-
Solar	-	-	0	0	0	0	0	0	0	0	-
Biomass	-	-	0	0	0	0	0	0	0	0	-
Total	20.9	16.7	19.2	24.5	48.9	96.1	191.7	406	879	1,929.1	12.3

In Pakistan, there are over 186 billion tons of coal reserves including Thar coalfield which await mining for harnessing through efficient technologies. Most recently in 2018, installation of the Port Qasim and Sahiwal thermal power generation facilities has significantly increased the clean coal import (GoP, 2018).

Therefore, in order to overcome the electricity shortfall, Pakistan needs to utilize its vast coal resources for power generation. This fact is also reflected in Figure 5.11 which shows immense reliance over hydel potential of the country, operationalization of the new coal and combined cycle technology facilities in coming years.

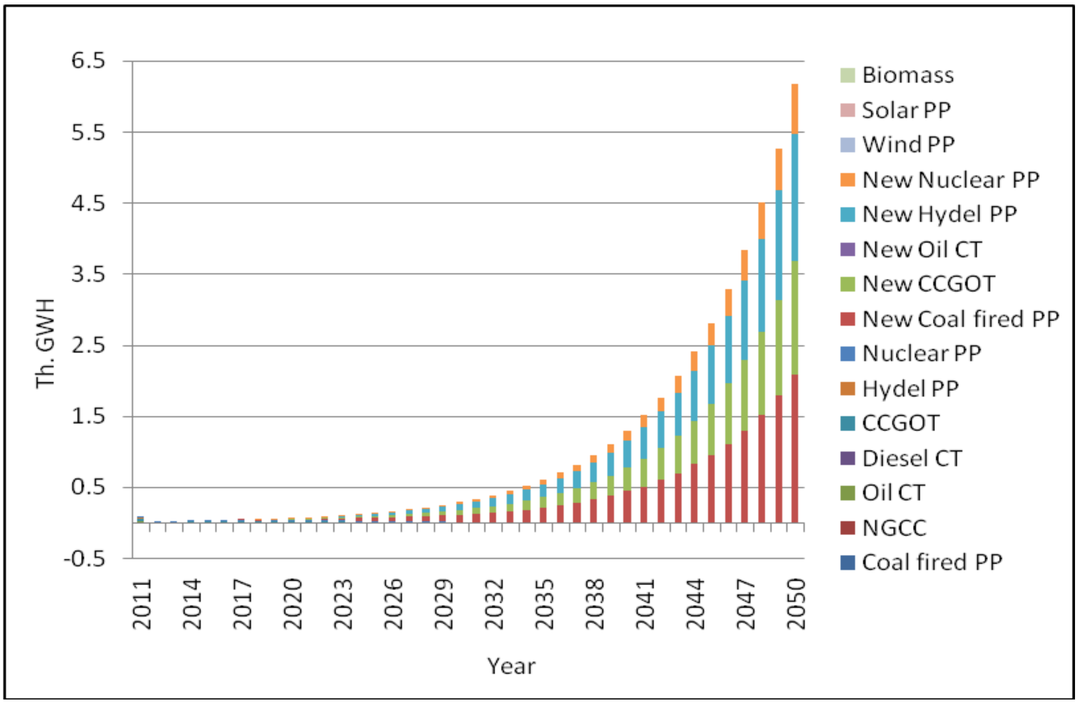


Fig. 5.11: Projected Electricity Output (Th.GWh) in REF

In contrast to the vast indigenous reserves of coal in Pakistan, the conventional energy supplies of indigenous gas and oil are inadequate. Contrary to the environmentally clean and safe natural gas, oil is considered as an expensive and dirty fuel. The natural gas reserves constitute up to thirty eight percent of the national energy mix. This caters energy needs of above 8.9 million consumers. During year 2018, average demand for natural gas reached to 3,837 mmcfd with highest consumption in power sector, followed by the domestic sector (GoP, 2018).

Table 5.8 demonstrates that in 2050, the total electricity generation in Pakistan would rise upto 6175200 GWh in 2050 as compared to 95,358 GWh in the base year of this study, 2011. Also, the share of natural gas and oil fuels for electrical energy generation is anticipated to shrink 5% and 10% shares in electricity installed capacity, respectively. Whereas, electricity outputs will face 10.4% decrease in the supply from oil fired plants and 4.6% decrease in natural gas based units, accounting to 15% decline in the annual average growth of electricity generation.

In terms of energy-economic dynamics, Mirjat *et al.* (2018) found that lack of realistic planning approach and structural gaps in power transmission has lead to historically worst circular debt amounting to US$ 7.60 billion. The electricity supply situation of Pakistan is not only indicative of poor energy mix but at the same time shows lack of expansion in the supply side capacities as well as efforts to reduce line losses to an acceptable level.

Table 5.8: Projected Electricity Output in REF (Th.GWh)

POWER PLANT	2011	2015	2018	2020	2025	2030	2035	2040	2045	2050	Ann. Avg. Growth (%)
Coal	0.1	0.3	0.3	0.3	0.2	0	0	0	0	0	0
NGCC	10.3	5.5	5.9	6.3	5.5	4.5	3.5	2.7	2.1	1.7	-4.6
Oil CT	17.2	5.2	4.7	4.5	3	1.9	1.1	0.7	0.4	0.2	-10.4
Diesel CT	0	0	0	0	0	0.1	0.1	0	0	0	0
CCGOT	36.8	17.4	17.3	17.2	9.6	0	0	0	0	0	0
Hydel	28.1	10.1	11.1	12	10.1	7.1	3.6	0	0	0	0
Nuclear	2.9	1.2	1	1.2	1.4	0	0	0	0	0	0
New Coal	-	-	7.6	18.2	40.8	96.7	207.8	442.2	953.7	2,080.3	-
New CCGOT	-	-	0	2.9	24.3	65.8	147.9	328.4	719.7	1,597.1	-
New Oil	-	-	0	0	0	0	0	0	0	0	-
New Hydel	-	-	6.6	7.8	35	83	178.3	379.3	817.9	1,793.7	-
New Nuclear	-	-	2.6	3.1	13.7	32.5	66.1	144.8	320.2	702.3	-
Wind	-	-	0	-	-	-	-	-	-	-	-
Solar	-	-	0	-	-	-	-	-	-	-	-
Biomass	-	-	0	-	-	-	-	-	-	-	-
Total	95.4	39.6	57.1	73.6	143.7	291.4	608.4	1,298.1	2,814	6,175.2	11.3

5.3.3. Environmental Assessment

Current trends in energy development show that GHG emissions from domestic sector keep on adding both in terms of relative and absolute potential through 2050. According to PAEC (2009), there were estimated 310 M.T.CO_2Eq.s greenhouse gas emissions in 2008 which comprised up of carbon dioxide, methane, nitrous oxide, carbon monoxide, and non-methane volatile organic compounds.

On sectoral basis, energy sector contributes to the most emissions in the country. Figure 5.12 shows that transformation will continue to pose more global warming as compared to the household sector. Environmental emission due to these sectors will quadruple the current global warming potential in 2050.

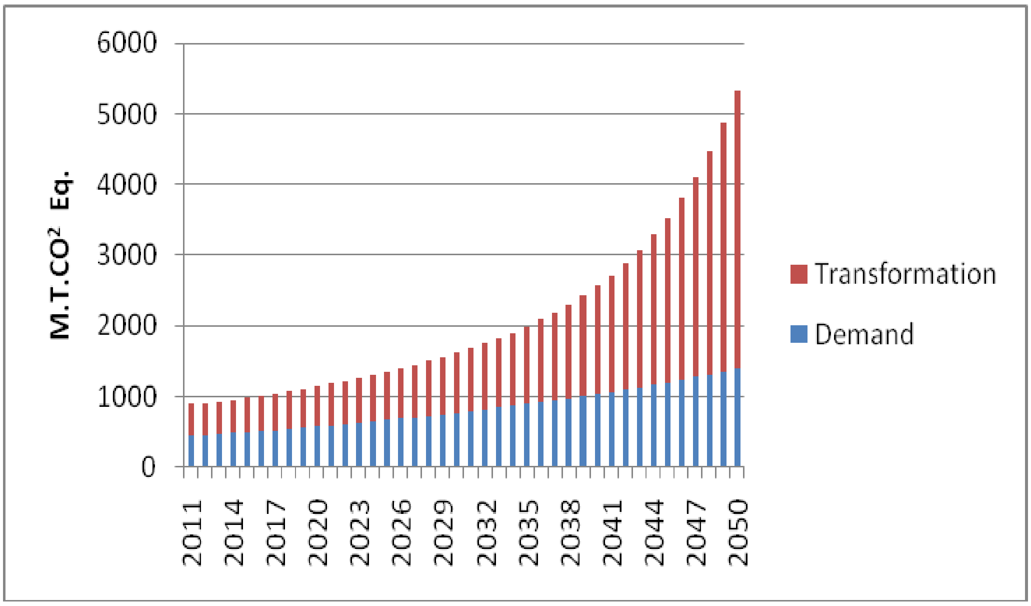


Fig. 5.12: Environmental Global Warming Potential in REF

5.4. Results for Least Cost Electricity Generation Scenario (OPT)

International policy researches and experiences of energy-rich countries emphasize upon promotion of clean energy. This involves demand and supply side resources that deliver clean, reliable, and low-cost ways to meet energy demand and reduce peak electricity system loads. Some of the benefits include meeting load growth with fewer environmental impacts, reduction in energy emissions, increased fuel diversity, beat rising fuel cost, and increased economic development with sustainability.

To overcome this higher initial cost barrier, a number of policies are being used for renewable based energy promotion in different parts of the world. These are categorized as regulatory policies, fiscal incentives and public financing (REN21, 2013).

As of now, the proportion of renewable-based energy makes up 2.16% of the country's energy mix, providing contribution of 0.6 M.TOE.CO_2 to national grid. This contribution from renewable resources constitutes up of solar (23.6%), bagasse (26.7%), and wind (49.7%) energy resources. The hydropower contribution is only 9.7% (i.e., 7.7 M TOE CO_2). On the other hand, energy losses have reached 18% (HDIP, 2017).

There exists 63,000 megawatt potential of wind energy, in view of which the country has planned to execute some power developments through solar-hybrid-with-wind within end of 2019 (GoP, 2018).

Under the Power Development Programme, 106,656 megawatt capacities will be achieved till 2030. Another 1,604 MW has been added through operationalization of the six new 1,264 megawatt IPPs, and a 340 megawatt nuclear power station (Asian Development Bank, 2012).

In view of clean energy initiatives, the earlier governmental aim for tapping renewable energy was enhanced from five percent to fifteen to twenty percent till 2030. It has been anticipated that till year 2030, a boost of eight percent in nuclear-based electricity will evade energy sector emissions by an estimated 58.8 M.T.CO_2Eq. (WRI, 2017).

The study proposes a supply side management scenario in which various thermal, nuclear and renewable power plant options were analyzed as independent scenarios for assessment of the supply outlook. This combination of different options as power generation alternatives included coal, natural gas, oil, hydel, nuclear, wind, solar and biomass resources. It aims to reach to a least cost electricity generation mix for the country.

Findings of OPT scenario suggest that wind, solar and hydel power plants are the most cost-effective options in terms of their fuel inputs, whereas residual oil based plants incur huge cost due to consumption of expensive imported furnace oil. Figure 5.13 shows the results generated by the model. In comparison with renewable power generation, a high level cost is required for mining and extraction of indigenous fuels.

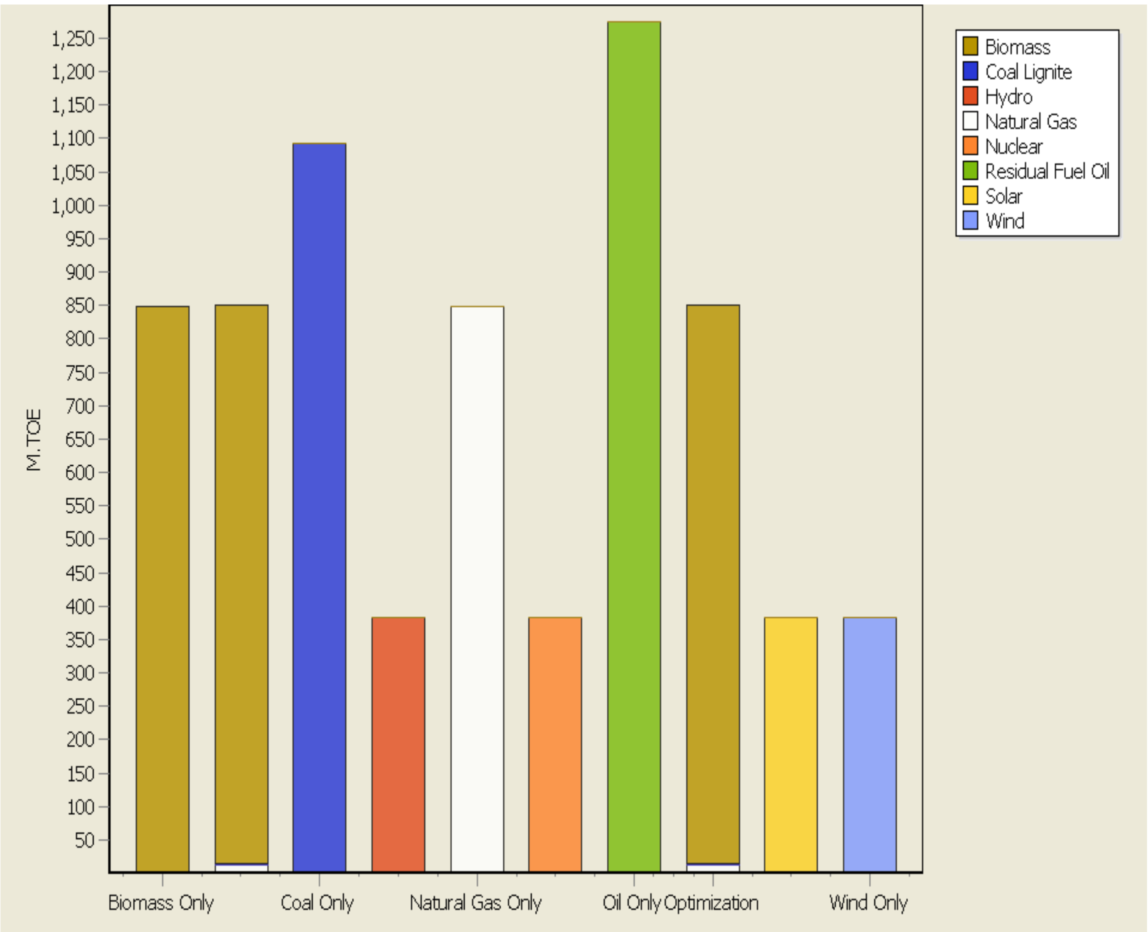


Fig. 5.13: Comparison among Supply Alternatives for Fuel Inputs (M.TOE) in 2050

These power supply scenarios were examined to assess their future electricity production capacity, keeping the exogenous capacities similar for all scenarios. Comparison among these scenarios is shown in Figure 5.14. Results show that the renewable scenarios i.e. hydel, wind, solar and biomass, have the highest potential to generate the most units as compared to other facilities.

The US National Renewable Energy Laboratory (NREL) estimated that the wind energy potential of Pakistan is 346,000 MW, while the wind corridor of Gharo-Ketibander alone can generate 43,000 MW (Lahmeyer International GmbH and IPEK Energy GmbH, 2008). With regard to the solar energy potential of Pakistan, irradiation of more than 5–6 kWh/m2/day has been estimated in many areas by the Alternate Energy Development Board (Tahir and Asim, 2017).

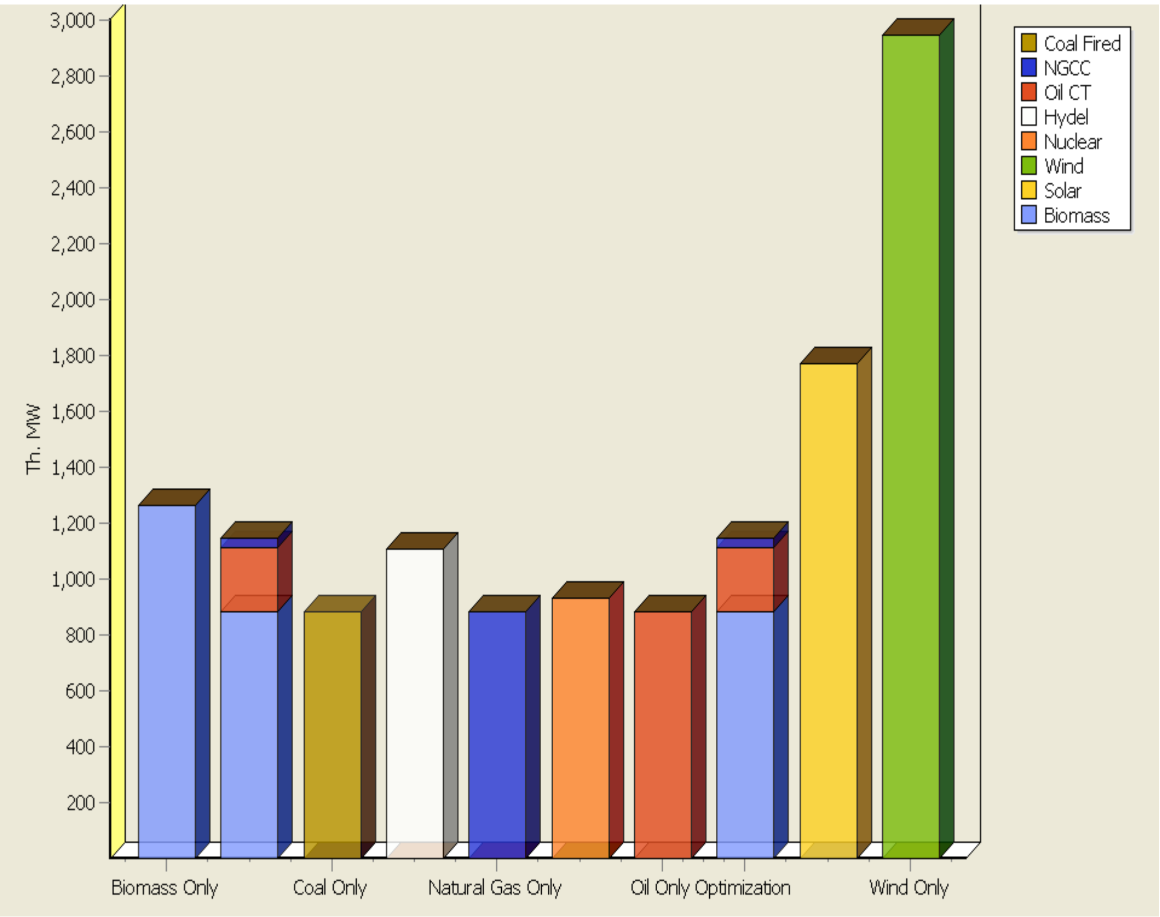


Fig. 5.14: Comparison among Supply Alternatives for Fuel Outputs (Th.MW) in 2050

In terms of environmental emissions, major contribution of GHGs is posted by residual-oil and coal power stations during the study period. Meanwhile, natural gas based power generating units exhibited lesser global warming potential. From the renewables side, only the biomass-based unit, liberate carbon dioxide non-biogenic, methane and nitrous oxide, as shown in Figure 5.15.

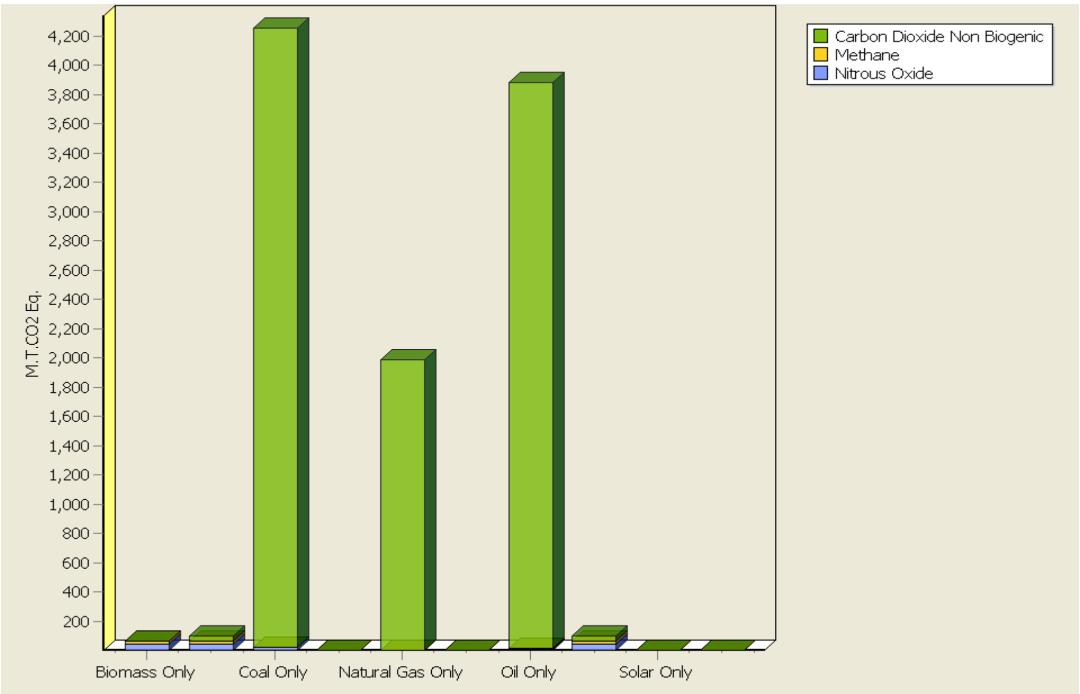


Fig. 5.15: Comparison among Supply Alternatives for GWP in 2050

Interestingly, the above mentioned results portray only one side of the image. The other side shows completely different results while taking the socio-cost into account (Fig. 5.16). Though, the renewable power supply options pose lowest input-fuel cost and highest output potential which makes them seemingly cheaper options. Also, the lowest or negligible GWP of renewables adds to their favor.

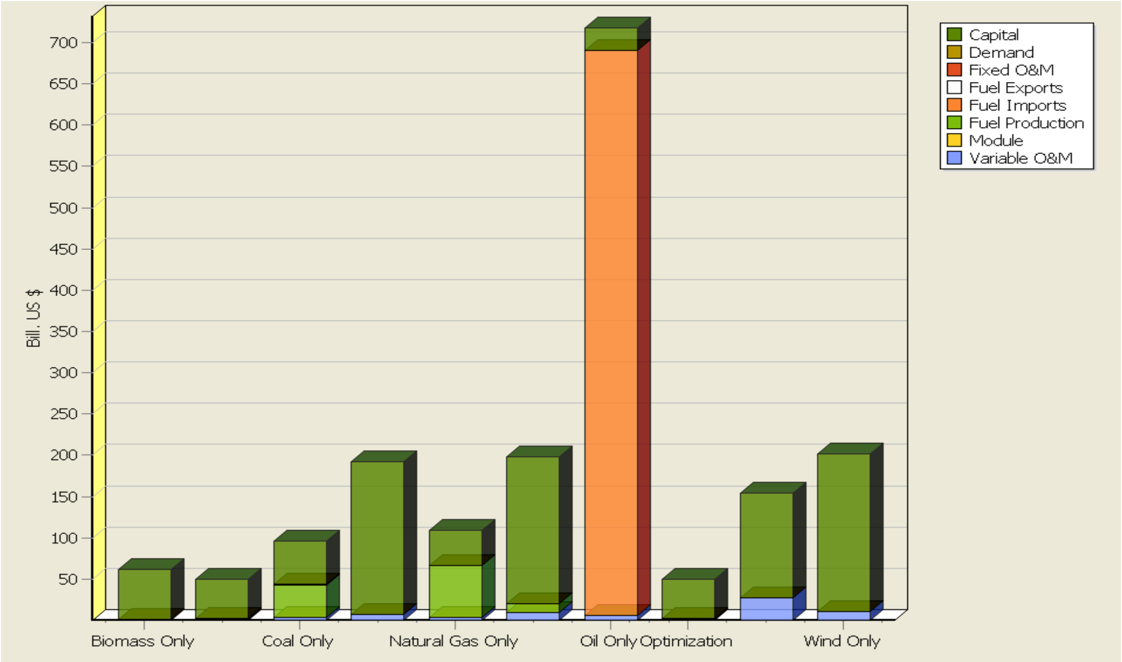


Fig. 5.16: Social Cost of Supply Alternatives without Externalities (GHGs)

But the investment, construction and O&M cost of renewables is the highest when compared to other options (Figure 5.17). Similarly, power plants based on indigenous fossil reserves undertake less capital and O&M costs which balance their externality cost with time.

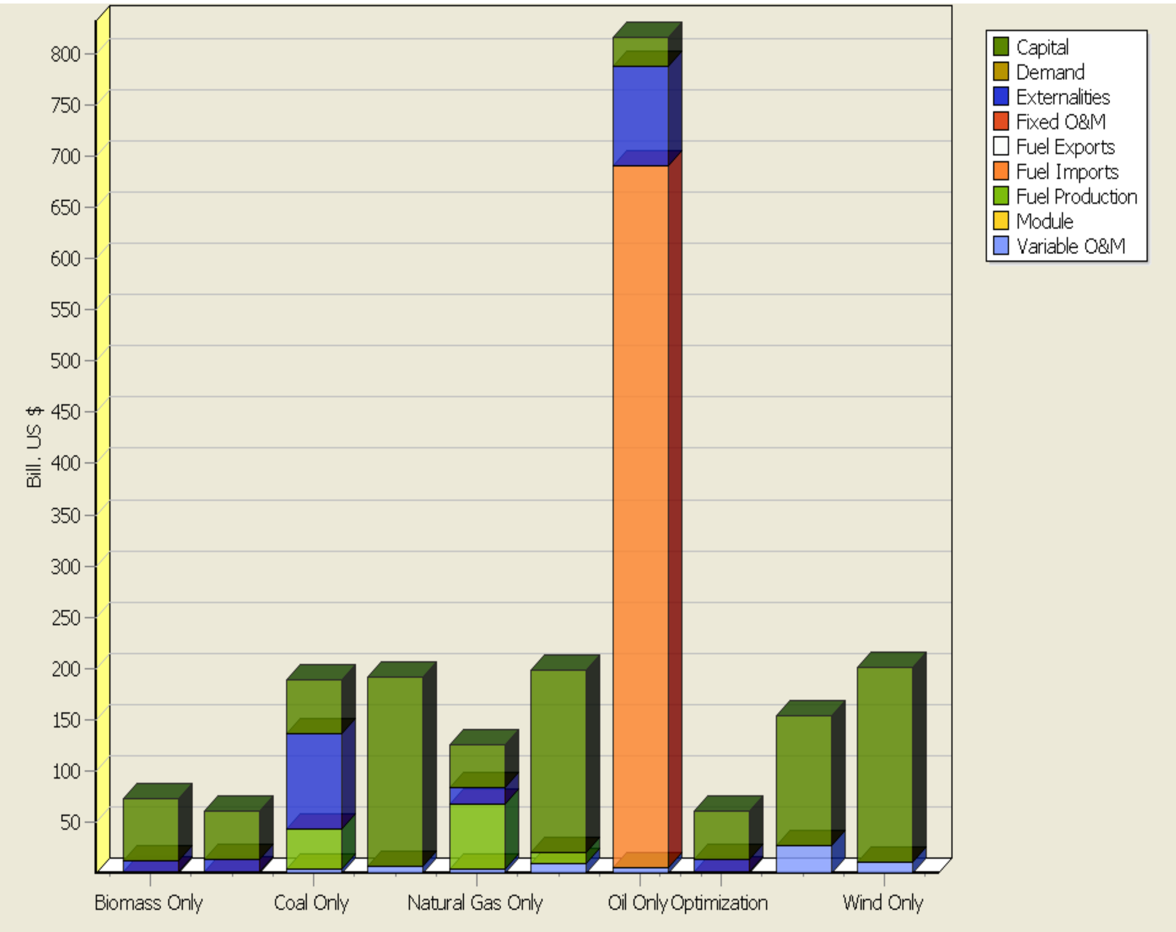


Fig. 5.17: Social Cost of Supply Alternatives with Externality Cost

In view of above findings, the optimization operation in LEAP model generated an optimum electricity generation mix scenario (OPT) for future supply. Features of the OPT are favorable in all dimensions of sustainability costs. This mix was extracted from the scenarios of biomass, coal, oil and natural gas as shown in Figure 5.18. In cumulative terms, biomass forms the largest fraction (836.2 M.TOE) of optimization scenarios whereas furnace oil makes the smallest (0.5 M.TOE). This reflects a low GHG emission share from the future electricity generation.

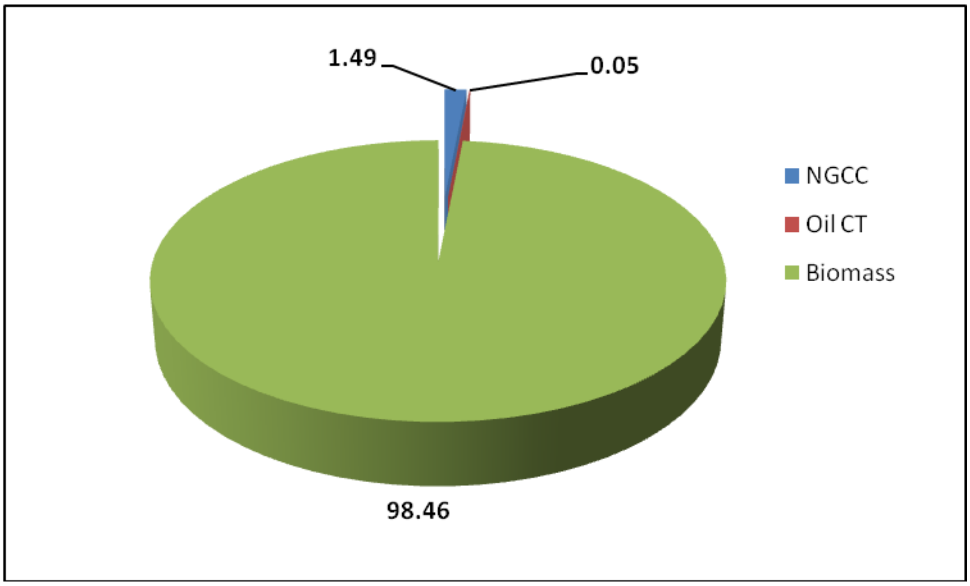


Fig. 5.18: Fuel Composition of OPT

The least cost electricity generation scenario is expected to consume 849.4 M.TOE of fuel input to produce 4,444.5 Th.GWh in year 2050. Figure 5.19 shows the output potential of this scenario which is estimated to produce 4376300 GWh using renewables (biomass), 66400 GWh by natural gas and coal combined cycle units, and 1800 GWh by oil combustion turbines. Figure 5.20 depicts fuel efficiency and maximized outcomes achieved under OPT.

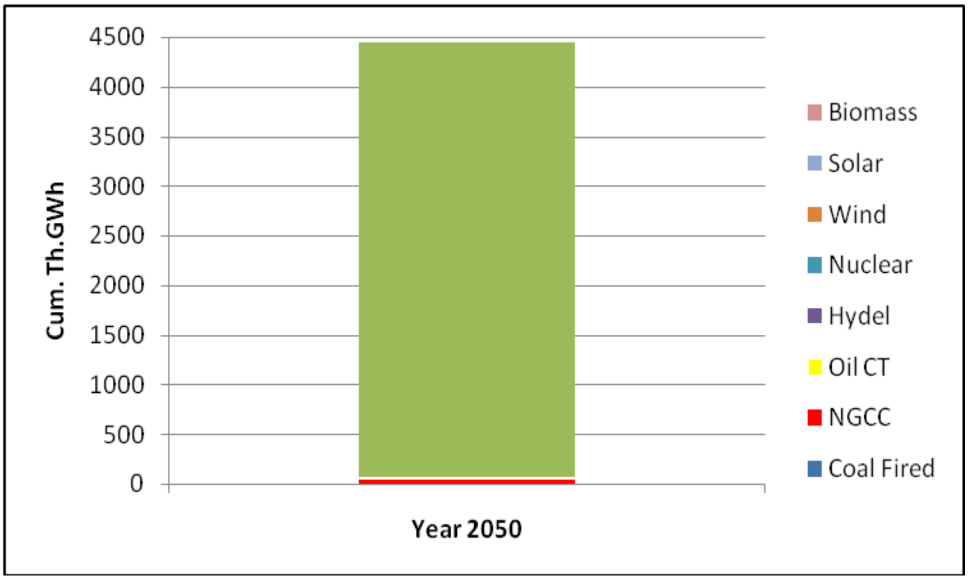


Fig. 5.19: Electricity Generation Potential of OPT in year 2050

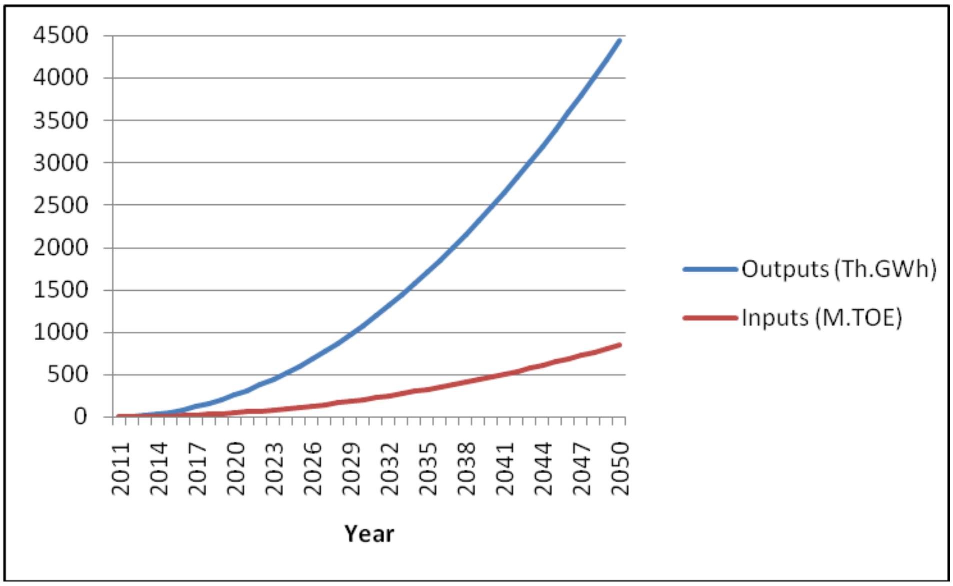
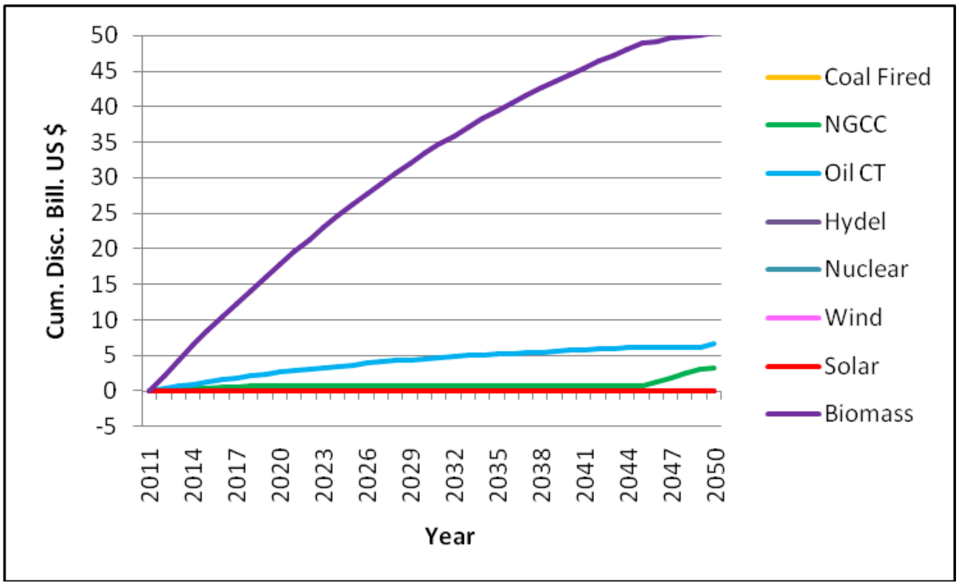


Fig. 5.20: Maximum output achieved under OPT

The comparison of cumulative discounted social cost of OPT with reference to the power supply options combined in this scenario is shown in Figure 5.21. Among the overall cost of electricity generation, cost of biomass fuel will reach up to US $ 50 billion in year 2050. Whereas, natural gas and oil run units show lesser cost shares due to their less weightage in the power mix.



5.21: Social Cost of OPT by Power Mix

Figure 5.22 shows the cumulative discounted social cost of optimization scenario by the cost categories. Due to the highest fraction of biomass resources, this scenario exhibits very high capital cost in comparison to fixed and variable O&M costs. Also, the GHG emissions due to usage of non-renewable fuels cannot be ignored as these pollutants add to the externality cost in this scenario.

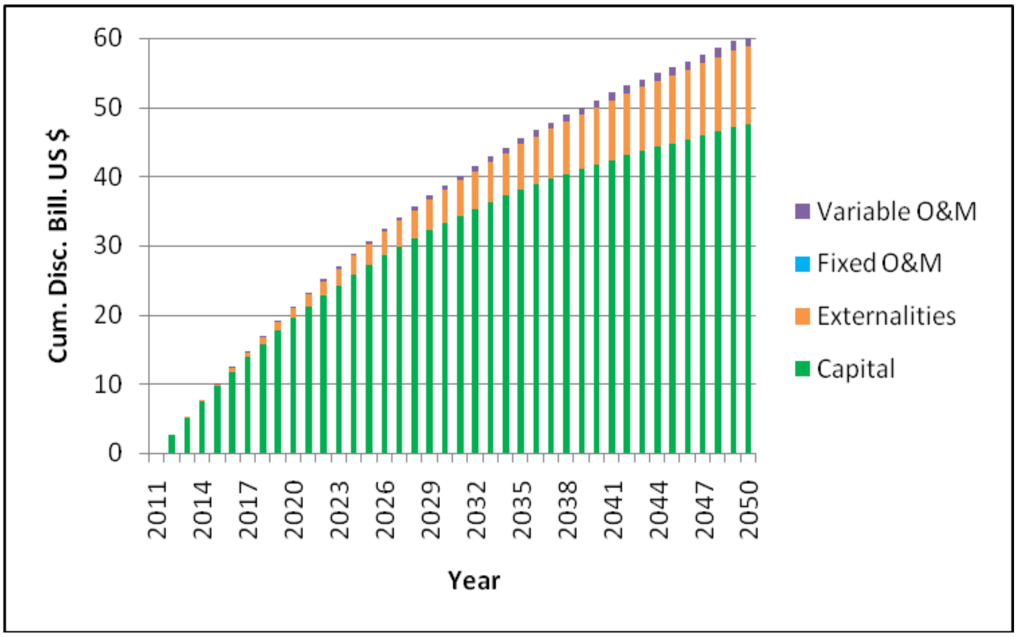


Fig. 5.22: Social Cost of OPT by Cost Category

With reference to global warming potential of OPT policies during 2050, this scenario is estimated to emit 96.8 M.T.CO_2Eq. of green house gases in cumulative terms (Figure 5.23). These gases comprise up of 31.2 M.T.CO_2Eq. of carbon dioxide non-biogenic, 41.5 M.T.CO_2Eq. of nitrous oxide, 24.2 M.T.CO_2Eq. of methane, and small amounts of other gases.

With reference to the power supply options that contribute to these emissions, power generation using renewable resources (biomass) emits 65.6 M.T.CO_2Eq., combined cycle units emit 29.6 M.T.CO_2Eq., whereas oil combustion turbines contribute up to 1.6 M.T.CO_2Eq. of green house gases, in cumulative terms.

Coal is an important option to bridge up the shortfall of 6500W in Pakistan. Thar coal reserves have the potential to supply power alone for 50 years. Lakhra coal is operating at 25% of its capacity. IGCC system has come out to be a revolutionary. It operates at 58% efficiency comparable to 28-33% for other power plants. It consumes natural gas or coal gas as fuel which make it environmentally approving.

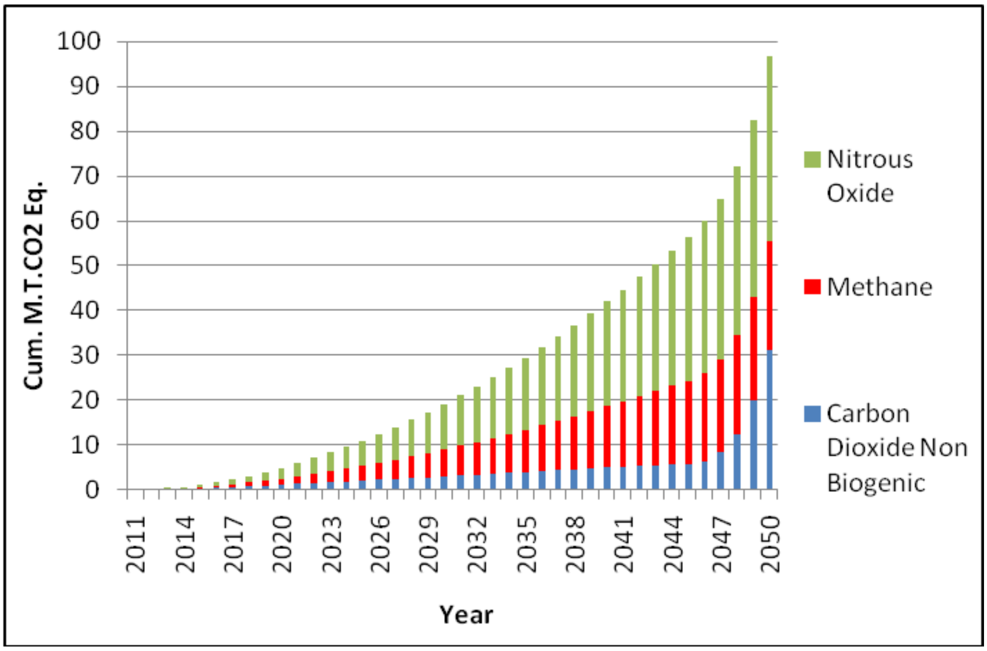


Fig. 5.23: Cumulative Global Warming Potential (GWP) of OPT

The coal power stations have caused a range of serious air quality issues, specifically its harmful emissions of sulfur and nitrogen are the usual causes of particulate emissions and acid rain. Subsequently, the upgraded coal gasification combined-cycle power generation technology presents with environmentally clean and efficient version of coal based power generation (Bhutto *et al.* 2005).

Though, natural gas is a good quality option in terms of environment and is cheapest due to its low capital and power generation cost. But unplanned use of its vast indigenous reserves has lead to depletion of its resources. The country is facing gas load shedding which makes significant part of our demand gap. 60% of power stations are furnace oil based which runs on imported fuel. Furnace oil offers less cost than renewable but its high sulfur content makes its environmentally unfavorable. The plant boiler corrodes after 4-5 years of its operational life. This reduces the generation capacity to almost 30-50%. A simplified summary of cost benefit results of the proposed is shown in tables 5.9 to 5.11.

Table 5.9: Cumulative Costs and Benefits of All scenarios versus OPT (2011-2050)

	Coal Only	**Natural Gas Only**	**Oil Only**	**Hydel Only**	**Nuclear Only**	**Wind Only**	**Solar Only**	**Biomass Only**
Demand								
All Electricity	0	0	0	0	0	0	0	0
Transformation								
T&D	0	0	0	0	0	0	0	0
Electricity Generation	8.1	-2.5	-16	143.1	139	152.2	105.4	12.9
Resources								
Production	38.8	62.3	-0.4	-0.4	10.3	-0.4	-0.4	-0.4
Import	-	-	684.6	-	-	-	-	-
Export	-	-	-	-	-	-	-	-
Environmental Externality Cost	81.4	4.9	87	-11.3	-11.3	-11.3	-11.3	-0.1
Net Present Value	128.2	64.7	755.2	131.4	138	140.5	93.7	12.4
GHG Savings (M.T.CO_2Eq.)	-4158.3	-1888.4	-3785.7	96.8	96.8	96.8	96.8	30.2
Cost of Avoided CO_2 **(U.S. \$/Tonne CO_2Eq.)**	-	-	-	1357.4	1425.6	1451.2	967.3	409.2

Table 5.10: Cum. Costs and Benefits of All scenarios versus Coal Only (2011-2050)

	Natural Gas Only	**Oil Only**	**Hydel Only**	**Nuclear Only**	**Wind Only**	**Solar Only**	**Biomass Only**	**Optimization**
Demand								
All Electricity	0	0	0	0	0	0	0	0
Transformation								
T&D	0	0	0	0	0	0	0	0
Electricity Generation	-10.6	-24	135	130.9	144.1	97.3	4.8	-8.1
Resources								
Production	23.5	-39.2	-39.2	-28.4	-39.2	-39.2	-39.2	-38.8
Import	0	684.7	0	0	0	0	0	0
Export	-	-	-	-	-	-	-	-
Environmental Externality Cost	-76.4	5.6	-92.6	-92.6	-92.6	-92.6	-81.4	-81.4
Net Present Value	-63.5	627.1	3.3	9.9	12.3	-34.5	-115.8	-128.2
GHG Savings (M.T.CO_2Eq.)	2270	372.7	4255.2	4255.2	4255.2	4255.2	4188.5	4158.3
Cost of Avoided CO_2 **(U.S. $/Ton CO_2Eq.)**	-28	1682.7	0.8	2.3	2.9	-8.1	-27.6	-30.8

Table 5.11: Cumulative Costs and Benefits of All scenarios versus Hydel Only (2011-2050)

	Coal Only	**Natural Gas Only**	**Oil Only**	**Nuclear Only**	**Wind Only**	**Solar Only**	**Biomass Only**	**Optimization**
Demand								
All Electricity	0	0	0	0	0	0	0	0
Transformation								
T&D	0	0	0	0	0	0	0	0
Electricity Generation	-135	-145.6	-159.1	-4.2	9.1	-37.8	-130.3	-143.1
Resources								
Production	39.2	62.7	0	10.8	0	0	0	0.4
Import	-	-	684.7	-	-	-	-	-
Export	-	-	-	-	-	-	-	-
Environmental Externality Cost	92.6	16.2	98.2	0	0	0	11.2	11.3
Net Present Value	-3.3	-66.8	623.8	6.6	9.1	-37.8	-119.1	-131.4
GHG Savings (M.T.CO_2Eq.)	-4255.2	-1985.2	-3882.5	0	0	0	-66.6	-96.8
Cost of Avoided CO_2 **(U.S. $/Ton CO_2Eq.)**	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a

5.5. Results for Demand Side Management Scenario (DSM)

Results of the proposed DSM polices show remarkable decline of energy demand by household sector as compared to REF (Figure 5.24). This is also reflected as the energy saving potential of DSM. Resultantly, these expected energy savings due to the introduction of energy efficient appliances will not only reduce the energy demand but also corresponds to the rapid fall in demand for power generation (Figure 5.25).

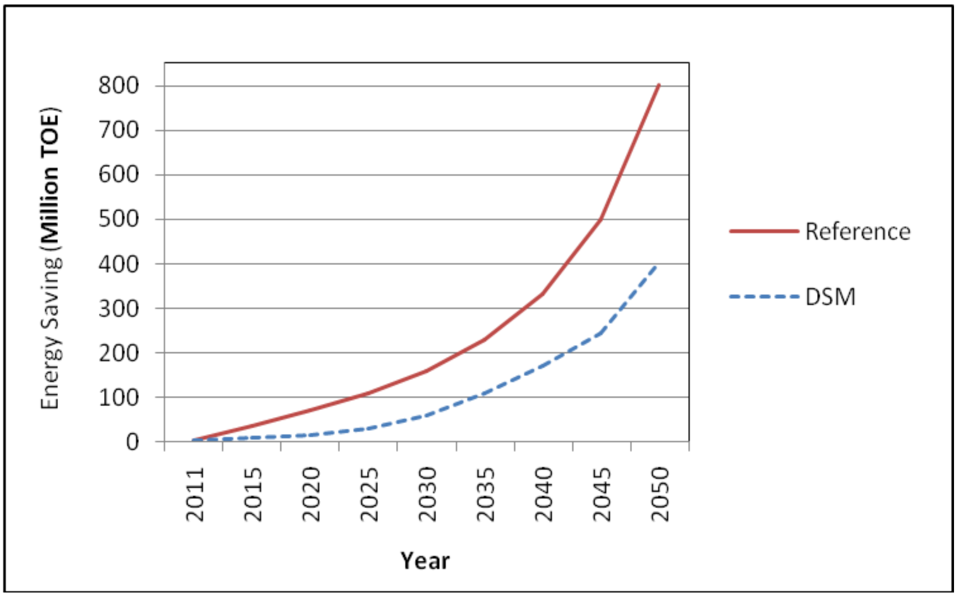


Fig. 5.24: Trend of Energy-saving Potential under DSM (2011–2050)

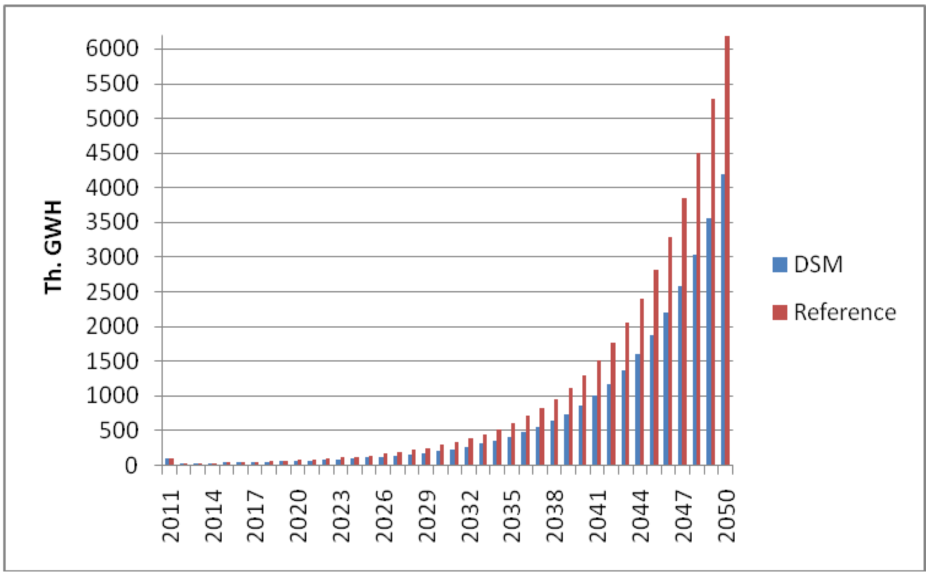


Fig. 5.25: Fall in Demand for Power Generation under DSM (2011–2050)

The Pakistan's NDCs aim to cut 20% of GHG emissions below its projected 2030 emissions under business-as-usual conditions. To achieve this, targets have been set to increase energy efficiency, at both the energy demand and supply sides. This also involves the introduction of efficient technology in the building sector, in addition to energy standards and labels for household appliances.

In this study, results show that fall in power demand under DSM will eventually lift up the burden on natural gas supplies. This situation is evident form Table 5.12 and Figure 5.26. This is due to the introduction of efficient water heating appliances i.e. geysers and conical baffles. Implementation of this scenario can prevent further exhaustion of natural gas supplies. Details of energy savings due to the introduction of efficient appliances in household sector are presented in Table 5.13.

Table 5.12: Fuel-based reduction in Energy Demand under DSM (absolute values in M.TOE)

	2011	**2015**	**2018**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**Ann. Avg. Growth (%)**
DSM	171.5	164.5	153.7	143.4	103.9	117.4	136.6	170.7	241.8	403.6	2.20%
REF	171.5	193.7	212.6	226.4	266.4	317.2	386.2	488.2	655.5	959.3	4.50%

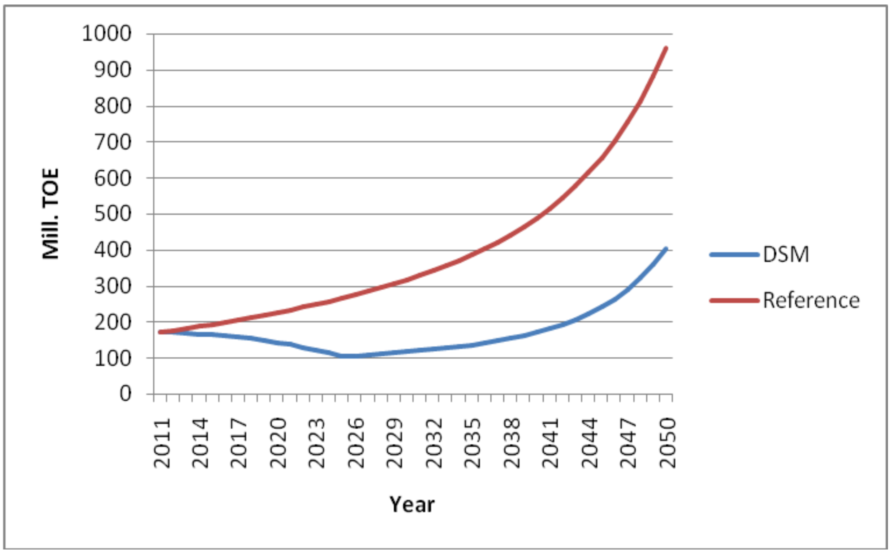


Fig. 5.26: Fuel-based Reduction in Energy Demand (DSM vs. REF)

Table 5.13: Household Device-based Energy-saving potential under DSM (absolute values in M.TOE)

Device	**2011**	**2015**	**2018**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Bio-fuel Stove	0	-0.1	-0.1	−0.2	−0.3	−0.5	−0.7	−1	−1.4	−1.8
Electricity Stove	0	0.2	0.4	0.6	1	1.7	2.5	3.5	4.9	6.6
LPG Stove	0	0	0	−0.1	−0.1	−0.2	−0.2	−0.3	−0.5	−0.6
Natural Gas Stove	0	0	-0.1	−0.1	−0.2	−0.3	−0.6	−0.9	−1.3	−1.9
Air conditioner	0	−0.1	-0.1	−0.2	−0.4	−0.8	−1.3	−2.1	−3.4	−5.2
Fan	0	0	0	0	0	0	0	0	0	0
Refrigerator	0	−0.3	-0.6	−1	−2.6	−6.1	−13.2	−27.7	−56.8	−114.6
Electric Lamps	0	0	0	−0.1	−0.1	−0.2	−0.2	−0.3	−0.4	−0.5
Kerosene Lamps	0	0	0	0	0	0	0	0	0	0
Biomass Heater	0	0	0	0	0	0	0	0	0	0
Gas Heater	0	0	0	0	0.1	0.1	0.1	0.1	0.2	0.2
Biomass Geyser	0	0	0	0	−0.1	−0.1	-0.2	−0.3	-0.4	−0.5
Efficient Geyser	0	0.2	0	0.6	1	1.6	2.3	3.2	4.4	5.8
Existing Geyser	0	−29.1	0.4	−82.6	−160.7	−195	−237.9	−291.7	−359.1	−443.3
TOTAL	0	−29.2	-58.6	−83	−162.5	−199.8	−249.6	−317.5	−413.7	−555.8

It has been found out that air conditioner/AC is the second most energy consumptive device, especially in high-income-level households. However, its replacement with roof insulation technology could save energy up to 500 M.TOE in year 2050, as compared to the REF. Device-based results under DSM and the consequent end-use based energy savings in household sector are depicted at Figures 5.27 and 5.28.

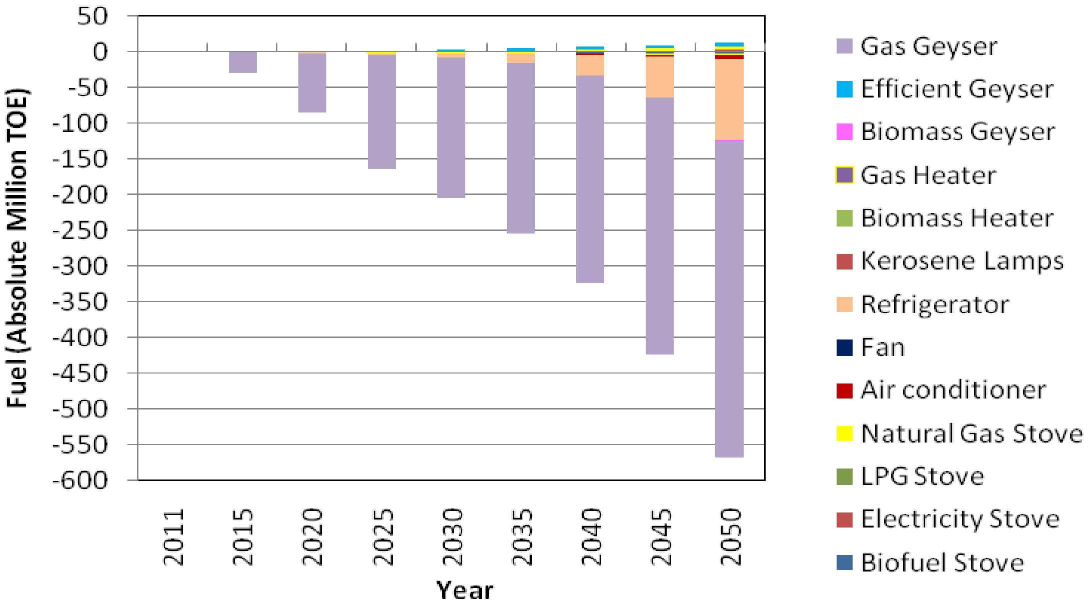


Fig. 5.27: Device based Energy-saving potential (DSM vs. REF)

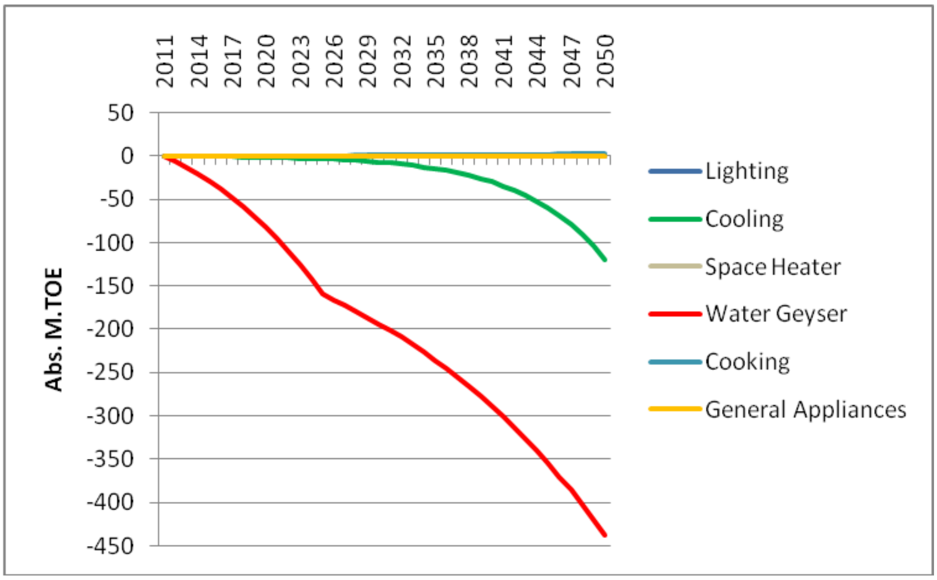


Fig. 5.28: End-use based Energy-saving potential (DSM vs. REF)

As per energy usage trends, power consumed by electric home appliances represents 50% of the total power consumed by domestic and commercial buildings in Pakistan. These appliances are mainly refrigerators, air-conditioners, electric motors, fans, and lighting systems. It is assumed that the introduction of efficient appliances will save energy by 10%, which makes up over 350 MW. The annual percentage load from household devices has been estimated to be 34% from electric lighting, 33% from fan usage, 13% by refrigerators or freezers, 7% by irons, 5% by room air-conditioners, 1% by air coolers, and 7% from miscellaneous uses (ENERCON, 2009).

Conventional technology and inefficient electronic devices have been successfully phased out from the households of all developed and some developing countries. Similarly, the import and sale of IBs is banned in most European countries. The United States' Clean Energy Act (2007) and the Australian Clean Energy Act (2011) also commit to the replacement of conventional lighting devices with efficient ones. According to a national household survey of Pakistan (Kojima, 2006), 40 W FTLs with an average of 11 W electromagnetic ballasts are commonly used in Pakistan. Replacing these with 32 W FTLs with ballast losses of 1 W could achieve as much as 80% of the technical savings potential.

With regard to energy efficiency measures in Pakistan, one such step was taken under a USAID program for the distribution of efficient light bulbs among households. However, its benefits were undermined due to prolonged load-shedding, which increased the sale of diesel-run generators, illegal gas compressors, and cheap fuels for household usage. This further increased the average energy usage cost and GHG emissions.

As indicated in Figure 5.29, the alternative policies under the DSM exhibit remarkable potential to successively lower GHG emissions. Figure 5.30 further elaborates this situation where a marked decline of carbon-dioxide non-biogenic emissions, followed by sulfur dioxide and methane emissions can be observed. As a consequence of residential side management plan, 478.3 M.T.CO_2Eq. green house gases will be emitted from urban households in 2050 as compared to 3,468.5 M.T.CO_2Eq. emissions observed in the reference scenario.

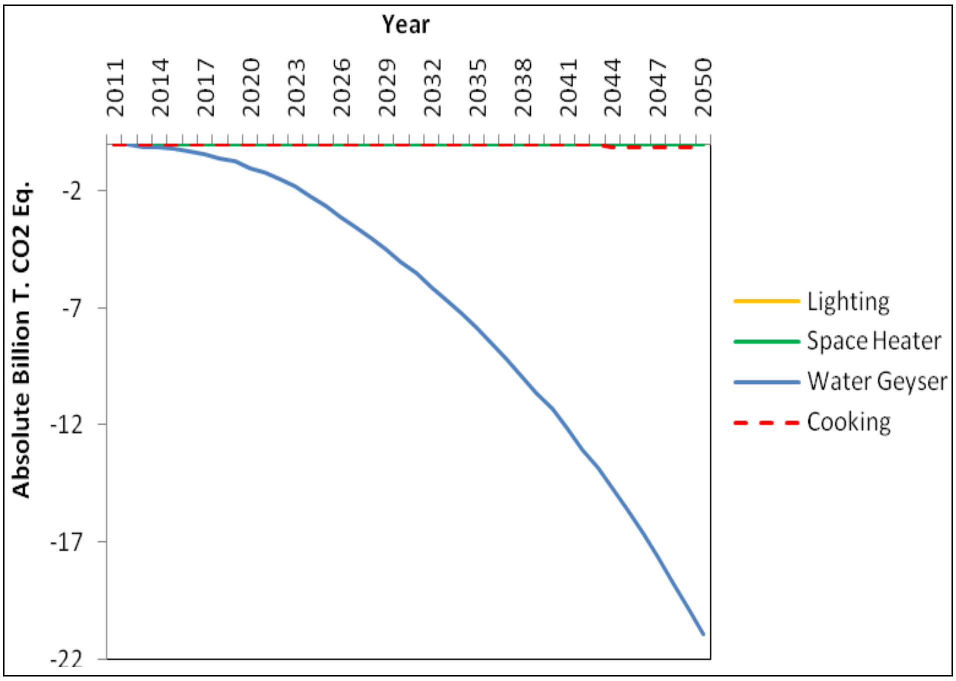


Fig. 5.29: Decline in Global Warming Potential (DSM versus REF)

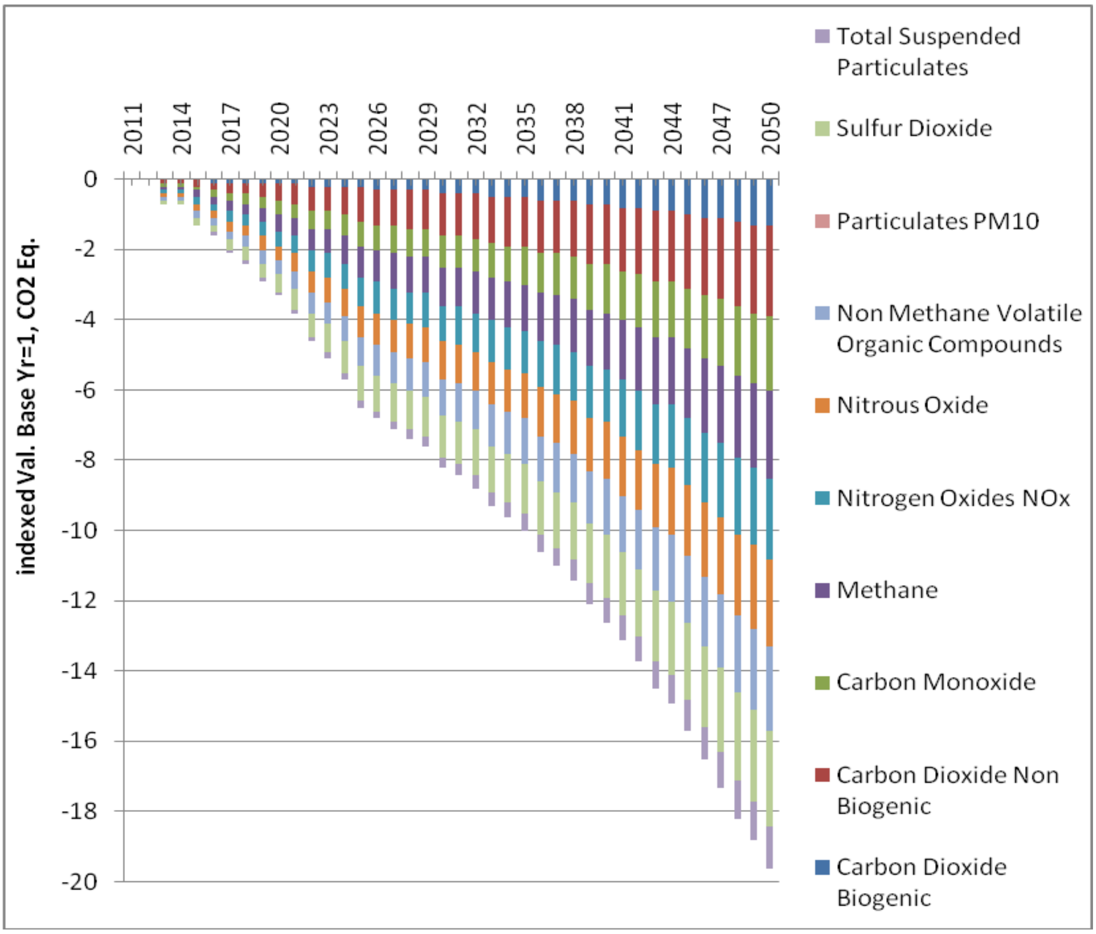


Fig. 5.30: Avoided Greenhouse Gas Effects (DSM versus REF)

5.6. Results of Mitigation Scenario (MIT)

In order to overcome the impacts from energy demand and supply side policies, a mitigation scenario is formulated in this study that inherits from the anticipated policy scenarios. Owing to the vast renewable energy potential in Pakistan, targets for the deployment of renewable energy were also introduced in this scenario. This scenario (MIT) is best-suited in terms of energy saving, social cost, and GHG emissions.

Description of these policy alternatives is given in Table 5.14 which is a combination of energy efficient household devices and renewable energy options for electricity generation. A cost benefit analysis of energy efficient technologies was carried out which were proposed to reach Mitigation scenario. These scenarios include penetration of relevant energy efficient technology in households, performance of that technology and its cost in US dollars.

Table 5.14: Alternative Policies for Valuation of Mitigation Scenario

Sector	Policy or Measure	Description
Urban Household (H.H)	• Efficient Lighting	**Technology Penetration:** An efficient lighting program would reduce electricity consumed in urban households, using CFLs and other technologies. The program is capable of reaching 40% of households by 2020 and 100% in 2050. Thus reducing the share of conventional device to 10%. **Technology Performance:** It will consume only 30% of the electricity used by conventional lighting in urban household. **Technology Cost:** Standard light bulbs cost approx. $ 1 each but have a lifetime of only 1 year. Efficient light bulbs cost $ 6 each but are assumed to last for 3 years. Each household is assumed to have an average 3 working

		lights.
	• Efficient Cooking	**Technology Penetration:** This program will accelerate the share of electric and LPG stoves to 1% and 20% in 2050, res. Existing inefficient stoves will be replaced with efficient ones by 30% in 2030 and 70% in 2050. **Technology Performance:** Old stoves are 40% efficient whereas new ones are 70% efficient. It will consume only 43% of the gas used by conventional stoves in urban household. **Technology Cost:** $ 10 per piece
	• Efficient Space Heaters	**Technology Penetration:** Efficient space heaters will replace existing low quality heaters by 30% in 2040 and 70% in 2050. The existing gas heater share is assumed to reduce to 10% in 2050. **Technology Performance:** Existing devices are 40% efficient whereas new ones will consume only 36% of the gas used by the existing heaters. **Technology Cost:** $ 25 per piece
	• Efficient Water Geysers	**Technology Penetration:** SSGC and SNPGL have devised retrofits which are assumed to replace existing inefficient water heating appliances by 65% in 2050. The share of conical baffles and instant geysers will increase to 25%.

		Technology Performance: Conventional geysers are 30% efficient whereas new ones are 60% more efficient. **Technology Cost:** $ 12.5 per piece
	• Efficient Cooling	**Technology Penetration:** • New efficiency standards for household electric devices will be introduced. By 2050 all existing inefficient refrigerators will be replaced by efficient ones. • Roof insulation is targeted to reach 50% of households in 2050 as an efficient technology in place of air conditioners. **Technology Performance:** • The standard would require that manufacturers produce refrigerator with an average energy intensity of 380 KWH per household. • Roof insulation consumes 20% less energy than A.C.s **Technology Cost:** $ 42 per efficient refrigerator $ 1500 per household cost of roof insulation
Supply Side	A target of 10% electricity generation from renewable resources by 2025	To meet the target, the assumptions made for future electricity generation are as follows: • Assume 100MW of hydel power plant with capacity factor of 0.7 by 2025 • Assume 120 MW of wind plant will be installed by 2025

		- Assume 400 MW of solar thermal electricity plant by 2025 - Assume 100MWof biomass power plant with capacity factor of 0.7 by 2025
	Renewable electricity (R.E)	Include all scenarios from supply side.
Mitigation	**Mitigation** (LIG, RFR, ROOF, GEY, HEA, STOV, RE)	Include all scenarios from demand (H.H) and supply sides.

Globally, many studies assessed the benefits of household energy optimization through the integration of renewable options, energy storage systems, load scheduling, etc. Benefits include high-performance smart grids, reducing the demand–supply gap, and CO_2 mitigation (Supasa, 2017; Ahmad *et al.* 2017; Chaudhry, 2010; Phdungsilp, 2010; Sheikh, 2010, Chaudhry, 2010; Avami and Farahmandpour, 2008; McNeil and Letschert, 2005.; El-Fadel *et al.* 2001; Ghanadan and Koomey, 2005).

In order to determine the best suitable demand side scenario for urban household sector, the proposed policies were compared with the reference scenario, as independent scenarios. Scenario analysis suggests that in year 2050, a total 540 M.TOE is consumed by efficient water heating scenario whereas, 343 M.TOE of energy consumption was proposed in DSM and 810 M.TOE in case of REF.

Results show that among all of the proposed scenarios, maximum energy saving in household usage can be achieved under the ‘Efficient Water Heating Scenario’ i.e., up to 270 M.TOE in year 2050. In terms of fuel usage, a high potential of natural gas saving is anticipated through the introduction of the ‘Efficient Cooking Stoves’ and ‘Efficient Water Heaters’ scenarios. The comparison among reference and Mitigation scenario for energy demand is shown in Figure 5.31.

The mitigation plan of Pakistan’s NDCs also emphasize upon the potential of energy savings in the residential sector (WRI, 2017). However, no local or community level disaggregated plan exists for the sustainable management of energy demand in the household sector of Pakistan.

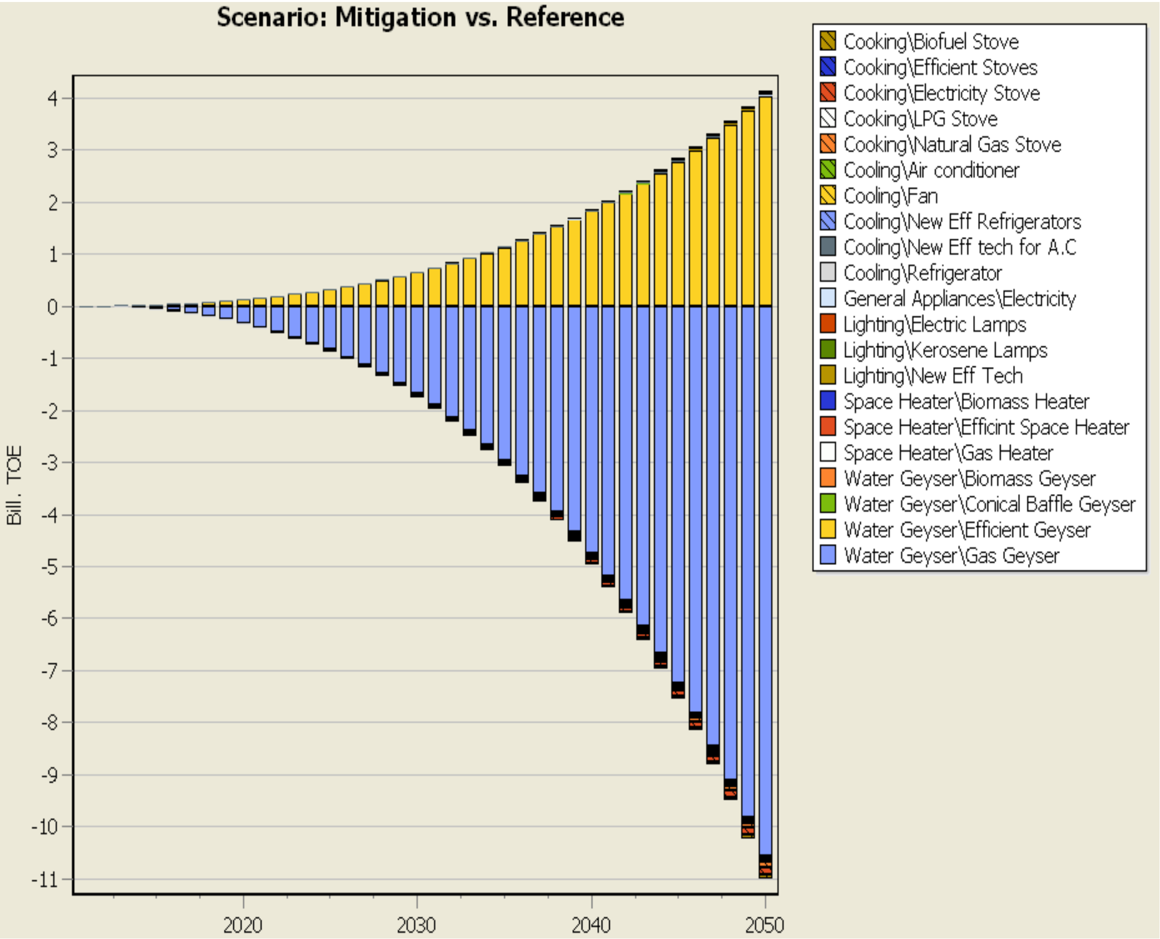


Fig. 5.31: Comparison of Energy Demand between MIT and REF in 2050

A simplified summary of cost benefit results of the proposed scenarios of this study is shown in Table 5.15. Here, the net present value (NPV) is negative which shows the reduction in cost as compared to reference scenario. The cost required to invest for implementation of these efficient policies, is estimated to be US $ 3.4 billion/Ton CO_2 Equivalent, lesser than the reference scenario. The comparison among cost and benefit results of DSM and REF also shows a high reduction in green house gas emissions under the DSM Scenario i.e. up to 46,932.6 M.T.CO_2Eq.

Table 5.15: Cost-benefits analysis of DSM versus REF (2011–2050) (in billions of US dollars in 2010, discounted at 5% to the year 2011)

DSM Versus REF	Cumulative Costs
Net Present Value	−157.3
Environmental Externalities	0.0
GHG Savings (M.T.CO_2Eq.)	46,932.6
Cost of Avoided CO_2 (US $/Ton CO_2Eq.)	−3.4

While determining the cause of increasing energy demand, numerous studies highlight income level as a key determinant of energy transition in households. Studies conducted in the urban residential sector of China, India, South Africa, Zimbabwe, and other African countries also identify various sub-variables associated with the income factors that determine final energy usage (Gupta and Kohlin, 2006; Farsi *et al.* 2007; Hosier and Dowd, 1987; Davis, 1998; Zhao *et al.* 2012).

The objective of such studies is low-cost energy supply though optimization techniques. Similarly, most of the studies conducted in Pakistan focus on the energy demand forecast and economic growth (Aqeel and Butt, 2001; Shahbaz *et al.* 2012; Khan and Ahmad, 2008; Siddiqui, 2004; Shahbaz and Lean, 2012; Hye and Riaz, 2008; Zaman *et al.* 2012; Raza *et al.* 2015; Cheema and Javid, 2015; Ahmed *et al.* 2015; Komal and Abbas, 2015; Shahbaz *et al.* 2013; Shahbaz *et al.* 2015; Arshad *et al.* 2016).

As per the mitigation plan of Pakistan’s NDCs, the total implementation cost of the energy sector plan is US $40 billion (WRI, 2017). With the aim of increasing energy security and reducing energy poverty, 7650 MW coal power plants are to be installed. However, implantation of this plan requires an investment of US $27.6 billion through the China-Pakistan Economic Corridor (CPEC).

Owing to the vast renewable energy potential in Pakistan, targets for the deployment of renewable energy were also introduced in this scenario. Pakistan is home to some of the world’s largest reserves of coal and natural gas. However, unplanned usage is rapidly causing their exhaustion. Shortages of gas supplies during winters further add to the supply-demand gap. Due to this, the majority of power stations, which are furnace oil-based, are being run on expensive imported fuel.

Farooq *et al.* (2013) and USAID (2015) analyzed cost of investment of Renewable Energy Technologies (RETs) and their projections till year 2050. It was found that among all renewable resources, investment cost of solar-thermal is the highest in year 2015, i.e. $4420/kW which will reduce up to $2340/kW in year 2050. Whereas, bagasse cost least investment in year 2015 i.e., $1356/kW which will decline further to 12601356 $/kW in year 2050.

In terms of fuel-based cost of energy production, it was found that hydel energy is the cheapest option costing Rs 1.5 (7+)/kWh, followed by Gas Rs 5.55/kWh, Nuclear Rs 6/kWh, Coal 10, Wind 14, RFO 13-18, Solar 15-20 Rs/kWh (First 10 Yrs.) and 11-14 Rs/kWh (Levelized Value). Whereras, thermal (HSD) based power generation was found to be most expensive option i.e., 20-23.

In terms of social cost of the proposed scenarios in this study, ‘Efficient Space Cooling’ comes out to be the lowest-cost scenario in 2050, due to roof insulation technology. Figure 5.32 shows a comparison of social cost between the MIT and REF.

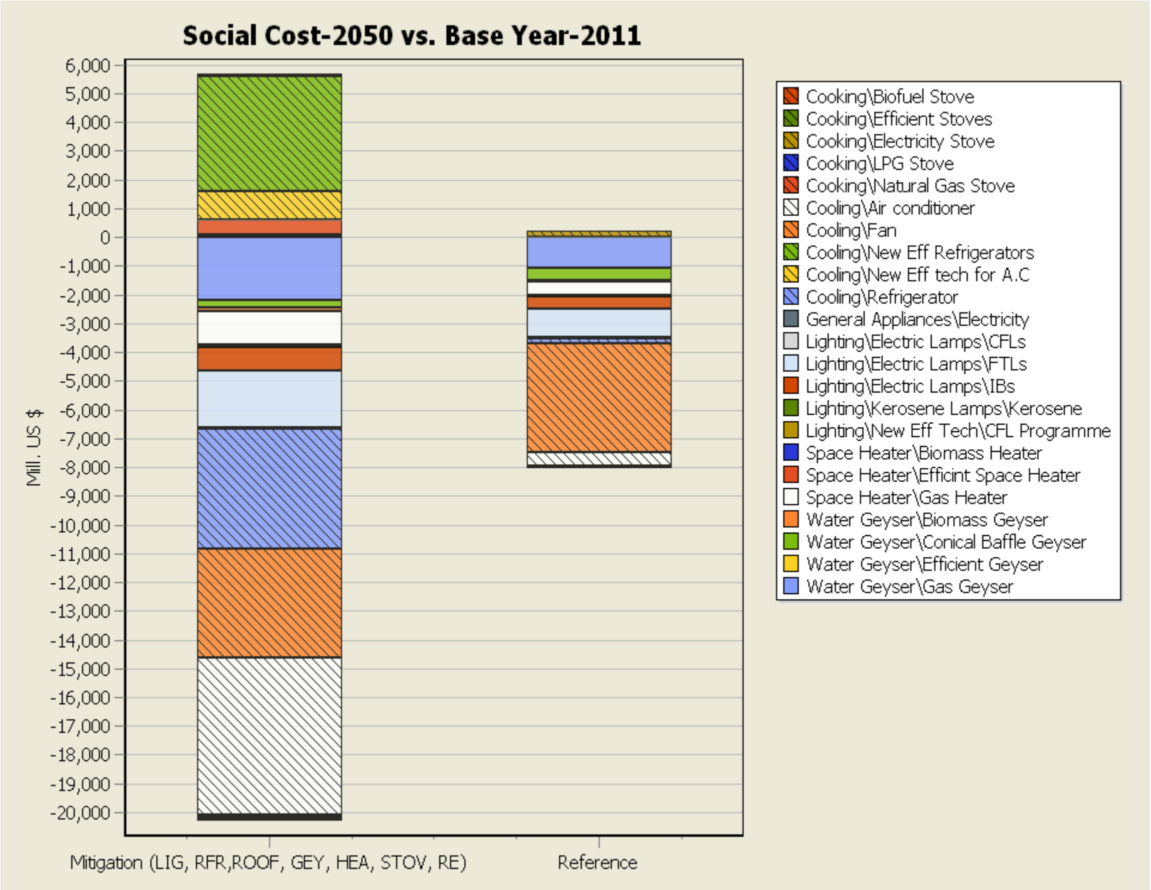


Fig. 5.32: Comparison of Social Cost between MIT and REF

More recent studies also suggest that income is an important variable, but its key reliance on achieving a sustainable demand-side system is irrational (Zeng *et al.* 2011; Alam, 2007; Nasir and Ur Rehman, 2011; Ali and Abbas, 2013). These studies highlight the importance of institutional, social, and environmental aspects of energy systems.

For instance, Rehman *et al.* (2017) studied that evaluation of GHG contribution from household energy usage demonstrates that a 1% rise in per-capita energy usage leads to a 1.65% increase in per-capita carbon emissions. This is also evident from the results of this study.

Results of the current study affirm that implementation of the MIT policy options will not only lift the demand load in household sector, but also reduce GHG emissions (Figure 5.33). The capital and energy generation cost of thermal plants is much less than renewable. However, excessive emission of sulfur, nitrogen, and particulate matter are responsible for various environmental problems and reduced cost-effectiveness.

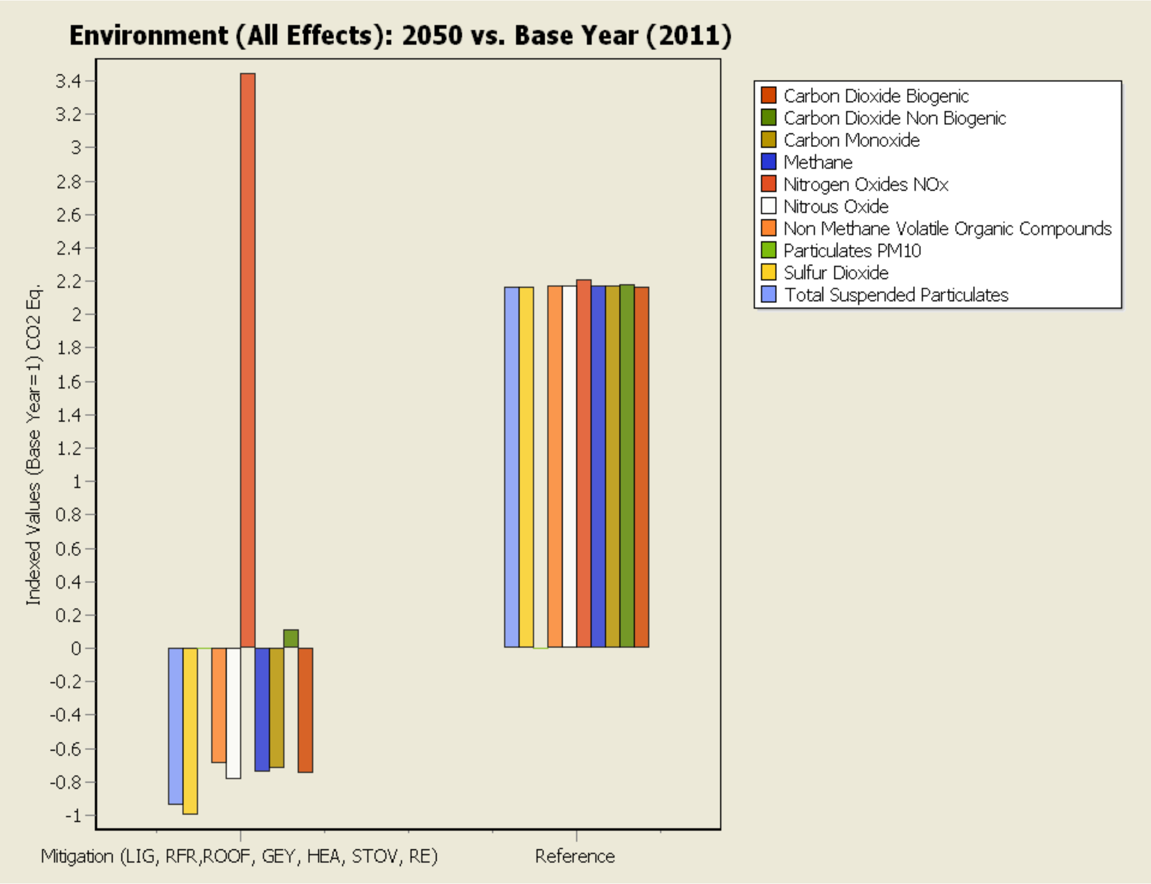


Fig. 5.33: Comparison of Global Warming Potential between MIT and REF

A study of prospective electricity analysis using 450 scenarios also found that a huge reduction in GHG emissions and water-footprint can be achieved through sustainable measures (Mekonnen, 2016). Therefore, the importance of the pre-assessment of energy policies has been emphasized in many studies for allotting finances to green policies (Cellura, 2018).

The above results conclude that the incorporation of renewable energy targets multiplied the benefits gained under MIT. The capital cost incurred by these renewable alternatives is high, up to $ 2300–2500/MW, but insignificant emissions and longer plant life covers their cost economics.

Recently, the World Bank and the German Financial and Technical Development Cooperation planned to provide strategic support for promotion of energy efficiency measures. However, no serious effort has been made until now for the sustainable management of energy demand in the household sector.

Chapter Six

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Energy and power sector has its specific strategic role in Pakistan's socioeconomic and environmental protection sectors. It is worth mentioning that increase in energy demand is reflective of economic prosperity of a society. In case of Pakistan, the total electricity demand has increased at an annual average growth rate of 4.54% since the beginning of twenty-first century (GoP, 2018).

Whereas, the domestic sector alone has continued its average annual growth of 5.94%. However, the country's energy and power supply growth is inconsistent with the soaring demand to meet the development needs of its 207.774 million population. Hence, the electricity consumption per capita is only 452 kWh, an approximate quarter of the world's average (NEPRA, 2017).

Energy sector of Pakistan has faced serious negligence on part of administration and policy makers. The power generation capability is limited due to slow enhancement of national grid whereas T&D losses are very high. Consequently, 51 million people in Pakistan lack access to electricity. Hence, the energy and more specifically power sector has come out to be one of the most challenging sectors to deal with. The deep-rooted energy crisis must not be blind-folded with the supply-shortfall alone. It is confronted with many other associated challenges which have multiplied its magnitude manifolds.

Consideration of residential sector in the overall energy planning and environmental policies is vital for energy sustainability. But no serious effort has been made until now for sustainable management of energy demand in the household sector of Pakistan. In practice, very few efforts have been made towards integrated planning for energy sector and its modeling in Pakistan. This is evident from the fact that majority of energy studies from Pakistan relate to economic growth and demand forecast alone.

However, formulation of such a plan takes time and is not easy. This requires an agreed upon process for collecting, reviewing and agreeing on data and developing a strategy for filling data gaps. Hence, rational and reliable IEPM is not a cheap and effortless choice. These limitations altogether result in provision of misleading information to policy makers. Therefore, reassessment of energy models is also necessary for transition towards sustainable energy development.

With the aim to combat the current energy crisis and to manage excessive energy consumption in household sector, this study provides long-term integrated energy modeling using LEAP simulations techniques accounting framework which has a significant impact in shaping energy and environmental polices worldwide for time-series data. The ultimate scope of the study was set to suggest a mitigation scenario that poses least socio-economic and environmental impacts over the study period, 2012-2050, using the year 2011 as base year.

This study involved detailed analysis of existing energy models and energy systems uncertainties along with an extensive policy review. Future policy scenarios were built upon integration of various energy efficient measures including Pakistan’s NDCs, which were then analyzed in terms of socio-economic value and GHG emission. Bottom up end use modeling techniques of the model were used to propose an efficient demand side management plan for household sector.

On electricity generation side, combinations of different power generation resources were proposed and compared keeping in view the externality cost of environmental emissions. The results were optimized, through OSeMosys optimization calculations, to reach to a supply-side scenario for the period 2012-2050. To attain the best suitable energy mix for Pakistan, energy sustainability indicators were selected for this study as per literature review and data availability, i.e. climatic and socio-economic conditions, fuel prices and consumption patterns, consumer choices, trends in use of household energy appliances, technology cost, its performance and emission factor.

The comparisons thus made between energy efficient policy scenarios to manage its demand were undergone through a cost benefit analysis from societal perspective. The results were obtained in the form of net present value of these policies, social cost and environmental externalities (GHG). A summary of the findings from the scenarios analysis, their impact mitigation and cost benefit analysis is as under:

In case of ‘**Reference scenario (REF)**’, total electricity generation in Pakistan would raise up to 6175200 GWh in 2050 as compared to 95,358 GWh in the base year of this study, 2011. Also, the share of oil and natural gas in power generation is expected to decrease which will result in 10% and 5% decrease in their shares in electricity installed capacity, resp. Electricity output will face 10.4% decrease from oil fired plants and 4.6% decrease from natural gas based units, accounting to 15% decline in the ann. avg. growth of electricity. In light of these results and cited literature, the electricity transformation sector is expected to continue posing more global warming as compared to any other sector. Environmental emission due to these sectors will quadruple the current global warming potential in 2050.

Reference scenario results for the demand side energy consumption show that the total energy demand by household sector is increasing by 4.5% each year which is estimated to be about 801.89 M.TOE in 2050. With reference to the annual average growth of residential urban energy intensity through 2050, the energy consumed for lighting increases to 3%, 16.4% for cooling devices, 6.8% for general appliances, 2% for gas heaters, 3% for water geysers and 2.8% for cooking. Heavy reliance on indigenous natural gas is expected to remain steady at 3% annual growth. Thus accounting for a total 374.87 M.TOE of natural gas consumption in 2050. Electricity usage grows to 423.2 M.TOE making its largest proportion of energy utilization. LPG usage increases by 3% during 2011 to 2050. Whereas, increased access to electricity is expected to decline the share of biomass and oil products. The social cost of domestic energy appliances is expected to reach US $ 34 billion in 2050 with the highest usage by space cooling devices. Also, in comparison to the base year 2011, this cost is expected to decrease to US $ 8.5 billion if necessary improvement steps are taken. The largest saving upto US $ 4.3 billion can be contributed by cooling appliances and US $ 2 billion by lighting.

An overall analysis of '**Supply Side Power Options (SSM**)' explain that the oil run units are least preferred due to their huge consumption of expensive fuel along with lesser output as compared to other scenarios, including renewable options. Though their construction and fixed O&M cost is the lowest but the massive contribution in environmental emissions adds to its externality cost which cannot be neglected. On the other hand, renewables based power has highest output potential which makes it seemingly cheaper options. Also, the lowest or negligible GWP adds to favor. But its investment, construction, O&M cost charge the highest when compared to other options.

The '**Least Cost Electricity Generation Scenario (OPT)**' generated for future supply is favored in all three aspects of sustainability i e socio, economic and environmental cost. It is proposed to consume 849.4 M.TOE of fuel input to produce 4,444.5 GWh in 2050 using renewables (biomass), natural gas and coal combined cycle units, and oil combustion turbines.

In case of the '**Demand Side Management (DSM)'** scenario proposed to reduce energy consumption in urban households, a wide energy gap of 557 M.TOE can be seen between the DSM and reference scenarios due to the energy savings by demand side management policies. Scenario analysis suggests that in 2050, a total 540 M.TOE is consumed by efficient water heating scenario whereas, 343 M.TOE of energy consumption was proposed in DSM scenario and 810 M.TOE in case of reference scenario. The largest decrease in energy demand is observed for natural gas mainly due to the introduction of efficient water geysers including the currently introduced instant water heaters and conical baffles. Air conditioners are the second most energy consumptive devices especially in high income level of urban population. Their replacement with roof insulation technology can save 500 M.TOE in 2050 as compared to the usual situation. This will eventually lift up the burden on natural gas supplies. As a consequence of residential side management plan, 478.3 M.T.CO_2Eq. green house gases will be emitted from urban households in 2050 as compared to 3,468.5 M.T.CO_2Eq. emissions observed in the reference scenario. The comparison among cost and benefit results of DSM and Reference scenario shows a high reduction in green house gas emissions under the DSM Scenario i.e. up to 46,932.6 M.T.CO_2Eq. The cost required to invest for the implementation of these efficient policies, is estimated to be US $ 3.4/Ton CO_2Eq., lesser than the reference scenario.

Results of the comparison among demand side policies to reach '**Mitigation Scenario (MIT)**' reveal that the 'Efficient Water Heating' scenario has the highest energy-saving potential, up to 270 M.TOE by 2050. Meanwhile, the 'Efficient Cooking Stoves' and 'Efficient Water Heaters' scenarios offer significant savings of natural gas fuel. In terms of the social cost, 'Efficient Space Cooling' promises to be the lowest-cost scenario in 2050.

The final **MIT**, hence obtained is a triple-win in all aspects of sustainability. It also incorporates targets to utilize the untapped renewable energy potential from the supply side. It is anticipated that the long-term benefits of renewable energy will overcome its huge capital cost. A cost-benefit analysis of the proposed policies suggests their immediate adoption in national plans. In comparison with the usual case (REF), the implementation cost of these policies is US $157.3 billion less, with an additional savings of US $3.4 billion due to avoided CO_2 emissions.

Hence, in contrast to the NDCs, which provide sectoral targets for GHG emissions reduction, this study offers more realistic strategies to achieve maximum targets in the most energy-intensive sector. Deployment of renewable energy will further reduce environmental emissions and promote clean energy in developing economies. The consideration of socio-economic and prospective climate change variables in this study makes it suitable for application in other developing countries in achieving NDCs related to energy-GHG nexus.

6.2 Recommendations

From this study, following recommendations have been identified for adoption of its findings and further study in this aspect:

To control GHG emissions from electricity generation and supply, and to address global climate change, the government needs to adopt the study findings immediately by putting the suggested pathway into practice. If these strategies are simultaneously implemented along with energy-efficient consumption patterns, the highest potential of energy and cost savings can be gained in the year 2050.

Lack of requisite authentic data and problems in data collection is huge obstacle in generating realistic energy system analysis of Pakistan. Moreover, absence of sub-sectoral studies and decentralized data is also a big problem. Therefore, this study addressed the main aspects of the energy system for which data is available. In the least cost electricity generation module of this study, actual cost data of the power plants in operation should be used for more realistic results.

Keeping in view the importance of ‘income level variable’ for studying household energy demand, this study included household data of middle income level to represent the largest fraction of urban population. For future study, all income levels need to be considered. Also, a dedicated research is required to study causes of fluctuating energy demand among households.

In the present world, cities are considered to be engines of growth. Sustainability indicators vary among cities due to their characteristic geographical, meteorological, economical, social and environmental features. Hence, it is also recommended that city-specific or local indicators shall be studied to determine energy sustainability of individual cities and societies.

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Annex-A

Government Policies and Reports reviewed for the study

- 10th Five Year Plan (2010-15)
- 25 Years National Energy Security Action Plan (2005-2030)
- Annual Plan (2011-2012)
- Integrated Energy Plan (2009-2022)
- Mid Term Development Framework (2005-10)
- Millennium Development Goals, 2015
- National Energy Conservation Policy, 2005
- National Environmental Policy, 2005
- Pak Clean Air Programme
- National Power Policy, 2013
- Policy for Development of Renewable Energy for Power Generation, 2006
- Policy for Power Generation Projects, 2002
- Power Development Program (2010-2030)
- Public Sector Development Programme (2011-2012)
- Energy Efficiency Investment Program, 2009
- Task Force Final Report on Climate Change, 2010
- Integrated Energy Sector Recovery Report and Plan, 2010
- Vision 2030
- WAPDA Vision 2025
- Pakistan Census, 1998
- Provisional Summary Results of 6th Population and Housing Census 2017
- Pakistan Social & Living Standard Measurement (PSLM) Surveys, 2004-2015
- Pak Economic Surveys, 2007-2018
- HDIP Pak Energy Year Books, 2009-2016
- World Development Indicators, 2011
- Survey of Energy Resources, 2011
- International Energy Outlook, 2011
- World Energy Outlook, 2008, 2010 b
- Energy Access Outlook 2017: From Poverty to Prosperity, 2017
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- Compendium on Environmental Statistics of Pakistan, 2011; 2015
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- ADB Pakistan Sustainable Energy Efficiency Development Program, 2009
- Pakistan Sustainable Energy Efficiency Development Program, 2009
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- Power System Statistics 2016–2017
- Trends in the Use of Electric Goods in Pakistan, Gallup Pakistan Ltd, 2015
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- National Economic and Environmental Development Study, 2011
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- Climate Change Profile of Pakistan, 2017
- Asian Development Outlook 2012: Confronting Rising Inequality in Asia
- Alternate Energy Development Board Internal Report-2009
- Pakistan Integrated Energy Model Pak-IEM, 2010
- Integrated Energy Planning for Sustainable Development, 2008
- Energy indicators for sustainable development: Guidelines and methodologies, 2005
- PAK-INDC Report, 2016
- National Power System Expansion Plan (2011–2030). Final Report.
- Electricity Demand Forecast Based on Multiple Regression Analysis for 2011-35
- Punjab Economic Report-2017
- Renewables 2011; Global Status Report
- Power System Statistics 2016–2017
- Hydro Potential in Pakistan, 2011
- Tracking SDG7: The Energy Progress Report 2018
- Our Common Future- WCED Brundtland Report, 1987
- NDC Country Outlook-Pakistan 2017

Reports Reviewed for determination of Emission Factors for TED module

- IPCC Guidelines for National GHG Inventories, 2006
- PAEC GHG Emission Inventory of Pakistan, 2007-08
- Greenhouse Gas Emissions Inventory of Pakistan for the Year 2011–2012
- MoCC Pakistan National GHG Inventory, 2014–2015

Annex-B

Electricity Consumption among Different Income Levels

Parameters	**Energy Intensity** (Watts)	**Usage** (hrs/day)	**No. of Devices as per Income Level**		
			Low	**Middle**	**High**
Monthly Usage (kWh)	-	-	Below 50	50-350	Above 350
Room	-	-	1	2-5	Above 5
IB	60	3	1	-	3
FTL	40	4	1	3	3
CFL	25	3		1	3
Fan	100	8/6 mths	1	3	5
TV	100	4	1	1	2
Iron	60	0.25	-	1	2
Refrigerator	200	24	-	1	2
Computer	160	1.5	-	1	3
Motor pump	400	1.5	-	-	2
A.C	1500	3/6 mth	-	1	3
Washing Machine	700	1.5/week	-	1	2
Electric Stove	-	-	-	-	1
Monthly Electricity Bill	-	-	34.2	292.6	500