Pakistan Integrated Energy Model (Pak-IEM)

ADB TA-4982 PAK

Final Report Volume I

Model Design Report

Prepared by
International Resources Group

for

Asian Development Bank

and

Ministry of Planning and Development
Government of Pakistan

December 2010

an L3 company
International Resources Group

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Air conditioning
ADB	Asian Development Bank
AEDB	Alternative Energy Development Board
BAU	Business As Usual (scenario)
CASAREM	Central Asia – South Asia Regional Electricity Market
CCS	Carbon Capture and Storage
CNG	Compressed Natural Gas
DGPC	Directorate General Petroleum Concessions
DISCO	Distribution (Electricity) Company
EIA	Energy Information Administration
ESMAP	Energy Sector Management Assistance Program (World Bank)
ETSAP	Energy Technology Systems Analysis Programme
EYB	Energy Year Book
FBS	Federal Bureau of Statistics
GCISC	Global Change Impact Studies Centre
GDP	Gross Domestic Product
GHG	Greenhouse gas
GoP	Government of Pakistan
GW	Gigawatts
GWh	Gigawatt hours
HDIP	Hydrocarbon Development Institute of Pakistan
HESS	Household Energy Strategy Study
HFO	Heavy Fuel Oil (known as Furnace Oil in the EYB)
HIES	Household Income Expenditure Survey
HP	Horsepower
HSD	High Speed Diesel
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPP	independent power producers
IPCC	Intergovernmental Panel on Climate Change
IRG	International Resources Group
ISGS	Inter State Gas Systems
KESC	Karachi Electric Supply Corporation
KWh	Kilowatt hours
LDO	Light Diesel Oil
LNG	Liquefied Natural Gas

LPG	Liquefied Petroleum Gas
LUCF	Land Use Change and Forestry
MEC	MEConsult
mpkm	Million passenger-kilometers
mtkm	Million ton-kilometers
MW	Megawatts
NARC	National Agricultural Research Centre
NTDC	National Transmission & Despatch Company
NTRC	National Transport Research Center
OCAC	Oil Companies Advisory Committee
OGRA	Oil and Gas Regulatory Authority
Pak-IEM	Pakistan Integrated Energy Model
PEPCO	Pakistan Electric Power Company
PIHS	Pakistan Integrated Household Survey
PJ	Petajoules
PM	Particulate matter
PPEPCA	Pakistan Petroleum Exploration and Production Companies Association
PSRMA	Pakistan Steel Rolling Mills Association
RES	Reference Energy System
SNGPL	Sui Northern Gas Pipelines Limited
SSGC	Sui Southern Gas Company
TA	Technical Assistance
TERI	The Energy and Resources Institute (India)
TOR	Terms of Reference
UETT	University of Engineering and Technology, Taxila
USAID	United States Agency for International Development
VEDA	VErsatile Data Analyst (FE-Front End / BE-Back End)
WAPDA	Water and Power Development Authority
WEO	World Energy Outlook (published by the IEA)
WEPP	World Electric Power Plants Database (published by Platts)

I. INTRODUCTION

A. Background

The Asian Development Bank (ADB) is carrying out this Technical Assistance (TA) with Pakistan's Planning Commission to assist the Government of Pakistan (GoP) in developing an Integrated Energy Model (Pak-IEM) that will allow a national energy planning group to assess the impacts of various strategies for meeting future energy needs in an optimal manner. The model integrates planning factors pertaining to financial investments, economic costs, energy supply, national resources, energy use, environmental impacts, technology improvement, energy efficiency, and conservation to assess the costs and benefits of policies that will shape the country for the coming decades.

This will allow national policymakers and stakeholders within the various ministries and regulatory bodies, as well as the private sector, to collaborate and work through an open and transparent process with a dedicated energy planning team capable of producing high quality integrated analysis of energy planning strategies and national policy options. The TA is also designed to build the multi-institutional capacity that will allow various energy system policies and options to be examined in a clear and comparable manner so as to facilitate better communication and foster better cooperation within the various stakeholders on an ongoing basis.

It is intended that this optimal integrated energy planning capability will provide the GoP with a framework for examining priority energy policy issues facing Pakistan, ranging from closing the current supply-demand gap to improving energy security by fully exploiting indigenous resources. Building this capacity over an 18-month period, including conducting such assessments during the mentoring phase, will create within the GoP a solid analytic foundation for designing appropriate policies and planning the evolution of the energy system, including taking into consideration strategies to account for future climate change pressures.

The organization of the TA is shown in Figure 1, with modeling capability centered at the Energy Wing of the Planning Commission and supported by a network of key institutions in Pakistan to comprise the Pak-IEM Planning Team as shown in Figure 2. The Consultant team, which consisted of International Resources Group (IRG) with support from MEConsult (MEC), designed the model, developed the model input data in cooperation with the Planning Commission, other ministries, agencies, and organizations (with the assistance of the Advisory Committee Task Force), and trained the Planning Team and Support Institutions in the use and ongoing stewardship of the model. The model is being developed using the MARKAL/TIMES framework.

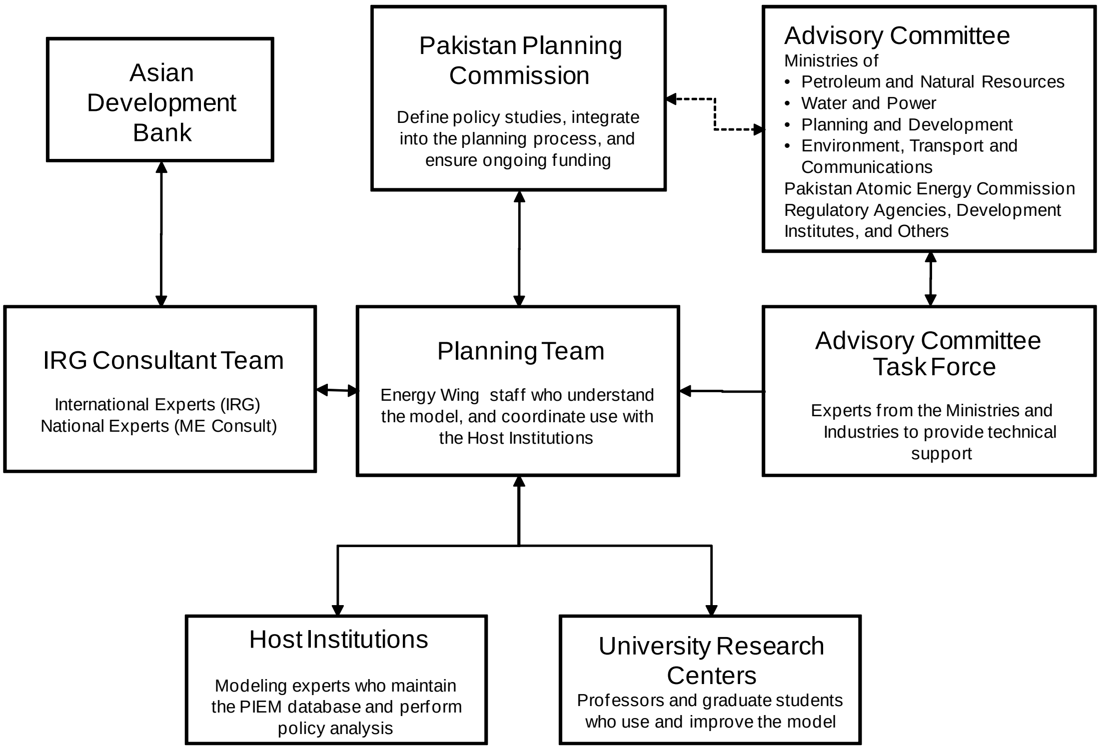

Figure 1: TA Organizational Structure

Planning Team Composition
Energy Wing ,Planning & Commission, Government of Pakistan
Global Change Impact Studies Center (GCISC)
Hydrocarbon Development Institute of Pakistan (HDIP)
National Transport Research Center (NTRC)
Pakistan Atomic Energy Commission (PAEC)
Pakistan Electric &Power Company (PEPCO)
Pakistan Institute of Engineering and Applied Sciences (PIEAS)
Pakistan Institute of Development Economics (PIDE)
University of Engineering & Technology, Lahore (UETL)
University of Engineering & Technology, Taxila (UETT)

Figure 2: Institutional Composition of the Planning Team

B. MARKAL/TIMES Modeling Framework

MARKAL/TIMES is the most widely used energy systems optimization model in the world today, deployed in some 70 countries in over 200 institutions. It has a 30-year track record of evolution and success. IRG team members have been involved in model development, capacity building, and policy analysis involving MARKAL/TIMES during much of that time.

A MARKAL/TIMES model requires a core set of data to characterize the energy system that the model is intended to represent. Once constructed, the model will solve for the least-cost solution that utilizes the available energy carriers (fuels, electricity, heat) and technologies (power plants, refineries, end-use devices) to meet the energy service demands (e.g., space conditioning, industrial process heat, lighting, passenger kilometers traveled), subject to physical limitations (e.g., resource availability, hydro/solar/wind potential), targets (e.g., energy independence and diversity in the terms of imports, renewables share of electricity generation) and policies (e.g., greenhouse gas (GHG) limits, emission caps, nuclear), and other constraints (e.g., rate of technology adoption) imposed on the system. A stylized representation of the underlying energy system depicted in the model is illustrated in Figure 3.

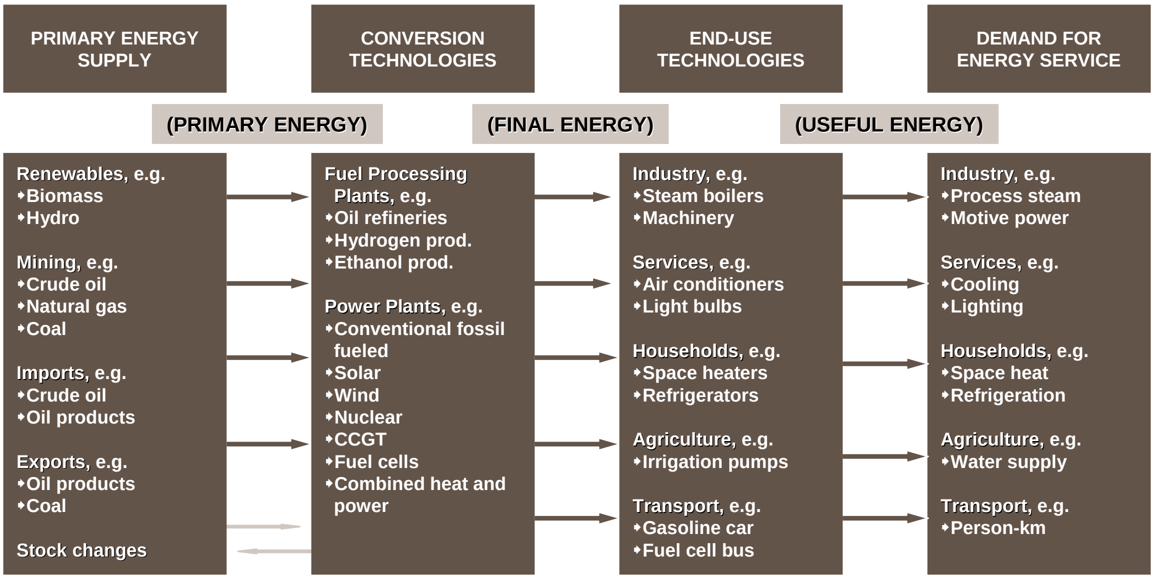

Figure 3: MARKAL/TIMES Model Overview

The underlying components of a MARKAL/TIMES model include:

- A Reference Energy System (RES), which is a network describing the structure of an energy system as interconnected flows of energy carriers (e.g., fuels, electricity, heat) through energy-producing (e.g., refineries, power plants) and energy-consuming technologies (e.g., air conditioners, cars, furnaces)
- Resources and imports, both current and projected, which are generally described through supply curves characterizing the amount of resource available at a particular cost
- Energy service demands, specified at a level of sub-sector disaggregation that meets the analytical requirements of the model user, and is supported by available or estimated data
- Sets of technologies (organized by type and sector) with their characteristics, such as investment cost, operating cost, efficiency, availability, emission rates, etc.

The term “technology or process” in MARKAL/TIMES is used as a general term for all physical facilities and energy transformation devices, such as refineries, power plants, home heating/cooling systems, light bulbs, and automobiles. The model “builds” physical devices by increasing the technologies’ installed capacities and “operates” them as measured by productive output. It does so by monitoring capital stock turnover to identify investment opportunities and timing. Similarly, “commodity” is a general term that refers to the various entities moving between processes, corresponding to energy, material, emissions, and energy services. Energy carriers include primary resources, processed fuels, electricity, heat, and renewable energy inputs – such as hydro, wind, solar, and geothermal energy. Materials and emissions, similar to energy, are flows into and/or from the processes. The demand for energy services (e.g., passenger transportation, lighting/heating/air conditioning of rooms, process heat for iron and steel) are satisfied by end-use technologies and must be met over the planning horizon, thereby serving to drive the Reference (Business-as-Usual or BAU) scenario evolution of the energy system.

Energy service demands represent consumption by individuals and activities associated with driving the economy. As such an initial projection is established according to relationships between drivers (e.g. trends of Gross Domestic Product (GDP), population, urbanization, commercial floor space, etc.) and individual sub-sectors of the energy economy; perhaps adjusted internally according to own-price elasticities (not currently employed for Pak-IEM). Then, using sensitivity analysis, the necessary configuration of the energy system to meet future economic growth under varying assumptions and policies can be evaluated.

C. A Framework to Institutionalize Energy Modeling Capability

1. Lessons Learned from Previous Pakistan Modeling Efforts

Early in the TA, the project team gathered information from the national experts, the Planning Commission and other stakeholders regarding an assessment of lessons learned from previous attempts to establish energy planning capacity for Pakistan. This was an important exercise to understand what energy modeling capacity had previously existed and why it had not been sustained. Such experiences have been used to develop a proposed framework to institutionalize MARKAL/TIMES capacity in Pakistan, and ensure that it is sustainable in the long term.

In mid-1980s USAID supported development of the RESPAK model, which was a least-cost optimization planning framework model with the Planning Commission. The model was used for a few years, but fell into disuse as the expertise established in the Commission was lost to other assignments. In addition, as power sector privatization started in the early 1990s, least-cost economic modeling was considered no longer necessary.

The RESPAK model was also criticized because of credibility issues arising from the large number of assumptions and analyst judgments needed for the model, and its inability to reflect real-world situations, especially in the near-term, such as the inability of developers to implement near-term optimal power plants.

A key lesson learned was that the institutional set-up in the Planning Commission was not sustainable, as the necessary high-caliber people could not be retained. They either got promoted to other posts within the government administration or left for higher paid private sector jobs. Maintenance of a reliable repository of data and the need for regular model updating were other challenges which could not be sustained. Extensive data collection, its diversity of sources, and respective analysis on an ongoing basis overwhelmed the limited resources of the Energy Wing resulting in a gradual abandonment of the model.

2. Experiences Using MARKAL/TIMES in Other Countries

The IRG team has been involved in many energy system modeling projects in different regions of the world, many of which are listed in Appendix 4 of this report. Several members of the team have also provided energy system modeling support their national planning agencies (e.g., US Department of Energy and Environmental Protection Agency, UK.Department of Energy and Climate Change and UK Committee on Climate Change). These experiences using energy system planning and optimization models in both industrialized and developing countries provides important insights and lessons for the Planning Commission, as it seeks to maintain, develop and use Pak-IEM. The insights and lessons from other countries are synthesized below, and include the benefits of using such models, but also the associated challenges faced by various national planning teams.

Benefits of Integrated Energy Analysis

The benefits of utilizing a modeling capability such as MARKAL/TIMES are described below. By their nature, integrated energy models are large, complex and data intensive mathematical tools that require highly trained specialists if they are to be used properly. Expertise from all sectors on the energy system must be represented and a dedicated staff is required to maintain and use these models if meaningful policy analysis is the desired product. Without a dedicated core staff that is supported with sufficient resources and regular requests to perform relevant policy analyses, trained staff will disperse and learned modeling skills will be forgotten.

- **Provision of a framework for integrated analysis**. Energy / climate policy can be assessed in an integrated way using MARKAL/TIMES. In many countries, policies are developed for single sectors or specific policy areas, with limited understanding of the impacts on other sectors or policies, and without insights concerning how multiple policy objectives could be achieved more cost-effectively. Recent analysis using MARKAL/TIMES models under the RESMD[1] project for USAID has supported the joint assessment of renewable energy, energy efficiency and low carbon objectives, highlighting the strong synergies between different policy areas. In Pakistan, this type of framework has been absent, with individual energy-related policy assessed by sector, and independently of other policy objectives.
- **Economics as an important policy driver.** MARKAL/TIMES has provided insights into the economic tradeoffs of various policies and goals. In the UK, the understanding that system costs in the longer term are not prohibitive (based on MARKAL analysis) has been critical to the acceptance amongst policy makers of a low carbon, sustainable energy system. Given the challenge associated with raising the necessary medium to longer investment, such insights are invaluable for proactive planning in Pakistan.
- **A long term planning perspective.** As most major investments in the energy sector (e.g., power plants and refineries) will be around for decades it is critical that near-term decision making and policy formulation take into consideration the longer term implications, which is a strength of MARKAL/TIMES. This has been particularly critical for those countries or agencies who have been undertaking low carbon analyses using MARKAL/TIMES models, which illustrate the significant shift in types of technologies that need to be employed (e.g., IEA Energy Technology Perspective (ETP), US-DOE Integrated Benefits Analysis (IBA), South Africa Long Term Mitigation Strategies (LTMS)). With rapid economic growth forecast over the next 20 years in Pakistan, significant investment will be made in the energy system, and it is critical that the medium to long term implications of such investments are understood.
- **Usability of modeling tools.** The diverse and extensive global community using MARKAL/TIMES indicates that whilst complex, the tools for managing the model and analysis process are able to be well understood and used effectively for a range of policy and planning issues by diverse and dedicated experts around the world under widely varying environments. The Pakistan Planning Team will become part of this international MARKAL/TIMES community that can be tapped to provide modeling support.
- **Engagement with policy community.** The least cost paradigm that MARKAL/TIMES employs provides a critical perspective that is well understood and accepted by policy makers, which is why it is so widely used across many different

[1] Regional Energy Security and Market Development project has built national integrated energy planning models in 11 countries in Southeast Europe and Eurasia..

countries. This fact should continue to help engage policy makers across Government in Pakistan.

- **Transparency.** The modeling frameworks allows for transparency, both in terms of assumptions and the model's mathematical foundation. This transparency addresses an important prerequisite for stakeholder engagement and acceptance of results. Across many countries, for example the UK, the ability for stakeholder's to know exactly what assumptions have been made for different sectors has ensured greater engagement, and avoided criticism associated with other so called 'black box' approaches. It also means that stakeholders know what the current assumptions are, and can be challenged to provide improved data where available. was the approach adopted during the development of Pak-IEM, where assumptions were sent to different experts for scrutiny. However, it is also important to note that ensuring transparency can also be challenging, with data assumptions needed to be made publically available, for example, through extensive documentation.

Challenges to Sustaining Integrated Energy Analysis

- **Maintaining team capacity**. To become a competent modeler takes several weeks of training followed by several months of continued work with the model under the guidance of a skilled and experienced manager. Therefore, losing key personnel from a team can have significant impact on the capacity to maintain its model and undertake studies. For many of the successful modeling teams across the world a critical mass of 3-5 people (as opposed to 1-2) is imperative to sustaining capacity. These core energy modeling experts need to be committed full-time to continually providing support and advise to policy makers. The institutional structure described below safeguards the current expertise, by proposing a core team to maintain the model, and ensuring a range of other institutions are involved with similar expertise.
- **Keeping models relevant**. Models need to be maintained, improved and updated regularly (based on the data available). It has been seen in many countries that models that are not kept current leading to the loss of confidence in them as credible tools for policy analyses. Country teams that are successful in maintaining models either have strong research funding or are used frequently by Government for different studies. For example, the UK MARKAL model has been systematically used for all of the major energy and climate strategy reviews over the last eight years, ensuring that it has the necessary funding and is kept current and thereby relevant. In addition, for the past 5 years, it has had significant additional academic research funding under the UK Energy Research Centre.[2]
- **Developing data systems and a network of providers.** Due to the data requirements of MARKAL/TIMES models, robust data systems and procedures are needed to manage data, while a network of providers is needed to ensure that the best available data flows to the modeling team. Strong links to statistical agencies, and to different sector experts, is important. This issue has been recognized in recent capacity building work undertaken by IRG and colleagues in the USAID-funded RESMD project. In a region where statistical information is not strong across specific sectors, additional links with experts and data providers has been critical. Developing a network of data providers has been an important part of the Pak-IEM TA project, whereby relevant data providers have been identified and asked to provide data in specific formats.

[2] Further information on UKERC can be found at the website http://www.ukerc.ac.uk/

- **Engagement with and understanding of modeling tools by different stakeholders.** Key stakeholders need to be engaged and able to understand the relevance of MARKAL/TIMES models, and how they can provide important insights on energy policy issues. Therefore the model should be made available to a wider suite of qualified institutions, as well as encouraging requests to the Planning Team to conduct analyses on their behalf of issues of particular interest to them. In the USA, the release of a national MARKAL model by the US EPA has been extremely successful, resulting in the engagement of numerous research and academic institutions in further developing and improving the model, and running a range of different analyses.

As reflected in the section below, an important part of the TA has been in developing an institutional structure that ensures a wide range of model users as well as strong engagement from interested stakeholders.

3. Conceptual Institutional Structure

The following recommendations for creating a sustainable institutional structure for the Pak-IEM MARKAL/TIMES modeling capacity are based on consideration of the above history, the observations in different countries and the experiences of the IRG team and the Planning Commission. These recommendations resulted in the conceptual institutional structure for the Planning Team, shown in Figure 4, which closely resembles how the Planning Team was organized during the TA.

- **Manage and coordinate modeling activities in Pakistan through a dedicated Planning Unit, overseen by the Planning Commission.** A central group needs to have lead responsibility, retaining the master version of the model, and overseeing any future development. A key responsibility of this leadership role is to ensure that the model remains fully documented (to maintain transparency) and is quality controlled (to maintain credibility). A dedicated unit can also be available to undertake assignments at short notice for the Planning Commission, other Government departments, and the private sector.
- **Recruit high calibre individuals to the Planning Unit who have an engineering or economics background. During the TA, the proje**ct team provided advice on the type of qualifications and skills that would be needed by members of the modeling team. One of the specifications written, for the role of Lead Energy Modeler and Analyst, is provided in Appendix 5. While there is a need for several individuals with diverse background and skills, one (or two) individuals need to be devoted full-time to overseeing the modeling system and team.
- **Host the model at several different institutions where it is likely to be used. The Planning Team composition (see Figure 2)** reflects this important view that having a number of host organizations fosters wider use of the model, establishes a national modeling community to promote joint working and learning, and expands the range of sectoral and technical expertise of the team.

  The types of institution are also important. While government planning needs to be the first priority, private sector involvement should be encouraged with a focus on enabling them to use the model to examine issues affecting their sectors. Universities can deliver training courses on and research using MARKAL/TIMES, and seed the next generation of energy planners.
- **Produce annual or biannual energy outlook report**. The regular publication of a policy and perspective report based on Pak-IEM would ensure that the model is consistently developed, used and improved.

- **Establish at network of data providers from different sectors that can provide information for model updates.** The TA has identified and established the relevant sources of data. Since data is needed on an ongoing basis, there is a need to develop the process, procedures and tracking system that identifies data requirements and providers, monitors and follows up on data requests, and quality controls said data, which in turn should lead to database for storing, organizing and disseminating the wealth of data provided.
- **Maintain the Advisory Committee Task Force**, which provided essential guidance during the TA. This would ensure that continued stakeholder involvement can be maintained, model development scrutinized and data requests satisfied.

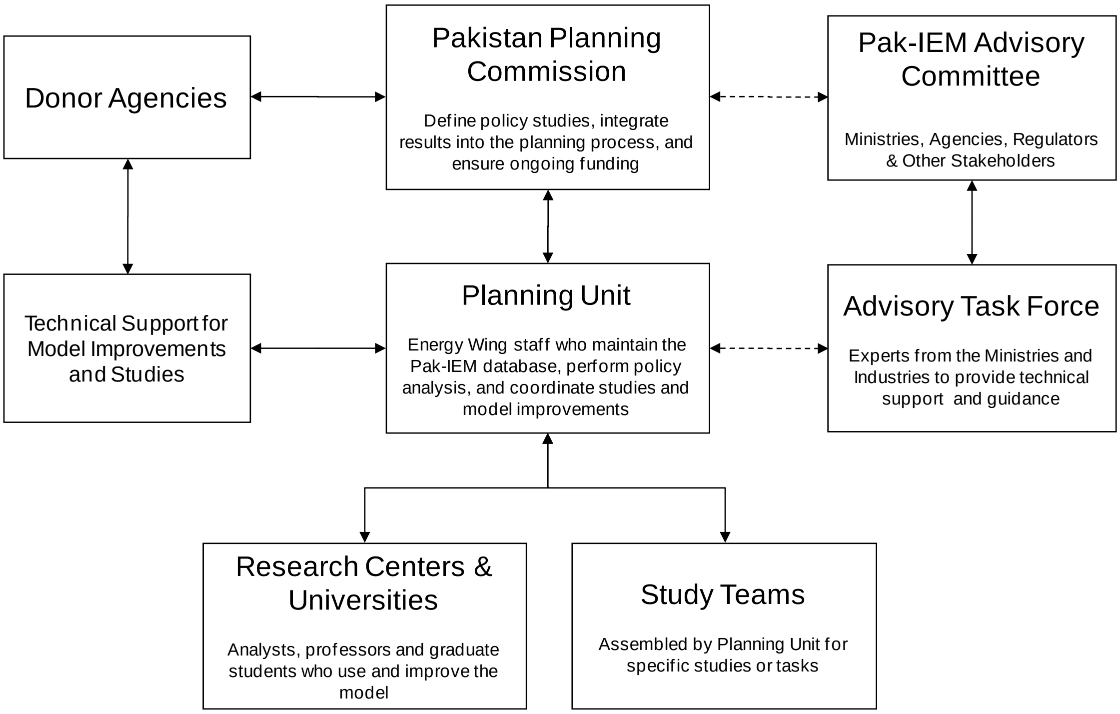

Figure 4. Conceptual Institutional Structure for the Pak-IEM Modeling Capability

D. Model Design Overview

The Pak-IEM is utilizi**ng the TIMES model generator, which is the successor to the MARKAL modeling framework which has bee**n conceived, developed and continually supported by International Energy Agency – Energy Technology Systems Analysis Programme (IEA-ETSAP). It e**m**ploys the VErsatile Data Analyst (VEDA) data and model management system to organize and handle the input data and process the results thereby overseeing all aspects of working with the model. The development of the model input data is organized into a set of Excel workbooks (templates) that are managed by VEDA-FE (Front End) to form the complete model for calibration (for the year 2006/2007) and development of the Reference scenario out to 2040, and beyond (see Figure 4). Any number of alternate scenarios can then be introduced to the mix as future options and policies for analysis.

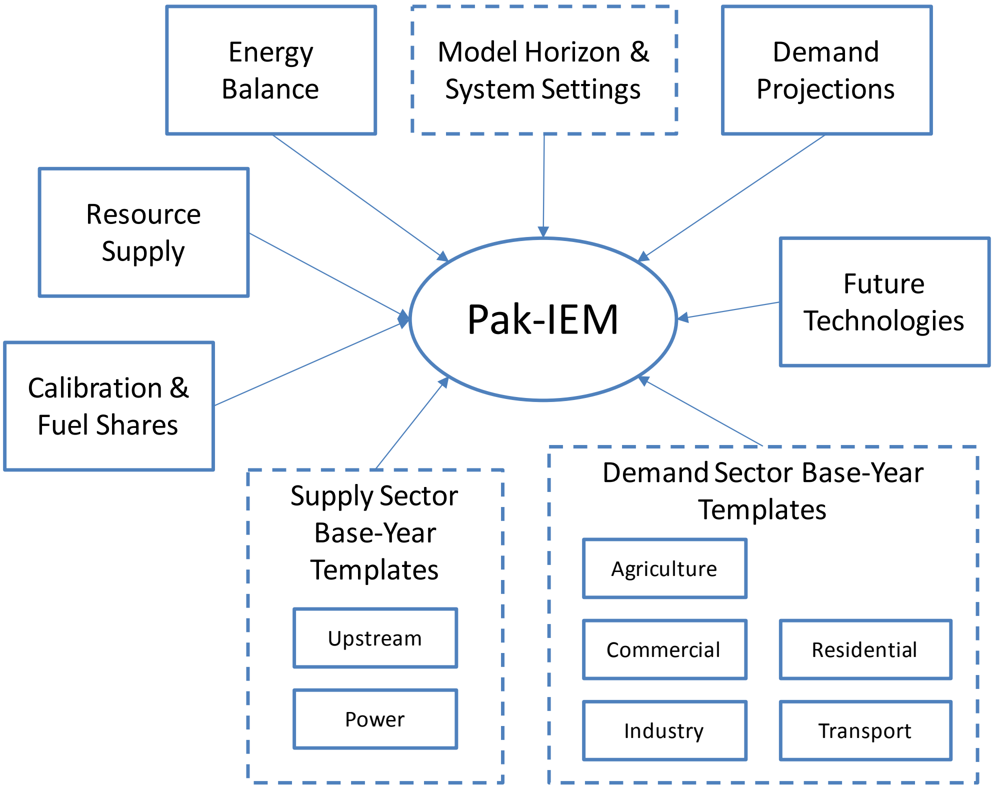

Figure 5: Structure of the Pak-IEM Data Inputs

E. Scope and Structure of the Report

The initial design of the Pak-IEM Reference Energy System was determined through discussions with MEConsult (MEC), the Planning Team, and Advisory Committee Task Force experts to determine the appropriate level of detail for the model based upon the available data collected to date and the policy issues for which the model will be used.

The Model Design Report in July 2009 presented a near finalized overview of the base year model templates and data assumptions across different sectors to the Planning Team. A presentation to the Advisory Committee Task Force Group provided a briefer discussion of the model design, and a more in-depth discussion on the ongoing critical data issues. Feedback from these groups has been critical in informing the model structure and design, and assisting with critical data issues, most notably leading to a Task Force Focus Group Mission in early August to again attempt to complete the known data collection process.

The Model Review Report, submitted in January 2010, was the second interim report providing additional detail on assumptions across new technologies, an overview of the key demand drivers and a preliminary version of the Reference Scenario.

This report presents the final version of the model structure, and comprehensively describes the assumption and data sources. It is meant to be the primary documentation resource. The report is organized according to the major sectors of the energy system that are represented in the model. Sections II and III present an overview of data collection activities, and key model design and data issues. Sections IV, V, and VI describe modeling structure and data assumptions across resource supply, upstream, and power generation sectors. Section VII covers end-use demand sectors. The latest model version for which this report relates is organized in a single input data folder named PIEM_TMPL_101222.

This report does not provide information on how to use the model. *Pak-IEM Final Report – Volume II – Policy Analysis* describes the initial use of the model to assess general policy and technical issues that serve to demonstrate how the model can be used and the nature of the results it produces. Comprehensive guidance in the form of detailed instructions on Pak-IEM under VEDA is provided in a separate document titled *Pak-IEM Final Report: Volume III – User's Guide*.

II. OVERVIEW OF Pak-IEM DATA REQUIREMENTS

A. Data Collection Process

The crucial first step in developing a credible integrated energy planning capability for Pakistan is acquiring and assembling the detailed data needed for a comprehensive national model. This begins with a thorough 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 (by sector) that is necessary for the model. The data development components are illustrated in Figure 5.

Data collection activities to characterize the base year energy system (in 2006-07) were largely completed at the end of the first year. Since then, the Planning Team has been organized into Sector Groups and has been charged with addressing outstanding data needs, validating the data depicting the current energy system and proposing options for consideration for the future. The data needs and sources used for the different sectors are listed in the sector-relevant sections of this report which follow.

An index of primary sources for the information included in Pak-IEM is provided in the associated sector sections of this report. Whenever possible, the source data are imbedded directly into the Pak-IEM model templates. The actual reports and other data sources are all located on the project specific FTP site, hosted and managed by IRG. It is intended that the Energy Wing will hold all of these background data files. Unpublished sources are listed in Appendix 3, while published sources can be found in the Reference section.

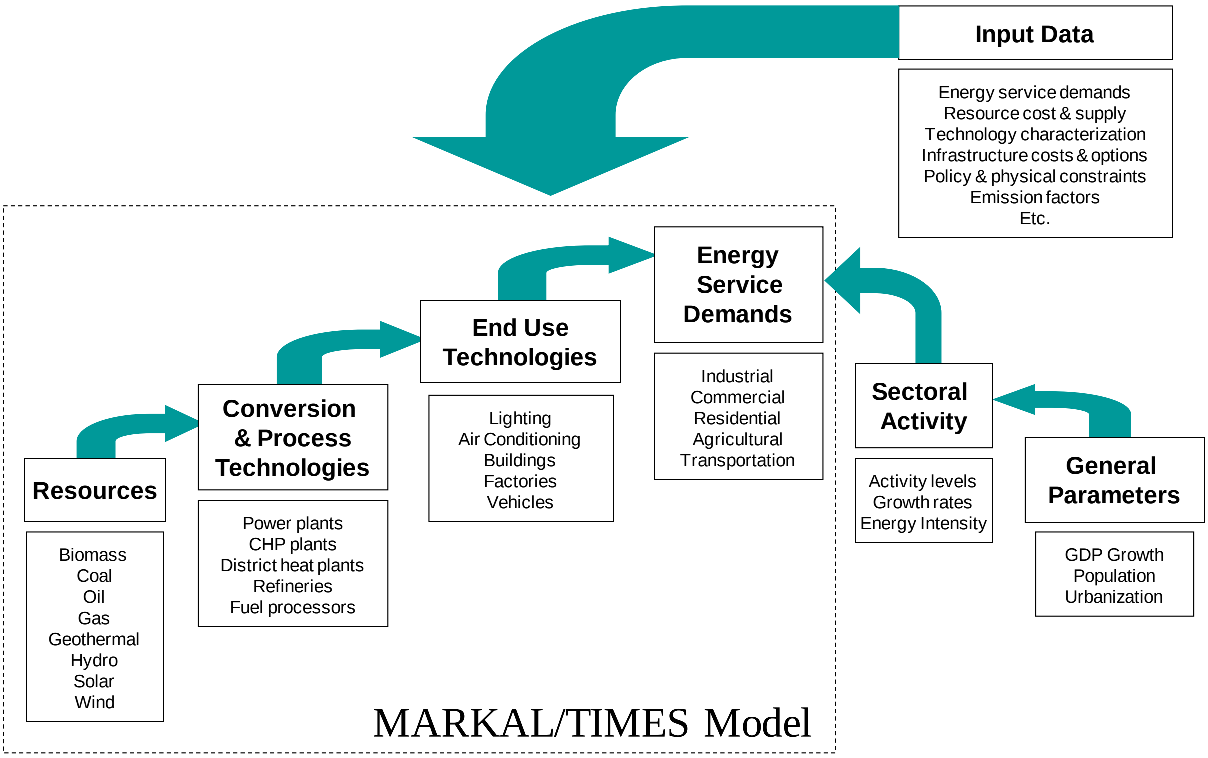

Figure 6: Data Development Process

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 which depicts the anticipated evolution of the Pakistan energy system under a Business-As-Usual situation. This involves sourcing data on:

- Demand drivers and their relationship for different sectors
- Information on known new power plant, refinery and major energy infrastructure builds and refurbishments
- Future resource potential and energy prices
- Technology options for future production / consumption of energy

These data collection activities were initiated by means of a number of Advisory Committee Task Force Focus Group meetings starting in August 2009 with repeated focused discussions as needed, when the Consultant team met key stakeholders in a series of sector-specific meetings. These meetings also addressed critical data needs for the base year energy system characterization.

In addition to the sector-specific information discussed later, there is a range of issues that are important for characterizing the underlying energy system, such as the number of regions, sector categorization, and time horizon, along with assumptions that cut across all sectors such as discount rate and emission factors which are discussed next.

B. Model Structure

Regional issues. Pak-IEM covers the whole of Pakistan's energy system, and can therefore be used for national policy studies. This first version of the model is comprised of a single region, which is most appropriate at this stage of model development, given the nature of some of the available data. It is recognized that significant regional differences in energy supply and demand do exist, and therefore future versions of the Pak-IEM should move towards regionalization; in view of this, data collection, where possible, captured any regional breakdowns.

Sector definitions. The model has been designed according to the following sectors as summarized in Table 1.

Table 1: Summary Sector Definitions

Sector	Description
Supply-side	
Resource supply	Domestic resources and imports
Processing and distribution (Upstream)	Processing (refining) and distribution of oil and gas
Electricity generation	Individual power plants and IPPs, along with self-generation in Industry
Demand-side	
Agriculture	Tractors (for field and transport), water pumping and miscellaneous demands
Commercial / Public sector	An aggregate (single) commercial sector broken out for the basic energy service demands (e.g., cooling, lighting, cooking, etc.)
Industry	Six major industrial sectors (iron & steel, textiles, sugar, cement, fertilizer, bricks) modeled at either the process level, or based upon generic energy service needs (e.g., process heat, motor drive, miscellaneous). Other industry modeled using a generic energy service approach.
Residential	Aggregate urban and rural residential sectors broken out for the basic energy service demands (e.g., cooling, lighting, cooking, etc.)
Transportation	Each basic transportation mode (e.g., passenger vehicle, trucks, buses, rail, ship, air) demand is modeled along with various devices for meeting each transport mode

Emission factors. Emissions being tracked in Pak-IEM include CO_2, SO_2, and NO_x. It will be possible to add additional GHGs and local pollutants in future versions of the model. The focus in this version is CO_2, due to fast developing policy issues on climate change (in particular the ongoing deliberations for a post-2012 agreement on greenhouse gas reductions). SO_2 and NO_x are being tracked as important air quality pollutants, and provide the potential for undertaking assessment of policy co-benefits.

For CO_2, and to some degree SO_2, the actual emission levels are directly proportional to the amount of fuel used and the carbon or sulfur content of the fuel (e.g. coal, crude oil, petroleum products, natural gas, etc.). Some technologies have controls to remove a proportion of the fuel-based emissions, and these will be specified according to their abatement percentage. NO_x and particulate matter (PM) emissions are technology-specific, so to some extent device-specific data (e.g., power plants, industrial processes, commercial and residential boilers and furnaces, and vehicles) will need to be collected.

It is understood that for CO_2 the national inventory uses Intergovernmental Panel on Climate Change (IPCC) default emission factors, based on 2006 guidance documents.[3] This is consistent with what is currently being used in Pak-IEM, using data from the GAINS-ASIA model.[4] For air quality pollutants, emission factor information from the GAINS-ASIA model is being used. For the base year, weighted (as opposed to technology-specific) emission factors have been used (by sector-fuel), as they include a range of different technologies which have different emission factors.

It is important to note that biomass use in the model is considered to be carbon-neutral, as per inventory guidelines.[5] The question is whether the biomass used is sustainable; if not, the emissions associated with unsustainable extraction are captured as removals under the Land Use Change and Forestry (LUCF) sector. In an energy-only model, biomass could therefore have carbon emissions associated; however, it would be important to know whether and to what extent the biomass resource was sustainable (e.g. extraction is less than (or equal to) rate of re-growth).

Model Horizon. As part of establishing the scope of the model a start period (base year) and series of model milestone periods (of varying duration) must be established (thereby determining the model horizon[6]). The start period is particularly critical as all the base year and calibration data will be developed for this year. The length of the first period is a single year, in order to calibrate the model to the energy balance for that year. The start year chosen for the Pak-IEM model is 2006/07, running from beginning of July 2006 to the end of June 2007. (Note that this is reported as 2007). This was chosen as the most recent year for which data were generally available for all parts of the energy system (at the time the project started). 2007/08 was subsequently considered as an alternative but it was decided that some of the required data for certain sectors were not available.

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[3] Based on personal communication with HDIP

[4] Data provided by GCISC from GAINS-ASIA model, developed by IIASA (see following website for further information – http://www.iiasa.ac.at/rains/gains_asia/main/index.html?sb=1. The name of the data files can be found in Appendix 3.

[5] The Revised 1996 Inventory guidelines from the IPCC state that biomass fuels are included in the national energy and emissions accounts for completeness. These emissions should not be included in national CO_2 emissions from fuel combustion. If energy use, or any other factor, is causing a long term decline in the total carbon embodied in standing biomass (e.g. forests), this net release of carbon should be evident in the calculation of CO_2 emissions in the LUCF sector.

[6] Note that TIMES supports extrapolation of all parameters permitting the modeling horizon to be extended with minimal additional data required.

The number of milestone periods and their respective duration for the planning horizon is shown in Table 2. Earlier time periods tend to be shorter because more is known about the evolution of the system, in respect of energy policy, resource forecasts, and planned new build; for later periods, less is known and therefore longer periods are more suitable. Right now the primary focus is out to the 2040 planning horizon. However, since TIMES allows for a separation of data years and model years, Pak-IEM can be run for any desired set of years (periods).

Table 2: Reference Case Period Lengths[7]

Period Start Year	Period Reporting Year	Period End Year	Period Length
2007	2007	2007	1
2008	2008	2009	2
2010	2010	2010	1
2011	2011	2011	1
2012	2012	2012	1
2013	2013	2013	1
2014	2014	2014	1
2015	2015	2015	1
2016	2016	2017	2
2018	2020	2022	5
2023	2025	2027	5
2028	2030	2032	5
2033	2035	2037	5
2038	2040	2042	5

Discount rate. A global discount rate is used in the model to discount all costs back to the base year and calculate the total discounted system cost (used in the model's objective function). The model is currently using a default 7% rate. Note that sector or even technology-specific discount rates may also be introduced if appropriate (e.g. to examine impediments to the uptake of efficient (more expensive) appliances). Such discount rates have been used in the electricity generation sector to account for the cost of capital.

Season and Day Time-Slices. Some demands for energy are typically non-uniform over the year. In particular, electricity and natural gas have seasonal and time-of-day consumption patterns that need to be properly modeled and tracked. Therefore, the setting up of the daily and seasonal temporal resolution of the model is important. The timeslices in the model representing this resolution are shown in Table 3.

Table 3: Season / Day Time Slices

Season	Months per Season	Months		Day Slices	Hours per Day	Hours
Intermediate (I)	3	April, October-November		Day (D)	11	0700-1800
Summer (S)	5	May-September		Shoulder (S)	4	1800-1900, 2100-2400
Winter (W)	4	November-March		Peak (P)	2	1900-2100
				Night (N)	7	2400-0700

[7] This Periods Definition set in the model is labelled *PIEMMSY*.

An explanation of how these timeslices were determined is provided in the Box below. Key inputs in determining the timeslice structure are the typical 24-hour load dispatch curve from Pakistan Electric Power Company (PEPCO) and the Karachi Electric Supply Corporation (KESC), and monthly sectoral consumption patterns.[8]

Based on the timeslice structure, timing of demands have then to be constructed. These have been developed on the basis of expert judgment, and are further detailed in each of the sections describing demand sectors. The timing of demands, for electricity (hourly basis) and gas (seasonal basis) need to be calibrated to match the supply profile in the base year. They are also used to determine the timing of demand in future years.

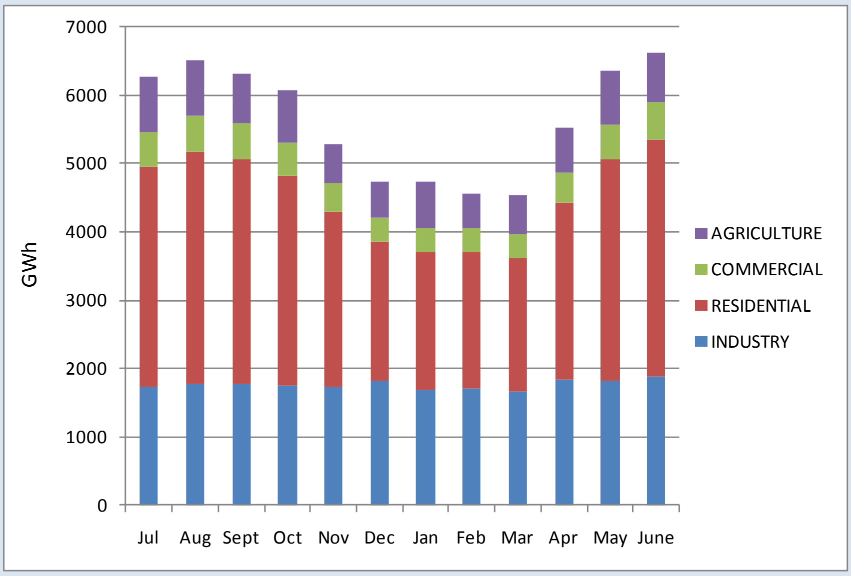
Determining Timeslices for Pak-IEM

There are a number of decisions to make relating to the seasonal and diurnal splits that are needed to help capture differences in generation during different times of the day in response to demand, particularly the peak demand. Time-slices need to be structured in a way that will enable the model to provide a 'reasonable' representation of the 24 load curve across different seasons.

The situation in respect of Pakistan is of course complicated by the serious load shedding issues that have been occurring over the last few years.

PEPCO and KESC data have been used to determine the time-slice structure, representing the combined system across all of Pakistan. This includes seasonal electricity consumption by broad sector (residential, commercial, agriculture, industry) and daily load profile for typical weekdays / weekend day (Sunday) in each month.

Seasonal electricity consumption for specific sectors in PEPCO / KESC systems is shown below.



The first issue was how to split the seasons up, based on the level of demand in the different months. The proposal was to have 3 seasons:

- Summer: May-Sep (5), accounting for higher demand driven by higher cooling demand.

[8] Data were provided directly by KESC / PEPCO to the project team for use in Pak-IEM. A full listing of these files, and the data providers, is provided in Appendix 3. In summary, KESC monthly consumption and load curve information were provided in files *KESC data sheet.doc* and *Hourly_Demand_KESC.xls*. PEPCO monthly consumption and load curve information can be found in *PEPCO_Consumption_Patterns.xls* and *PEPCO 24 hour and seasonal load profile data_v03.xls*

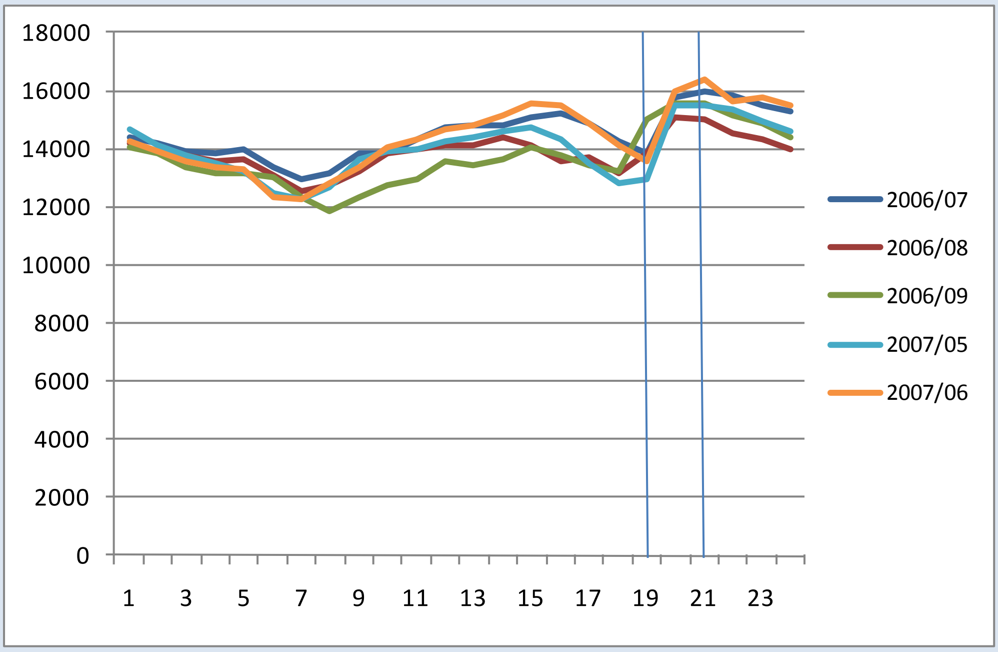
- Winter: Dec-Mar (4), in which occurs the lowest seasonal demand, and
- Intermediate (INT): Apr, Oct-Nov (3), which are the months between the high-low demand periods.[9]

Daily load data, provided by PEPCO and KESC, is shown for the three seasons proposed above. A daily time-slice structure was proposed that fit all three seasons, and was relevant for both weekday and weekend days. This was as follows:

- Night (0.00-07.00);
- Day (07.00–18.00);
- Peak (19.00-21.00), and
- Shoulder (18.00-19.00, 21.00-24.00).

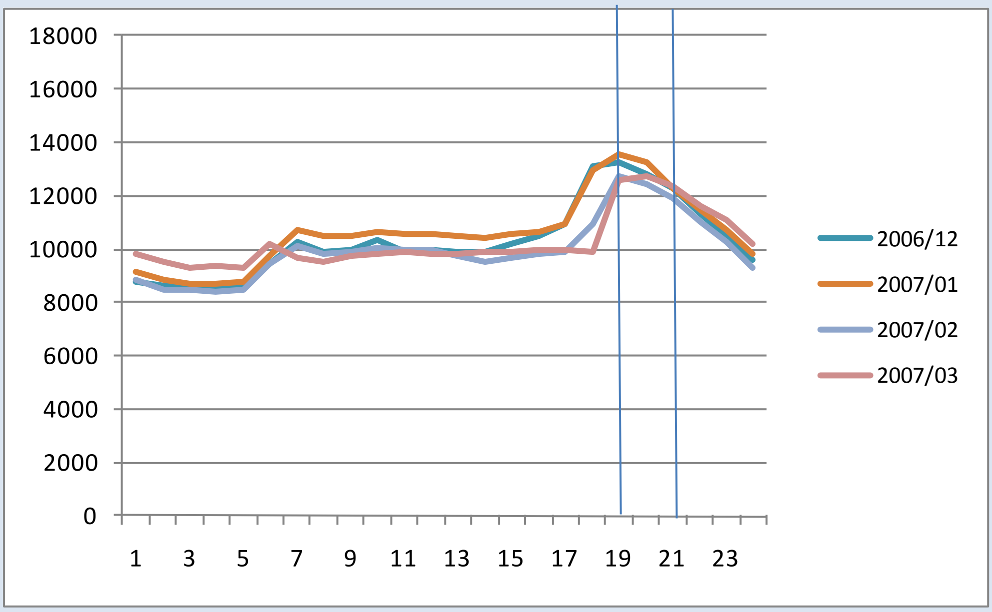
In all three seasons, a 2-hour peak can be observed although occurs slightly later in summer and is less pronounced, and earlier in winter. To ensure that the model does not have an overly complex representation, each season has the same daily timeslices. The graphs below represent the load level over time for typical weekdays; no distinction has been made for weekends as the shape of the curve is very similar to that observed below.

Summer



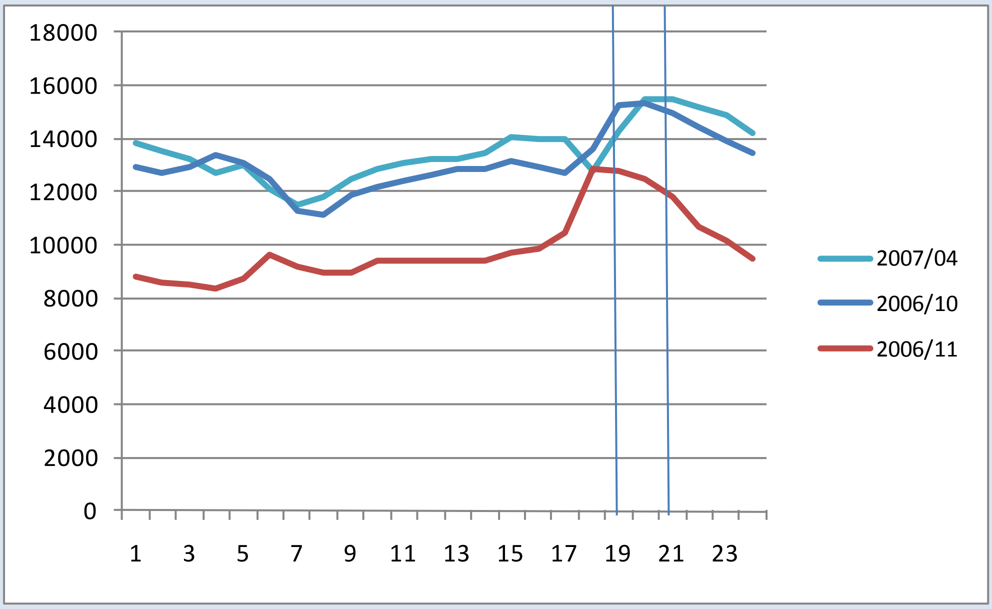
9 If seasonal storage was to be used in the model (e.g. pumped hydro storage) the intermediate season would need to be changed to a 2 season depiction – Spring / Fall – to ensure storage and dispatch can occur from one season to the next. However, this was not considered likely in the Pakistan context so the single intermediate season is employed.

Winter



Intermediate

For the intermediate season, it could be argued that November belongs to the Winter season due to the much lower load over the 24 hour period. This pattern emerged recently (following the use of year-specific data) from the combined load data from KESC / PEPCO. However, moving this month to the winter group is unlikely to impact significantly on the model solution, and would require significant base year recalibration.



An ongoing model development priority is to further assess whether the data used (2006/07) capture the full peaking requirement for the system. There has been some discussion that the peak should be more pronounced, and that load profile data from earlier years may be more suitable, when load shedding was not a significant issue.[10]

Supply-demand equilibrium. It is important to recognize that MARKAL/TIMES models always calculate a supply-demand equilibrium, whereby energy service demands are satisfied in every period. This makes assessment of future supply-demand gaps difficult. However, modeling techniques can be used to explore specific problems associated with insufficient energy supply, as described in Section V.F in the case of power sector load shedding.

C. Cost Accounting

All costs in the model (investment, operating and fuel) are expressed in 2007 US Dollars. All cost data is first converted to US Dollars, with Pakistan conversion factors sourced from the latest Economic Survey of Pakistan (GoP 2009). Deflators to adjust source data for the model to get all costs to US Dollars on a 2007 basis are sourced from US Bureau of Economic Analysis.[11]

D. Energy Balance

The national energy balance provides a comprehensive picture of the supply and consumption of energy in the form of each fuel type used and the sectors (demand, power, and refineries) where these fuels are consumed. The energy balance for 2006/07 for Pakistan is sourced from the Energy Year Book (EYB) 2007 (HDIP 2008), and provides the basis for characterizing the start or base year of the model. Figure 6 summarizes this data showing total primary energy supply and final energy consumption by sector.

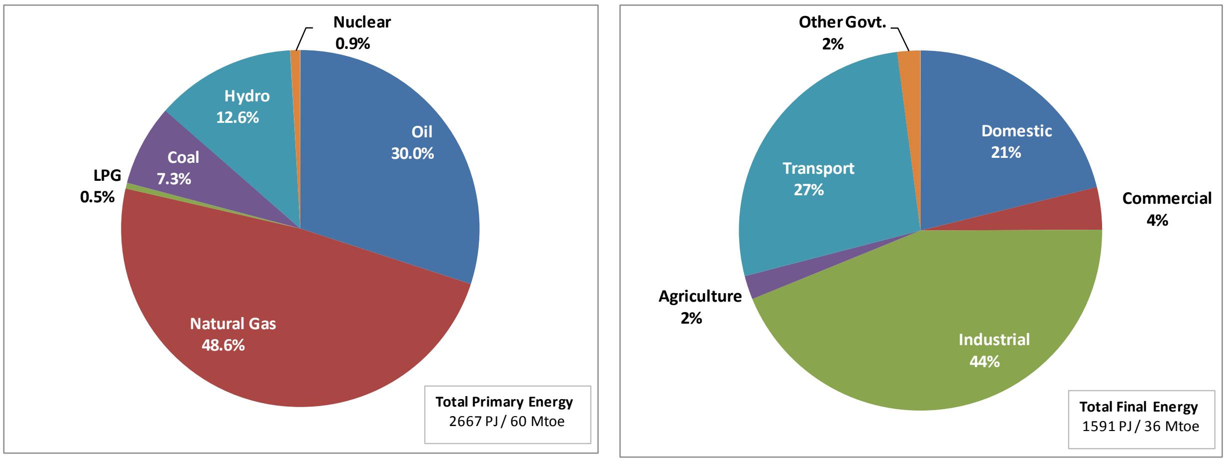


Figure 7: Primary Energy Production by Fuel type and Final Energy Consumption by Sector for 2006-07 (Source: HDIP 2008 (Pakistan Energy Year Book 2007))[12]

[10] Alternative load profile data (for PEPCO system only) listed in Appendix 3, and labeled *Hourly Load Data [DATE].xls*

[11] Bureau of Economic Analysis, National Income and Product Accounts Table, Table 1.1.9 Implicit Price Deflators for Gross Domestic Product, http://www.bea.gov

[12] The 2008 Pakistan Year Book shows some small changes in estimates for 2006-07 on primary energy production (as identified based on a review by PAEC); however, these do not fundamentally change the base year picture so have not been incorporated to date.

A number of issues have been identified with the Energy Balance, which have resulted in amendments to the overall Yearbook balance. These include the handling of high-speed diesel and non-commercial biomass.

- Concerning high speed diesel (HSD), based on bottom-up estimates of consumption across all end-use demand sectors, a shortfall has been identified. This has been attributed to a significant amount of black market diesel not accounted for in the official energy balance. Based on expert judgment, a 10% increase in HSD has been assumed in 2006/07. This issue is discussed in detail in the transport section of this report.
- Non-commercial fuels, in particular various forms of biomass, are not present in the official Energy Balance due to lack of statistics. Examples include wood use in the residential sector and bagasse use in the sugar industry. To date, estimates of biomass use in the sugar sector have been made, as have non-industrial sector estimates. No commercial biomass use is published in the Energy Balance either.

E. Sector Specific Data Needs and Design Issues

The following sections of this report focus on describing the structure of the different sectors depicted in the model, and key data sources and assumptions used for both the base and future years.

All sectors are linked to the centralized energy balance, ensuring that base year consumption of energy matches what is presented in the Energy Yearbook (augmented as discussed above). On a sector-by-sector basis, the number and types of sub-sectors are then considered. The level of detail is dependent on the energy uses in a given sub-sector, the availability of suitable data, the sub-sector energy demands to be modeled, and the role of future demand drivers (e.g. GDP, population) in projecting the future demand for energy services.

Each sub-sector then needs to be characterized by the technologies that it uses in the base year and the alternatives available in future years. The data required for technology characterization is extensive, and Table 4 provides a summary of the typical parameters used in MARKAL/TIMES models.

Table 4: Typical Technology Characterization Parameters

Technology Characteristics	Description
Start Year	Year in which the technology is initially available. For all Base Year technologies the default start year is the base year.
Residual stock	Existing capacity of each power plant, refinery, or technology type, which should be determined from statistical data where possible. Otherwise, for the demand devices this data can be derived from the decomposition of sectoral and end-use shares.
Lifetime	Number of years the technology is typically expected to be in service; this value determines how the existing capacity is retired, where it is assumed that for demand devices the available technology linearly decreases over the lifetime if no retirement profile is provided (e.g., anticipated power plant and refinery retirement should be explicitly provided).
Efficiency	Corresponding to the amount of output (energy or demand serviced) per unit of fuel consumed.
Investment	Total capital cost for each new technology, including interest during construction. This is needed for all new technologies and any existing technologies for which future investments (e.g., retrofits) are possible.
Fixed Operating and Maintenance	Fixed cost associated with the capacity of the facility or device.
Variable Operating and Maintenance	Variable operating cost associated with running the facility or device, other than fuel costs.

Technology Characteristics	Description
Utilization Factor	Annual utilization factor of device calculated from the amount of time that the fully rated capacity of a device is actually used during a year (for example, heating and cooling devices have a relatively low annual utilization factor as they are only used part of the year and even then only at full rating some of the time, for power plants there is usually utilization data available (seasonal for hydro and some other renewables)).
Base Year Share	Provided when there is more than one existing device using the same fuel to meet a sub-sector demand.
Input Energy Carrier	Share of each energy carrier (material) consumed per unit of output; the value is normally 1 (default) unless more than one commodity is consumed by the device (e.g., dual-fuel power plant, solar hot water with electric back-up).
Output Energy Carrier	Share of each product produced (e.g., gasoline/diesel/etc. from refinery, electricity and heat from couple heat/power plants) or demand serviced by devices, normally 1 (default) unless more than one product is produced or demand is served (e.g., heat pump doing both heating and cooling, car used for city/inter-city travel – note that these require different efficiencies and utilization factors).

Assumptions concerning future year evolution of the energy system are also critical, and are the focus of current data collection and modeling activities. This includes near-term known changes to the energy system, resulting from revised or new policies, or planned / nearly completed projects. It also relates to the different drivers across sectors that will result in growth of energy requirements in future years, and the different technology options that will be needed to meet increased demands.

III. RESOURCE SUPPLY

A. Sector Overview

The resource supply sector includes primary energy resources, supplied domestically or via imports, as well as exports of energy commodities. The resource supply picture is provided in Figure 7 below. Pakistan has significant indigenous resources of natural gas (though declining) and hydropower, while for crude oil and refined oil products there is a high reliance on imports. All of the naphtha produced by domestic refining and over 25% of the aviation fuel is exported. Coal is mainly used in the industry sector; domestic coal tends to be low quality (sub-bituminous or lignite) and used primarily for brick making; imported coal tends to be used in industries such as cement and iron & steel.

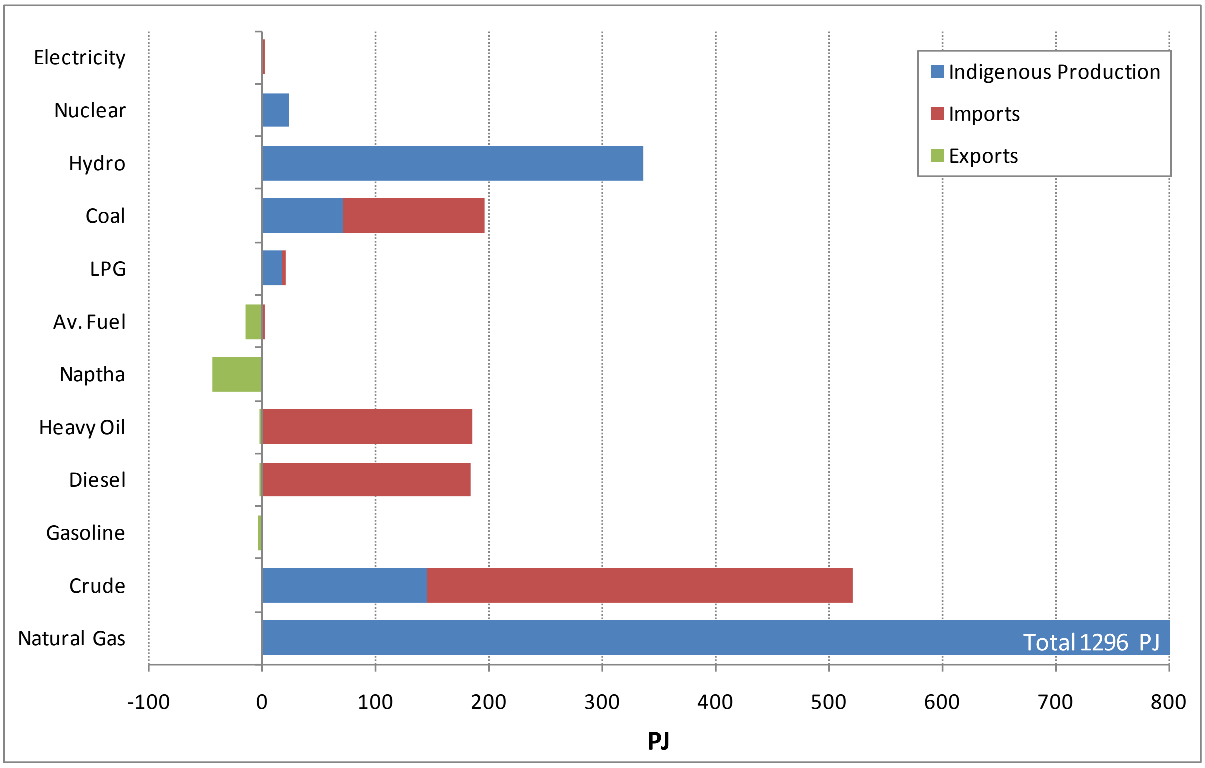


Figure 8: Energy Resource Supplies in 2006-07, excluding biomass (Source: HDIP 2008)

B. Current Fossil Fuel Resources

The primary energy totals shown in Figure 7 meet the energy needs of the economy (ignoring the issues of access to affordable energy, load shedding, as well as the substantial use of biomass) in 2006/07. In future years, the energy system will need to determine (within constraints imposed) where to source energy resources. For domestic resources, this may be dependent on the costs of extraction in different provinces, the available reserves in different fields, and of course the requirements of power and demand sectors. The balance of energy needed will then have come from imports.

Each domestic resource is characterized according to the following parameters:

- Maximum annual extraction rates, constraining the model's access to resources on an annual basis

- Proven reserves, constraining the model's cumulative access to resources over the model time horizon
- Cost of extraction (and delivery), to influence model choices about which resource is most economic

Extraction rates

Extraction rates in future years (out to 2030+) for oil and gas fields are capped at the maximum extraction values in projections sourced from Directorate General Petroleum Concessions (DGPC). That is the model may produce up to the level each year as long as the proven reserves are not exhausted. Extraction rates for coal come from DG Minerals.[13]

To account for new oil and gas resource finds in future years from continued exploration, an additional 5% uplift is applied to known reserves. Cumulative resource levels (see Table 5) are capped using data on reserves provided in the Energy Year Book (HDIP 2008). Indicative estimates on the number of years that resources will last are also provided, based on i) the maximum permitted extraction rate in the model and ii) if extraction continued at the rates observed in the base year.

Table 5: Crude Oil and Natural Gas Reserves, and Years Remaining Resource

Commodity type / Region	Reserves (Mtoes)	Years remaining (Max Rate)	Years remaining (Current Rate)
Crude oil – BALO	0.2	NA	NA
Crude oil – NWFP	12.0	9.7	9.7
Crude oil – PUNJ	15.6	11.9	14.8
Crude oil – SIND	22.0	9.5	10.0
Crude oil – Total	**49.8**	**10.2**	**11.1**
Natural gas - BALO	190.2	23.1	23.1
Natural gas - NWFP	55.7	12.5	12.5
Natural gas - PUNJ	27.7	20.5	25.6
Natural gas - SIND	415.9	13.9	20.8
Natural gas – Total	**689.5**	**15.6**	**20.4**

These data indicate that domestic crude oil supplies will last approximately 10 years, while natural gas will last between 15-20 years. The associated gas extraction rates are a function of the oil extracted. The reserves of associated gas add a further 11.3 Mtoes of resource to the system.

Costs

Primary energy resources are usually characterized by cost-supply curves, which characterize the amount of each resource that can be made available at a given cost in each period of the model planning horizon. This is the approach used for natural gas supplies, where fields are grouped or "binned" together based on the price of gas from the field, with the price variation representing differences in extraction costs. Gas prices are sourced from Oil and Gas Regulatory Authority (OGRA).[14] The rate of future increases in gas prices are

[13] See following data files received from DG PC and DG Minerals – Long term Gas Projections-DGPC.xls, Long term Oil Projections-DGPC.xls and Long term Coal Projections-DG Minerals.xls.

[14] Well head gas prices can be found at http://www.ogra.org.pk/

based on information from the IEA's World Energy Outlook (WEO) 2009 (IEA 2009b) (in the absence of Pakistan-specific data).

Coal prices are sourced from the Energy Year Book (HDIP 2008). These are province-specific, and dependent on coal quality and demand in local markets. Price projections are provided out to 2015 in the Energy Year Book; post-2015, prices are assumed to grow based on growth rates used in European model projections (in the absence of Pakistan specific data). Imported coal prices are sourced from WEO 2009 (IEA 2009b).

For oil supplies, the situation is different. Prices are primarily determined by the regional or global market prices for crude, and therefore provide no insights into variations in the costs of domestic production. The import crude price is based on an average gulf prices (plus average freight rate assessment), sourced from the EIA.[15]

The refinery sector sees the same crude price whether it is domestic or Arabian Light crude; the Government however mandates that all available domestic crude needs to be used by the refining sector. Therefore, the refining sector does not make decisions on the basis of price, and is more concerned about quality in terms of the product mix that can be produced from each crude type.

To ensure any domestic crude that is produced is used in the refining sector the domestic crude price is set at 70% of the import price. This also ensures that the domestic crude price does not interfere with the overall marginal price of the commodity, which should be tied to international market prices. Future prices of imported and domestic crude, as well as imported oil products, are tied to IEA projections for oil. The price of crude in 2007 was around $60 per barrel. The latest estimates from IEA can be found in WEO 2009, with oil rising (in real terms) to $100 per barrel in 2020, and $115 per barrel in 2030 (2008 prices). Note that this is the long run price of oil, and does not therefore take account of short-term volatility in the oil markets.

The price of oil products is based on information provided in the Energy Year book (HDIP 2008). The economic price is based on what is known as the ex-refinery price[16] plus the freight and distribution margin. Changes in prices in future years are tied to crude oil projections. The import price is determined by applying a 20% increase whilst export prices have a 40% decrease applied. This deflation factor is important to ensure that the model does not start producing oil products simply for export.[17]

Base year prices used in the model, which do not include sector taxes / subsidies are provided in Table 6 below.

[15] Energy Information Administration (EIA) website, http://tonto.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm

[16] The ex-refinery price of a product, which is paid to local refineries, equates to the landed cost of the product. See OCAC website for further description - http://www.ocac.org.pk/ex_refinery5.asp

[17] Allowing exports is particularly important in the model to ensure smooth refinery operation. Due to the product slate of a refinery, and limited flexibility, a situation could be envisaged whereby operation ceases and switches to imports because there is no demand for specific products produced.

Table 6: Prices of Energy Commodities in 2006/07

Commodity	Commodity type	$2007 / GJ	$2007 / toe
Crude Oil	Domestic	7.04	311.1
	Import	10.06	444.5
Oil Products	Motor Spirit	15.01	663.4
	Kerosene	15.50	685.1
	High Speed Diesel	14.23	629.0
	Light Diesel Oil	12.83	567.1
	LPG	12.08	534.1
	Heavy Fuel Oil	8.82	389.8
	Aviation Fuel	14.71	650.3
	Naptha	12.38	547.0
Natural Gas	Domestic	1.58-2.48	69.88-109.68
	Domestic (Assoc)	0.35	15.6
	Imports	6.60	291.7
Coal	Domestic	1.07-3.27	47.15-144.73
	Imports	3.93	173.7

Alternatively, the model can be run with full prices (including taxes / subsidies) that are seen in reality by different sectors. This information is important to help understand how the system responds under market distortions, using a “financial” rather than “economic” approach. These prices are sourced from the Energy Year book (HDIP 2008) for oil products and Pakistan Economic Survey (GoP 2009) for gas and electricity. [18]

C. Future Supply Options

A number of future major supply options have been included in the model. They include:

- Thar Coal
- Tight gas reserves
- Liquefied natural gas (LNG) shipping and regasification process
- Iran-Pakistan and Central Asia gas pipelines
- Regional electricity transmission network

All of the above project options require large up-front investment to ensure access to new energy resources. These investments have a large minimum threshold, although in the standard model set-up can be built based on any capacity increments. (The model could treat these as “lumpy or discrete investment” options, where the project can only be built to a specific size and smaller incremental investments may not occur. The model can be run using discrete investments if desired, which is further described in the accompanying User’s Guide.

[18] A scenario template labelled *SectorPrices* is used in the model to reflect sector price mark-ups.

Thar coal reserves

Whilst indigenous coal use is relatively low, as shown in the energy balance, very large reserves of lignite coal are available in the Thar coalfield. Total resources are estimated at 175 billion tonnes, accounting for 95% of Pakistan's coal resource base. TCEB (2008) suggests that Thar could be a potentially important fuel source for electricity generation, providing 100,000 MW (for 30 years) based on an estimated consumption of 536 million tonnes per year. Given the long term outlook of Pak-IEM, this resource is important to characterize.

The reserves of this field are available from 2020 onwards (in the model), with cost of mining derived on the basis of available feasibility studies (PPIB 2008).

Tight gas reserves

Pakistan Petroleum Exploration and Production Companies Association (PPEPCA) and Schlumberger have recently estimated that tight gas reserves of between 24 and 40 TCF exist in various basins in Pakistan.[19] This reserve has been included in the model although costs of the gas have been put at double the import price (until this option is better understood and properly characterized based on additional information). The availability of the resource is from 2020.

LNG imports

At the request of the Government, Sui Southern Gas Company (SSGC) are developing the Pakistan Mashal LNG Project to establish an LNG import facility capable of taking 3.5 million tons per annum (mtpa), equivalent to 500 million cubic feet daily (MMCFD) of gas. The LNG import project with a re-gasification facility will be located in the vicinity of Karachi. It is estimated that first imports will arrive in 2011.[20]

LNG regasification plant costs are sourced from the Energy Information Administration (EIA).[21] Current year and projected prices have been sourced from WEO 2009 (IEA 2009b). The amount of LNG imported can increase to twice the level in 2020 and three times the level in 2030 compared to that observed under the Mashal project.

In addition to the above option which feeds into the general gas network, there is also the option of a specific facility to provide gas for a coastal power plant. Currently, this option has the same characteristics as the generic LNG option (although the potential capacity in future years needs to be revisited).

Transnational Gas Pipelines

An Iran-Pakistan gas pipeline is being constructed (much of which is complete on the Iranian side) which will see a 42-inch diameter pipeline importing 750 MMCFD of natural gas. The Pakistan section of the pipeline is expected to cost US$ 1.3 billion and take four years to complete. Gas is expected to be available from this option by 2015, initially at 263 MMCFD, rising to 750 MMCFD by 2017.[22]

Turkmenistan is another major source of gas, and discussions have been ongoing since 2002 on a pipeline between Turkmenistan and India, via Afghanistan and Pakistan (known

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[19] Information provided by DG PC – see *Response of DGPC 7-10-2010.pdf* in Appendix 3.

[20] Information sourced from SSGC website, http://www.ssgc.com.pk/ssgc/projects/lng/

[21] See EIA website, http://www.eia.doe.gov/oiaf/analysispaper/global/lngindustry.html

[22] Data is sourced from direct correspondence (see file *ISGS's Response 28-9-10.pdf*) and the ISGS website, http://www.isgs.pk

as TAPI). Agreement has been made on levels of gas provision, with Pakistan getting 960 MMCFD in Year 1, rising to 1325 MMCFD by Year 3. The Asian Development Bank (ADB) is acting as the lead developer and coordinator for the project.

The following pipeline options have therefore been included in the model:

- New natural gas pipeline from Iran (available from 2015)
- New natural gas pipeline from Iran (Phase 2), adding capacity equivalent to the first phase (available from 2020)
- New natural gas pipeline from Central Asia (available from 2025), although this is currently excluded as an option from the Reference case

Technical facts about Iran-Pakistan Pipeline

The raw natural gas from the South Pars gas field in the Persian Gulf is brought onshore to Iran's port city of Assaluyeh where it is refined and processed to pipeline quality. The Iranian segment of the Iran/Pakistan/India (IPI) gas pipeline would comprise about 1,150 km long pipeline from Assaluyeh to the Iran-Pakistan border, travelling along the southern coastal area of Iran. Iran has already constructed almost 80 percent of the 900 km 56-inch diameter pipeline from Assaluyeh to Iranshehr the capital of its Sistan/Baluchistan province. The pipeline has the capacity to carry 3.2 Bcfd of gas, out of which 2.1 Bcfd is meant for export. The remaining about 250 km pipeline section from Iranshehr to Iran-Pakistan border is in the planning and tendering stage, which is expected to be completed in 2010. Pakistan has planned to build a 42-inch diameter pipeline with design capacity of 30 MMcmd (1.06 Bcfd) along the coastal line. The approximate length of the Pakistan segment of the IPI gas pipeline is 800 km from Iran-Pak border to the Pakistan gas off-take point near Nawabshah where it will be connected with the existing gas distribution network.

Source: Inter State Gas System (ISGS), http://www.isgs.pk

It has not been possible to source the price of gas imports from ISGS. It was recommended by the oil and gas expert group that such prices be based on 80% of crude price (Japanese Crude cocktail) as typically reported in press.[23]

Regional electricity transmission network

Afghanistan, the Kyrgyz Republic, Pakistan, and Tajikistan have been pursuing the development of electricity trading arrangements and the establishment of a Central Asia – South Asia Regional Electricity Market (CASAREM). The initial plan is to export power in the range of 1,000 to 1,300 MW from the Kyrgyz Republic and Tajikistan to Pakistan and Afghanistan. It is envisaged that the major share of the export will be used by Pakistan, while a relatively small quantity of power (100 to 300 MW) will be imported by Afghanistan. Pakistan has also expressed interest in increasing imports over the medium to long term beyond the initial power requirements of 1,000 MW (ADB 2009).

The total length of the transmission line is 750 km approximately, out of which 16% passes through Tajikistan, 75% through Afghanistan, and 9% through Pakistan. Transmission line costs are estimated at US$ 275,000/km. Total costs of the project are put at $US 543 million, with 143 million associated with the Pakistan section, mainly on converter station / substations. The costs of linking Kyrgyz Republic is a further $US 172 million. IDC and contingency takes the total project costs from $US 715 to 931 million.

The main uncertainty concerning this option is the price of imported electricity, and the timing of the actual construction of the grid. The current assumption in the model is that the

[23] Pak-IEM oil and gas expert meeting at Serena Hotel (2nd September 2010)

CASAREM system would be available from 2015, and that similar additional capacity could be envisaged by 2020. However, the option is rarely used in the model due to the high price of electricity assumed in the absence of any additional information.

D. Renewable resources

With increasing pressure on traditional fossil fuel resources in future years, renewable options are important to consider. Pakistan is, however, already heavily dependent on renewables, with a very high percentage of the population using biomass energy, particularly in rural areas. Memon et al (2008) state that the rural population meets more than 95% of their domestic energy needs by burning biofuels (citing Sial (2002)).

Current biomass consumption

Biomass is not included in the Energy Year Book of Pakistan, as it is often considered a non-commercial fuel and is also very difficult to estimate. However, it is clear that it is a very important energy source for many households, particularly in rural areas for cooking and heating, and therefore needs to be integrated into Pak-IEM.

The approach to estimating biomass totals is as follows.

- Energy Sector Management Assistance Program (ESMAP) (2006) provides data on the percentage of households in rural and urban areas that use biomass fuels – wood fuel, dung cake, and crop residues. This shows for example that 78% of rural households use wood fuel whilst for urban households, it is 27%. This does not indicate what other fuels are being used, or if indeed this is the main fuel consumed.
- Average annual consumption levels for different fuels (by household) have been sourced from the Household Energy Strategy Study (HESS) (1991). These levels and the information on numbers of households using biomass determine the aggregate level of biomass used.

The HESS data is also used to estimate how biomass types are used, for the provision of energy services e.g. cooking, water heating etc. Table 7 shows the estimates by energy service type and biomass type. Biomass is primarily used for cooking.

Table 7: Biomass energy use in Pakistan Rural / Urban Households (PJ), 2006/07

	Wood	Dung	Agr. Residues	Total
Urban				
Cooking	46	12	6	64
Space Heating	3			3
Water Heating	9			9
Other	1	1		2
Total Urban	**59**	**13**	**6**	**78**
Rural				
Cooking	340	90	69	499
Space Heating	32			32
Water Heating	37			37
Other	3	6		8
Total Rural	**411**	**95**	**69**	**575**
Total	470	108	75	653

The HESS survey features heavily in the above estimates, in the absence of any other data. However, for biomass, it is probable that there have been limited changes in the quantity used in those households for which it is the primary energy source. There may however, have been improvements the efficiency of use, depending on whether improved stoves in particular have been introduced.

The estimated total of biomass is approximately 650 PJ. The share of biomass in the base year of Pak-IEM as a percentage of household energy consumption is 66% overall, 89% for rural households, and 22% for urban households.

The aggregate estimate of biomass use from the International Energy Agency (IEA) Non-OECD Energy Balances (2009), which provides estimates of biomass consumption in 2006 and 2007, is 27.2 Mtoes (or 1140 PJ). This is significantly higher than the bottom-up estimate used in Pak-IEM. The IEA estimate is sourced from HESS and therefore does not represent new information that should necessarily be considered. It has, however, been used to derive an industry estimate for fuel wood.

Another important factor that needs to be reflected in the modelling is free vs. purchased biomass. This is important for understanding costs of energy service provision in the future, and the likelihood of households switching to more modern fuels (due to lack of incentive if indeed energy is already free). In the model, free biomass is not *free* in the sense that there are likely to be costs associated with growing / gathering it, particularly in respect of time. Therefore, a low cost of 20% of purchased biomass (based on HESS data) is assumed, important for incentivising switching to more efficient stove technologies. Data from the Pakistan Integrated Household Survey (PIHS), cited in World Bank (2003), suggests that 60% of rural biomass is free, while for urban areas the value is nearer 5%. These values have been applied to all biomass types.

Future biomass resource potential and patterns of use

Currently, the model is restricted to base year consumption levels of biomass. The rationale is that the levels of fuel wood and other biomass consumption are near to their available potential. An important issue that requires further work is the future rates and timing of switching away from biomass to more modern fuels.

Both the base year consumption levels and biomass potential estimates have been subject to significant discussion with experts from the National Agricultural Research Centre (NARC). [24]

Potential for other renewable energy

The main other type of renewable energy used in Pakistan is hydro electricity generation. Other renewable energy types are not so commonplace, although a limited number of household / community level biogas, micro-wind, micro-hydro, and solar projects have been implemented in a limited number of locations across Pakistan. The installation of a larger-scale wind power project at Jhimpir, Sindh began in 2009. Initially, this farm will have a 6 MW capacity, rising to at least 50 MW over the next few years.

The Alternative Energy Development Board (AEDB)[25] is the main expert body on opportunities for renewable energy development in Pakistan. It has produced a range of estimates on potentials of different energy types; these provide the basis for estimates of renewable potential in Pak-IEM.

[24] Biomass potential estimates provided by NARC can be found in document labelled *Biomass resource-Munir.jpg* (listed in Appendix 3).

[25] Alternative Energy Development Board (AEDB) website, http://www.aedb.org/Main.htm

Table 8: Renewable potentials for Pakistan (Source: AEDB)

Energy Type	Estimate (MW)
Wind	340,000
Solar	2.9 million
Hydro (Mini)	2000
Hydro (small)	3000
Hydro (large)	50,000
Bagasse Cogeneration	1800
Waste-to-power	500
Geothermal	550

More work is required in future to explore how technically / economically feasible these potentials are, and whether or not they can be represented as resource supply curves.

Note that most renewable resources are not characterized in the resource supply sector but rather in power generation (renewable electricity generation) or end-use demand sectors (for non-electricity sources or remote generation based applications). This is because such resources are often dependent on technology specifications, e.g., type of hydro-turbine technology, size of wind turbine, rather than the supply of the resource itself.

E. Data Sources

Most of the data for this sector is included in the Pakistan Energy Yearbook; the exception is information on costs or prices by resource and projected extraction rates of different resources, as well as the biomass as discussed in the previous section. Table 9 provides a summary of the data sources currently being used.

Table 9: Summary of Data Sources for the Resource Supply Sector

Data Type	Data Source	Notes and Comments
Coal		
Reserves by Field	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 4.1
Current Production Levels and Costs by Field	Pakistan Energy Yearbook 2007 (HDIP 2008)	Production in Table 4.2; Costs in Table 4.5
Future Extraction Rates and Costs by Field	DG Minerals (PDF file *Long Term Coal Projections-DG Mineral* provided on 8th April 09	Projections to 2015
Current Import Levels and Prices	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 4.5 for indigenous coal; Default PET (European) assumption for imports.
Thar coal cost estimates	PPIB (2008)	
Oil & Petroleum Products		
Reserves by Field	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 2.1
Current Production Levels by Field	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 2.2
Future Extraction Rates by Field	DG PC data (File Long term Oil Projection-DGPC.xls)	Projections to 2035, split into committed and anticipated supplies
Current Import Levels and Prices	Pakistan Energy Yearbook 2007 (HDIP 2008), Energy Information Administration (EIA)	EIA used for imported crude prices

Data Type	Data Source	Notes and Comments
Oil Sector Data on Primary Resources and Refining	Pakistan Oil Report 2006-07 (OCAC 2008)	Provides some additional level of detail to what is found in the Energy Yearbook
Future Crude Oil Prices	IEA (sourced World Energy Outlook 2009)	
Natural Gas		
Reserves by Field	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 3.1 (Table 3.1.1 for Associated Gas)
Current Production Levels by Field	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 3.4 (Table 3.4.1 for Associated Gas)
Future Extraction Rates by Field	DG PC data (File Long term Gas Projection-DGPC.xls)	Projections to 2035, split into committed and anticipated supplies
Infrastructure Characterization	Data (capacity / cost) provided by distribution companies (letter from DG Gas dated 26th May 09)	
Current Prices by Field	Oil and Gas Regulatory Authority (OGRA)	
Future LNG / Transnational pipeline options	ISGS / SSGC websites	
Electricity (Imports)		
Proposed regional interconnection	CASAREM project (ADB 2009)	
Biomass		
Indigenous Supply by Type	ESMAP (2006), HESS (1991)	
Renewables		
Potential estimates	AEDB website (http://www.aedb.org)	

Some of the above sources were not publicly available, and were provided directly to the project team for use in Pak-IEM. A full listing of these files, and the data providers, is provided in Appendix 3. The Energy Wing holds all of the data files listed.

IV. REFINING AND OIL & GAS DISTRIBUTION

The upstream sector characterizes the processes for transforming primary energy resources into petroleum oil products (from crude) and natural gas (from raw extracted gas), and transportation to end-use sectors. Therefore, there are two main sub-sectors – refining and oil / gas distribution.

The petroleum and refined products RES in Figure 8 shows how this sector has been structured in the model. Currently, the gas processing process is combined with gas pipeline / network step. Limited account is taken of oil distribution infrastructure in the model although this is an area that may need to be reconsidered in future model versions, particularly in view of industry concerns about port constraints, and differences between the transportation of various products e.g. HFO is only transported by road.[26]

In the oil refining sector, each refinery is modeled individually, taking account of plant crude mix, efficiency, and output product slates.

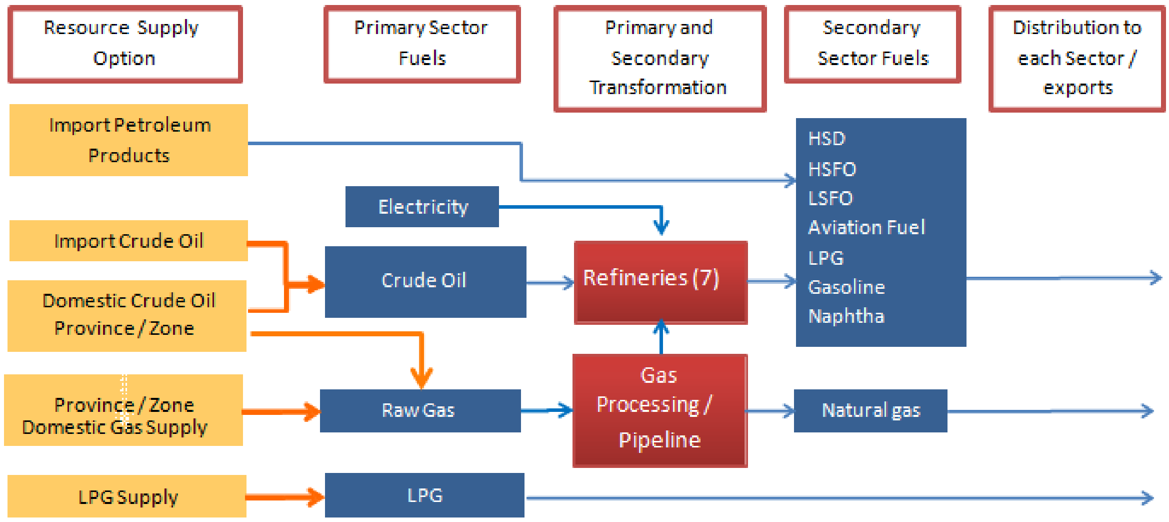


Figure 9: Current Structure of Oil and Gas Resource Supply and Upstream Processing Sectors

A. Oil Refining Sector

There are seven refineries in Pakistan. They are listed in Table 10, which includes their key operating characteristics for the base year 2006/07.

Table 10: Key Operating Characteristics of Pakistan Refineries

Refinery Name	2006/07 Crude Input (PJ)	2006/07 Product Output (PJ)	Efficiency (%)	Refining Capacity (PJ)
Attock	81.16	76.96	94.8%	87.17
Bosicor	32.54	30.24	92.9%	64.04
Dhodak	4.46	4.75	100.0%**	5.30
ENAR Petrotech	4.19	4.33	100.0%**	5.30
National	126.92	101.81	80.2%	126.92*
PakArab	169.58	162.68	95.9%	198.90

[26] Useful information on distribution and transportation can be found in OGRA (2008)

Refinery Name	2006/07 Crude Input (PJ)	2006/07 Product Output (PJ)	Efficiency (%)	Refining Capacity (PJ)
Pakistan	90.29	88.33	97.8%	92.82

Source: HDIP 2008

* Capacity value for National Refinery (119.78 PJ) is assumed to be equal to crude input values.

** Efficiencies for Dhodak and ENAR have been set to 100%; data currently puts the efficiency at 107% and 103% respectively.

An important assumption in the model concerns the type of crude that domestic refineries use. Attock and Dhodak refineries primarily use domestic crude oil in refining operations. Other refineries are limited to using between 15-20% domestic crude, as most are set up for using higher quality Arabian crude. This is reflected in the assumptions concerning shares of crude used in future years (see Table 11).

Table 11: Crude Input Shares for Pakistan Refineries

Refinery Name	Domestic Crude Share	Import Crude Share	Max. Future Domestic Crude Share	Max. Future Import Crude Share
Attock	1.00	0.00	1.00	0.40
Bosicor	0.00	1.00	0.20	1.00
Dhodak	1.00	0.00	1.00	0.40
ENAR Petrotech	0.00	1.00	0.20	1.00
National	0.16	0.84	0.20	1.00
PakArab	0.10	0.90	0.20	1.00
Pakistan	0.11	0.89	0.20	1.00

Source: HDIP 2008 (for current shares); Communication with Refinery stakeholders for future shares.

The product output shares from each refinery in 2006/07 are shown in Figure 9 below.

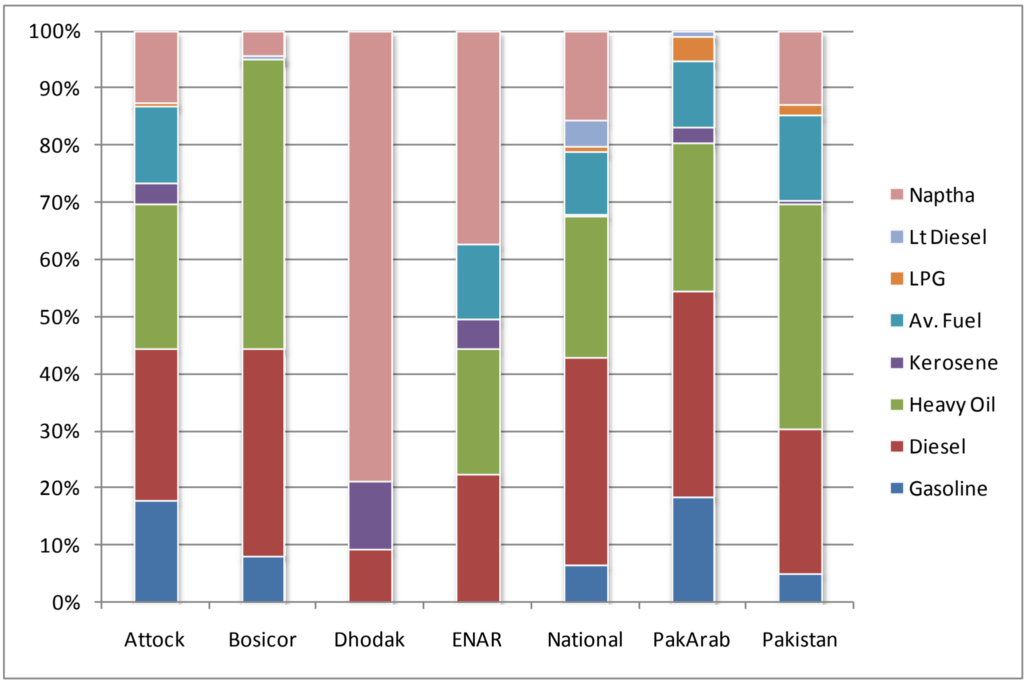


Figure 10: Product Shares for Refineries in 2006/07

Source: HDIP (2008)

In future years, existing refineries are allowed overall flexibility of 10% across their product slate (an assumption cross-checked with refinery experts), except for gasoline, where a 4% relaxation factor has been assumed. A rule has also been introduced that states if the share of a product is less than 3% in the base year, it will be permitted to produce up to 3% of this product in future years. Information provided by Attock and Pak Arab refineries resulted in being able to calculate the product slate flexibility, at a similar level in aggregate terms to the assumption on flexibility for other refineries.

The existing refinery stock (in crude input capacity) has been held constant to 2040, based on the assumption that refineries tend to be retrofitted on an ongoing basis and therefore will remain in the energy system. The costs of such retrofitting activities are not known across the whole stock, although some information has recently been provided by selected refineries, and should be considered in future model updates (see Model Development Priorities, section VIII for further information).

In the development of the model, there was significant discussion with experts concerning refinery margin. A significant element of this is the operating cost. For existing refineries we are using $1.25 / bbl although some experts have suggested this should be potentially higher. To date, we have not received the data from individual refineries to differentiate this cost estimate.

Planned new refinery builds, referenced in OCAC (2009) and listed in Table 12, are "forced" into the model solution in the year in which they are expected to be commissioned. For Bosicor, investment costs have been provided for a second-hand refinery build. These have been used for Transasia and Indus, although with a 20% multiplier due to relative simple configuration of Bosicor. An operating cost of $1/bbl has been assumed.

Table 12: Planned New Refineries

Planned Refinery	Refining capacity (BPD)	Investment cost, $ /BPD	Commissioning Date
Bosicor Oil Pakistan Limited*	115,000	5000	2010
Transasia Refinery Limited	100,000	5215	2013
Indus Refinery	250,000	5215	2014

* Investment cost information provided for Bosicor based on 2nd Hand Refinery costs. Equivalent to ~$5000/bbl. All refineries assumed to primarily use imported crude.

The product slate for the planned refineries is based on information in OCAC (2009). Khalifa Coastal refinery was dropped as a planned refinery due to the significant uncertainty around whether it will be built.[27]

There is a single new refinery technology in the model, only available in the model from 2017 after the planned refineries have been built. This technology is relatively flexible, with a product slate that is typical of the product slates observed for the planned build refineries. Investment costs are based on the proposed Khalifa refinery, reported to cost $5 billion for a 250,000 bbl / day capacity. This is estimated at over $8 million per PJ. UK / US model sources put new refinery costs at around $5 million per PJ. Based on discussions with the refinery expert group, it was decided to use an average investment cost of around $6.75 million per PJ.

[27] All of the assumptions around the refinery sector assumption were discussed in detail at a Pak-IEM expert meeting on September 2, 2010.

From 2017 to 2040, additional new capacity is capped at one new refinery with a capacity of 100,000 bbl per day every three years. This results in new capacity of over 1500 PJ by 2040. This is at the optimistic end of what could happen, based on discussion with the expert group.

B. Distribution of oil and gas

In Pak-IEM, the distribution infrastructure (capacity or costs) for crude oil / petroleum products are not modeled explicitly. Oil and gas transportation costs are taken into account, based on the additional costs seen by refineries and end-use sectors.

For gas, the pipeline network is critical as the primary means of transportation. Capacity of the system is based on comparing the flow of gas in the base year (2006-07) and utilization of the system for that year. There are two primary gas networks, Sui Southern (SSGC) and Sui Northern (SNGPL), reflecting both transit pipelines and the capacity of the associated distribution network. For both networks, utilization is near 100% across most parts of the network; therefore, the capacity is based on the 2006-07 flow of gas, with an assumed 5% spare capacity. In future years, exceeding 2006-07 levels plus the 5% extra capacity will require additional investment in the system. Costs for incremental capacity are being sought but are not yet finalized in the model.[28] Furthermore, a nationally integrated gas network is assumed owing to the fact that SSGC / SNGPL are well connected.

C. Data Sources

The key sources of information for the upstream sector are listed in Table 13. Information is primarily sourced from the Energy Yearbook, supplemented by the Pakistan Oil Report (OCAC 2008).

Table 13: Summary of Data Sources for Refining and Gas / Oil Distribution Sector

Data Type	Data Source	Notes and Comments
Refinery capacities	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 2.3
Crude oil processed	Pakistan Energy Yearbook 2007 (HDIP 2008)	Table 2.4
Refinery specific data	Pakistan Energy Yearbook 2007 (HDIP 2008)	Tables 2.5 and 2.5.1-7
Refinery flexibility / operating costs	Data provided by two refineries – Attock, Bosicor and National	Bosicor also provided cost estimates regarding plant capacity upgrade
Planned new build	Pakistan Oil Market Report 2007-08	
Gas network capacity / utilization	SSGC / SNGPL	Data provided directly (see file Letter & Data from DG Gas.pdf, and Response of DG Gas 4-10-2010.pdf)

Some of the above sources were not publicly available, and were provided directly to the project team for use in Pak-IEM. A full listing of these files, and the data providers, is provided in Appendix 3. The Energy Wing holds all of these data files.

[28] Costs of system expansion have been provided by SSGC and most recently by DG PC, although these are in terms of pipeline length rather than energy delivered to the system, which is what is needed. Further work is needed to assess how to use such information. See file *Response of DG Gas 4-10-2010.pdf*, listed in Appendix 3.

V. POWER SECTOR

The Pakistan power generation and distribution sector in 2006/07 has been modeled in detail, with individual power plants characterized based on their historic operating characteristics. Problems with electricity generation in Pakistan, in particular load shedding due to lack of capacity at high demand and peak periods, means that detailed modeling of this sector is important for stakeholders who will use the model and / or its outputs to think through planning options in the medium and long term.

A. Sector overview

Figure 10(a) shows that fossil energy requirements for the power sector are dominated by natural gas and furnace oil. Figure 10(b) shows that over 90% of all electricity generation is provided by these oil and gas plants along with hydropower plants, which provide about 33% of all electricity.

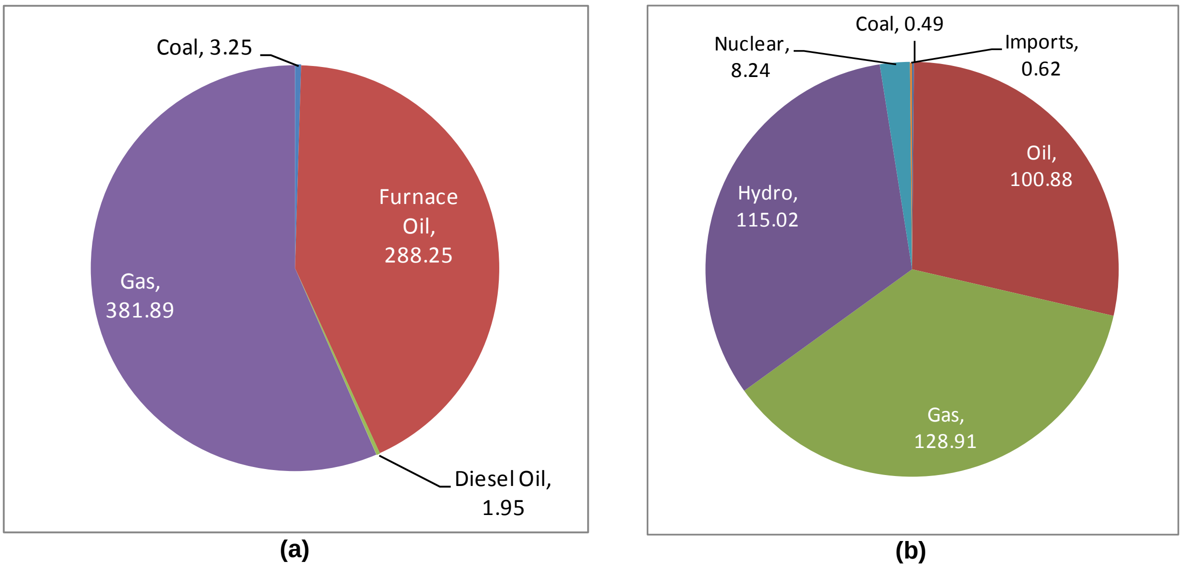


Figure 11: 2006/07 (a) Power Sector Fossil Energy Use (PJ)

and (b) Electricity Generation by Plant Type (PJ)

All large centralized hydropower generation is overseen by Water and Power Development Authority (WAPDA). Thermal generation in the model can be categorized into three groups: 1) public sector thermal plants operated by PEPCO, 2) independent power producers (IPPs), and 3) plants operated by Karachi Electricity Supply Company (KESC).

B. Approach to modeling the power sector generation

The approach to modeling the above groups of generation plant differs, primarily due to the type of plant and availability of data. However, the types of data required to characterize power plants in Pak-IEM apply across all of these groups, and are listed in Table 14.

Table 14: Data Requirements for Power Plant Characterization

Characteristic	Unit	Comment
Name		
Fuel(s) used		
Capacity	MW	Electric rating only
Remaining life	Years	TIMES can also use the start year for the plant
Efficiency (by fuel)	OUT/IN	
Fixed O&M Cost	$M/MW	
Variable O&M Cost	$M/PJ	
Availability factor	Annual or seasonal	Hydro, wind and solar plants have seasonal availability factors.
Fuel Input Share(s)	Fraction	Needed for multi-fuel plants.
Output to Power Ratio	Fraction	Needed when non-electric outputs are also produced, such as heat (co-generation plant), fuels or water.
Investment cost for new options	$M/MW	

Table 15, Table 16, Table 17, and Table 18 provide an overview of the modeling approaches taken for the PEPCO, IPP, KESC, and WAPDA power plants respectively. Generation from decentralized wind and solar generation are also included in the model, although they are not detailed here due to their relative low generation output (2006/07 total of 600 MWh).

Table 15: Model Assumptions for PEPCO Thermal Power Plants

Parameter	Description of approach	Source
Existing Installed Capacity	Established at the “block” level (aggregation of similar units of same type and fuel(s) used) using the installed de-rated capacity	Data provided directly by PEPCO (see file PEPCO THERMAL POWER STATIONS1.xls)
Input Fuel Consumption	Available by unit, aggregated by block t for consistency	Data provided directly by PEPCO (see file Planning Commission 20-03-09.xls)
Fuel Shares for Duel Fuel Plant	Evaluated based on block fuel consumption	Data provided directly by PEPCO (see file Planning Commission 20-03-09.xls)
Efficiency	Evaluated as the ratio between block production and consumption. For multi-fuels plants we assumed the same efficiency for both fuels	Data provided directly by PEPCO (see file Planning Commission 20-03-09.xls)
Utilization Factor	Evaluated on the basis of the installed de-rated capacity and block production in 2007	Data provided directly by PEPCO (see file Planning Commission 20-03-09.xls)
Availability factor (for future years)	As per base year value	A constraint has been put in the model that ensure operation of plant at least at 2006/07 levels (see template Scen_REF-ELCvXX.xls)
Remaining lifetime of plant	Retirement schedule provided by PEPCO	Data provided directly by PEPCO (see file Response to Remaining Power Sector Issues 3-2-10.pdf)
Operating costs	The O&M costs are calculated from the various tariff decisions of NEPRA related to PEPCO thermal power plants and IPPs	Cost calculations undertaken by project team
Potential for retrofit	Rather than invest in new plant, an important alternative option might be the retrofit of existing plant	Three plants are being considered for retrofit; other existing plant do not have this option

Table 16: Model Assumptions for IPP Thermal Power Plants

Parameter	Description of approach	Source
Existing Installed Capacity	Plant level capacity (de-rated)	Data provided directly by PEPCO (see file Data of Existing IPP.xls)
Efficiency	Plant level efficiency adjusted based on calibration to get correct fuel consumption totals	Data provided directly by PEPCO (see file Data of Existing IPP.xls)
Utilization Factor	Calculated using energy use by plant from Electricity Market Data publication (and capacity as provided above) because IPP data is for 2005-06	Data provided directly by PEPCO (see file Data of Existing IPP.xls) plus Electricity Market Data report
Availability Factor (for future years)	As per base year value	A constraint has been put in the model that ensure operation of plant at least at 2006/07 levels
Remaining Lifetime of Plant	Based on generic technical lifetime of technology type, accounting for start year of plant.	Planning Team advised on lifetime level
Operating Costs	The O&M costs are calculated from the various tariff decisions of NEPRA related to PEPCO thermal power plants and IPPs	Cost calculations undertaken by project team

Table 17: Model Assumptions for KESC Thermal Plants

Parameter	Description of approach	Source
Existing Installed Capacity	Plant level capacity	Data provided directly by KESC (see file PIEM KESC data.pdf)
Efficiency	Plant level efficiency	Data provided directly by KESC (see file PIEM KESC data.pdf)
Utilization Factor	Plant utilization in base year	Data provided directly by KESC (see file PIEM KESC data.pdf)
Availability Factor (for future years)	As per base year value	A constraint has been put in the model that ensure operation of plant at least at 2006/07 levels
Remaining Lifetime of Plant	Based on generic technical lifetime of technology type, not accounting for start year of plant.	Planning Team advised on lifetime level
Operating Costs	The O&M costs are calculated from the various tariff decisions of NEPRA related to PEPCO thermal power plants and IPPs	Cost calculations undertaken by project team

Table 18: Model Assumptions for WAPDA Hydropower Plants

Parameter	Description of approach	Source
Existing Installed Capacity	Existing installed generation capacity	Electricity Market Data report
Utilization Factor	Seasonal availability factors provided for 2006-07 (and 2 subsequent years)	See file *Power Sector Load Shedding & Captive Power Data.pdf*
Availability Factor (for future years)	Seasonal availability factors provided for 2006-07 (and 2 subsequent years)*	See file *Power Sector Load Shedding & Captive Power Data.pdf*
Remaining Lifetime of Plant	Based on generic technical lifetime of technology type, accounting for start year	Planning Team advised on lifetime level

Parameter	Description of approach	Source
	of plant; assessing need to increase typical lifetimes so Pakistan-relevant	
Operating Costs	Derived from tariff set by WAPDA where. one composite tariff is awarded by WAPDA for all hydro power plants, therefore same value applied to all plants	Cost calculations undertaken by project team (but could be subject to update to make plant specific)

Many of the existing thermal plant do not continue to operate without forced operation, often due to the very low efficiencies observed. In the current model Reference case, many of these plants have been forced to operate at least at the level that was observed in the base year, 2006/07, which seems reasonable, based on the realities on the ground.

C. Planned new build

The Pakistan Government has a plan to install significant levels of new generation capacity over the next 10 years. The approach taken in this model is to ensure any thermal plant proposed for commissioning by June 2010 are "forced" into the model. Planned hydro plants are also included in the model even where commissioning dates are post-2010, if the completion rate of construction is greater than 50%.

A total of 7.9GW of planned capacity is included in the model Reference case, as shown in Figure 11 below. Of this 1.3GW of capacity is short-term (3-5 years), based on rental contracts. Data has been provided directly by PEPCO and KESC.[29]

Cost data for planned new builds are based on the assumptions provided in the next section, as new technology options. For rental plants, costs assumptions are from a recent review by the ADB (2010).

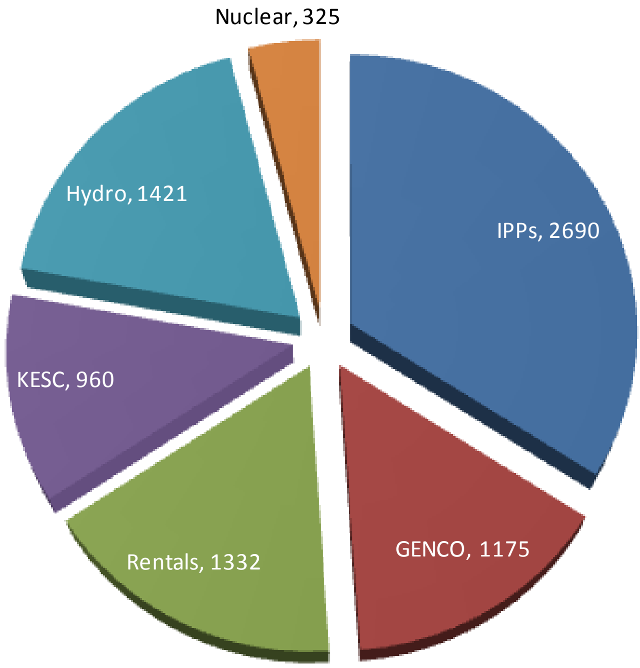


Figure 12: Planned New Generation Capacity, MW

[29] PEPCO information in letter *Response to Remaining Power Sector Issues 3-2-10.pdf*. KESC information in *KESC data sheet.doc*.

D. New technology options

In the medium to longer term, a full range of power generation options are included in the model. The assumptions for these different options are listed in Table 19.

Estimates of the cost and performance of future power generation technology options were based on a range of sources, including US data from the Assumptions to the Annual Energy Outlook 2010 (EIA 2010), European data from the IEA Projected Cost of Electricity 2010 Edition (IEA 2010), and Pakistan-specific estimates from AEDB and others. Data from these sources were compared for each technology option, and the data most appropriate to Pakistan was selected based on review with the Planning Team. In many cases, the local and international data sources are in good agreement. In a few cases, Pakistan specific factors resulted in selection of the Pakistan data or modification to the international values.

Table 19: New technology options in the Power Sector

Technology	Fuel Type	Start Year	Efficiency	Lifetime	Investment costs	Fixed O&M	Variable O&M	Construction time	Discount rate	Annual AF**
			%	Years	$/kW	$/kW	$/GJ	Years	%	%
New Gas Turbine Open Cycle - Gas or Fuel Oil	NGA	2011	32.7%	30	709	11.79	0.96	2.00	10%	70%
	HFO	2020	38.8%		674					
		2030	45.0%		638					
New Heavy Oil Reciprocating engines with Combined cycle	HFO	2010	48.0%	30	1200	16.92	1.72	3.00	10%	70%
New Heavy Oil Steam turbine with Reheat Cycle 1	HFO	2010	40.0%	40	1000	17.52	0.67	3.00	10%	70%
New Coal Integrated Gasification Combined Cycle	COA	2016	45.8%	40	2898	37.63	0.79	4.00	10%	75%
		2030			2608					
New Gas turbine Combined Cycle - Natural gas and diesel	NGA	2010	47.4%	30	1063	12.15	0.56	3.00	10%	70%
	HFO	2020	53.7%		1010					
		2030	60.0%		957					
New Gas turbine Combined Cycle with Reheat - Natural gas and diesel	NGA	2011	54.0%	30	1200	15.84	0.83	3.00	10%	70%
	HFO									
New Gas turbine Combined Cycle - LNG dedicated	LNGP	2010	47.4%	40	1169	26.79	1.24	3.00	10%	70%
		2020			1111					
		2030			1052					
New Nuclear Power Plant	NUCD	2011	34.1%	40	4501	87.60	0.13	6.00	10%	85%
		2020			4051					
		2030			3601					
New Coal Steam Turbine Plant (using imported coal)	COAP	2010	37.1%	40	2000	26.79	1.24	3.00	10%	75%
		2020			1900					
		2030			1800					

New Coal Supercritical Steam turbine Power Plant (Thar)	COA	2010	37.1%	40	2560	26.79	1.24	3.00	10%	75%
		2020	43.5%		2432					
		2030	50.0%		2304					
New Hydro Power	HYD	2016	34.1%	50	1911	53.19	1.43	4.00	10%	
New Solar Photovoltaic Systems	SOL	2011	34.1%	20	6390	11.37	0.00		10%	
		2020			5432					
		2030			4473					
New Solar Thermal Power Systems	SOL	2011	34.1%	30	3500	19.08	0.67	3.00	10%	
		2020			3255					
		2030			2975					
New On Shore Wind Turbines-Classification 4	WIN	2012	34.1%	20	2500	63.24	0.11	2.00	10%	
New On Shore Wind Turbines-Classification 5	WIN	2012	34.1%	20	2500	63.24	0.11	2.00	10%	
New On Shore Wind Turbines-Classification 6	WIN	2012	34.1%	20	2750	63.24	0.11	2.00	10%	
New Off Shore Wind Turbines	WIN	2012	34.1%	50	3700	87.84	0.19	2.00	10%	
		2020			3441					
		2030			3145					
New Coal IGCC with Carbon Capture & Sequestration	COA	2017	41.1%	40	4260	44.88	1.20	3.00	10%	75%
		2030	48.0%		3408					
New Adv Gas turbine CC with Carbon Capture & Sequestration	NGA	2017	39.6%	30	2088	19.37	0.80	3.00	10%	70%
		2030	56.0%		1775					
New Municipal Solid Waste	MSW	2010	25.0%	30	2809	111.18	0.00	3.00	10%	70%

* Weighted average. The costs of new hydro are project specific but are not listed in detail in this table.

** Renewable generation options have seasonal or diurnal based AFs, not shown in this table.

Hydro generation potential in the model is shown by site in Table 20 below. The total potential is around 35 GW, with costs differing significantly depending on site-specific factors and the latest feasibility assessment. Seasonal availability factors are the same across all sites, sourced from the power sector experts on the Planning Team.

Table 20: Potential hydro sites in Pakistan

Hydro site	Year available	Capacity, MW	Investment cost, $M/GW
Diamer Basha	2020	4500	1730
Golen Gol	2012	106	1382
Kurram Tangi	2013	83	7582
Munda	2017	740	1145
Kohala	2017	1100	1844
Keyal Khwar	2016	122	1123
Phandar	2016	80	824
Basho	2015	28	1176
Lawi	2016	70	1188
Dasu	2021	4320	1699
Bunji	2022	7000	919
Akhori	2024	600	5176
Lower Spaigah	2021	567	1019
Palas Valley	2022	621	1011
Tarbel 4th extension	2014	960	691
Harpo	2015	33	1283
Pattan	2025	2800	2017
Thakot	2025	2800	2017
Dudhnial	2026	800	2118
Yulbo	2028	3000	2118
Tungas	2030	2200	1797
Skardu	2030	1600	4853
Yugo	2030	520	5430

Source: WAPDA (see file Response to Remaining Power Sector Issues 3-2-10.pdf)

Availability factor for other renewables such as wind and solar have been provided for all timeslices, taking account not only of seasonal differences but also variation across the day. Wind technologies have been categorized into three onshore types and a single onshore technology. These represent the differences in the wind resource (as reflected in the different capacity factors used), sourced from recent work by USAID / NREL.[30]

Carbon Capture and Storage (CCS) options are also included in the technology dataset, as shown in Table 19. The structure for modeling the CO_2 storage approach is described in the Model User Guide. Information on the costs and potential for storage still need to be developed.

The options in Table 19 only relate to public supply of electricity. Captive generation options in industry are described in the industry section of this report, as are microgeneration options in residential / commercial sectors.

[30] Wind Resource Assessment and Mapping for Afghanistan and Pakistan, Undertaken by National Renewable Energy Laboratory (NREL) under the SARI-Energy project (funded by USAID).

The maximum level of investment in new generation technologies is controlled in the model to reflect barriers faced in the real world, such as availability of capital, technical capacity for construction, and supply chain constraints. Annual build rates have therefore been introduced in the model's Reference case (see Figure 12). This figure compares annual build rates in 2015 with those in 2035, which are generally higher. These rates considered historical patterns of new build, and were developed in discussion with the Planning Team.

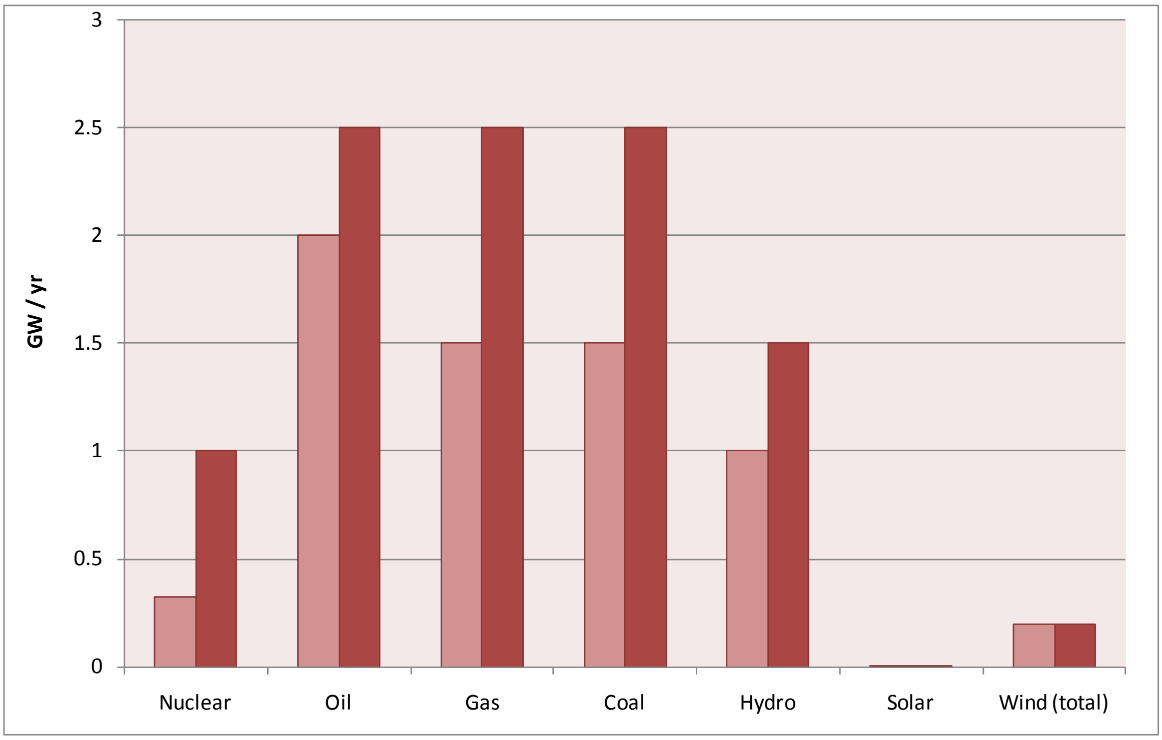


Figure 13: Build rates (GW) per year (2015/2030) by Generation Type

E. Transmission and Distribution System

The modeling of the power sector in Pak-IEM, including electricity transmission and distribution to end-use sectors, is shown in Figure 13 . Electricity generated from large-scale plants operated by PEPCO, KESC, WAPDA and IPPs, produce centralized electricity (*ELCC*). This then feeds into the transmission grid (labeled *ELCT in the model*) and then a general distribution system (becoming *ELCD*). *ELCT* and *ELCD* are subject to losses associated with the grids, and incur costs associated with maintaining and operating the network. In addition, they are subject to capacity constraints that can only be overcome by additional investment in new capacity.

Combined losses on both the transmission and distribution system were estimated to be 24% in 2006/07. Transmission losses are estimated to be 6%. Distribution losses include technical and non-technical losses (theft and non-payment), and while the split between such losses are uncertain, it is thought that non-technical losses account for over half of the distribution losses. In the Reference case, the level of these losses is held constant in future years, with no options currently modeled for reducing such losses.[31] Current grid capacity is assumed to be a function of the total installed generation capacity, with each unit of additional generation capacity incurring investment costs to build extra transmission

[31] A scenario labeled *Pol-T&D* is available to model a reduction in T&D losses over time.

capacity. Utilization of the existing system is set at 95%, whilst investment and operating costs for additional capacity above the existing stock are based on information provided in ADB (2008).

Distributed electricity (ELCD) feeds into the different sectors, and becomes <sect>*ELC*, which is prefixed by the sector abbreviation, e.g. *RSDELC* for electricity to the residential sector. Sector-specific differences in distribution of electricity can be captured at this level. Therefore, future model versions could seek to allocate non-technical losses to the sectors, if corresponding data can be provided (in which case the general distribution grid will be dropped and the losses applied to the sector grids instead). The same mechanism can be used to reflect differential electricity tariffs for different sectors.

Electricity produced by small-scale decentralized power plants (including some renewables), imports,[32] and back-up generation are labeled *ELCR* (or remote generation). They do not go through the main transmission and distribution system because they are connected in close proximity to the customers being served. Relative shares, currently under review, are used to apportion this type of generation to the different end use sectors. Figure 13 depicts the stylized RES for the power sector (excluding industry cogeneration), reflecting the energy forms, power plant types, and sector distribution nodes.

As discussed in Section III, an important option in future years may be imported electricity via a regional transmission grid.

[32] Imports from Iran are distributed onto a remote grid, which is not connected to the main transmission and distribution network in Pakistan and meets the needs of specific communities in Balochistan.

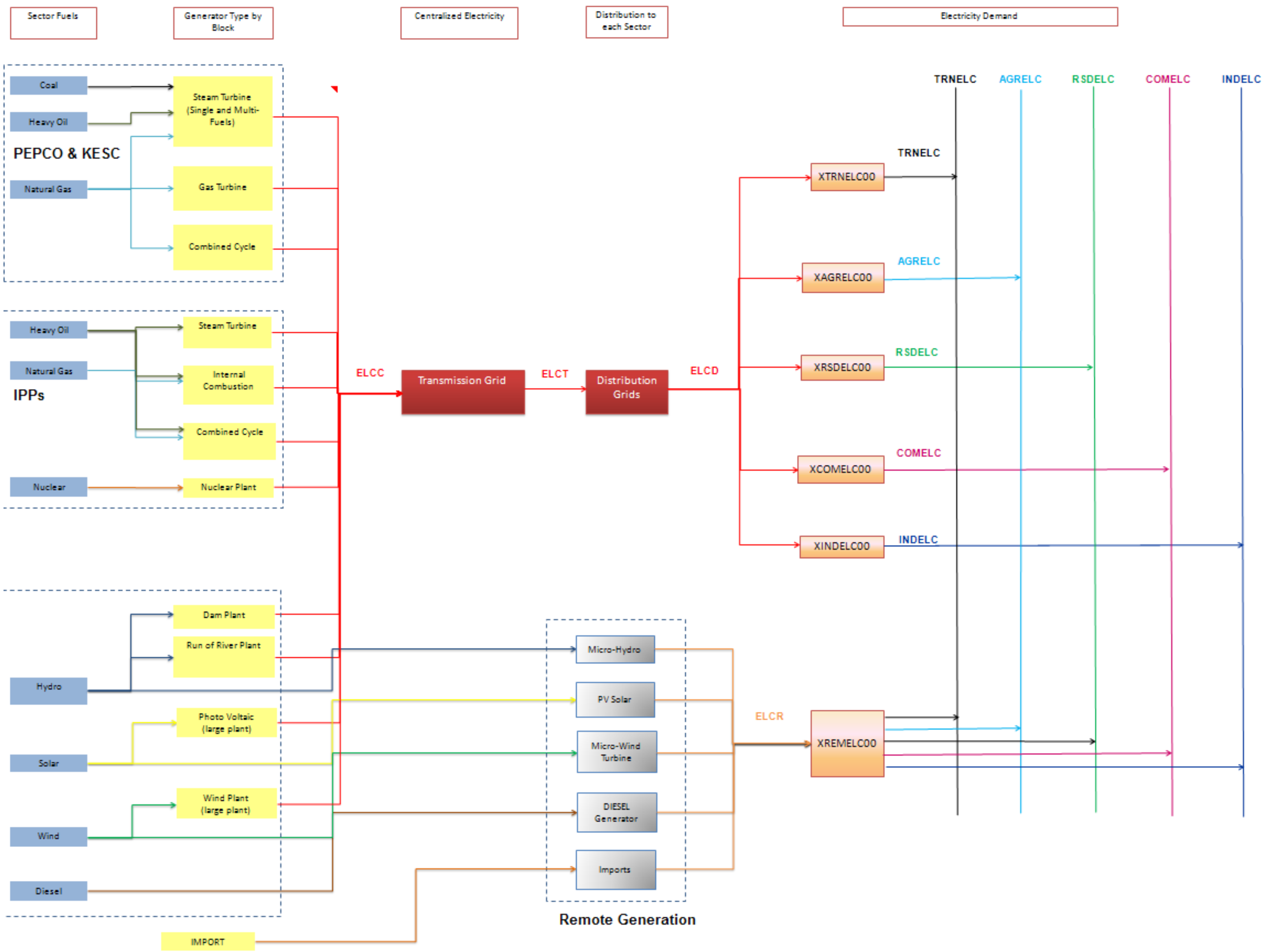


Figure 14: Distribution of Electricity from Centralized and Decentralized Power Generation and Imports

F. Load shedding

Load shedding has become a real problem over the last three years, as shown in Figure 14 below. Estimated demand far exceeded what the system provided (shown by the blue shaded area), particularly during the summer months. This has also been a significant problem for the KESC system.[33]

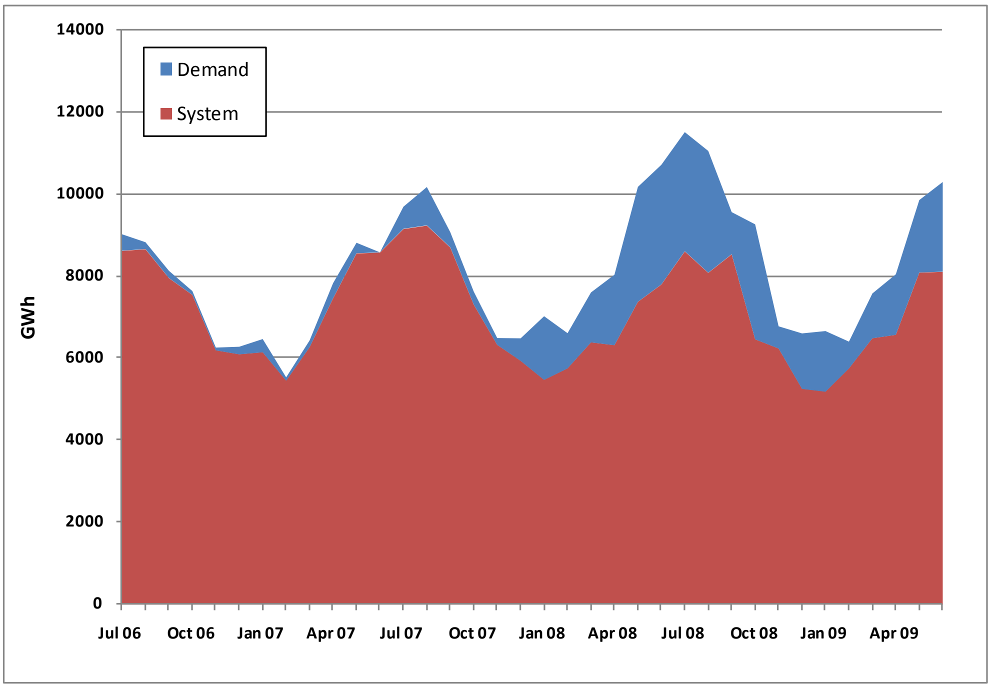


Figure 15: Load shedding on the PEPCO system, July 06-June 09

Given the significant economic problems arising from unreliable supply, it is important that this near term issue is properly modeled. The approach taken is illustrated in Figure 15.

Projection of the demand for energy services has been developed from basic drivers that factor in the recent load shedding. This is necessary so as not to bias the projections by using the current suppressed levels of consumption. Thus, the top line in Figure 15 represents the projected demand, while the blue area (to 2009) represents recent data on actual consumption. The deficit (unmet demand) between 2007-2009 is shown, identified by the white arrows.

[33] Data provided directly to modelling team by PEPCO / KESC. See file *Power Sector Load Shedding & Captive Power Data.pdf* (PEPCO) and *KESC data sheet.doc* (KESC).

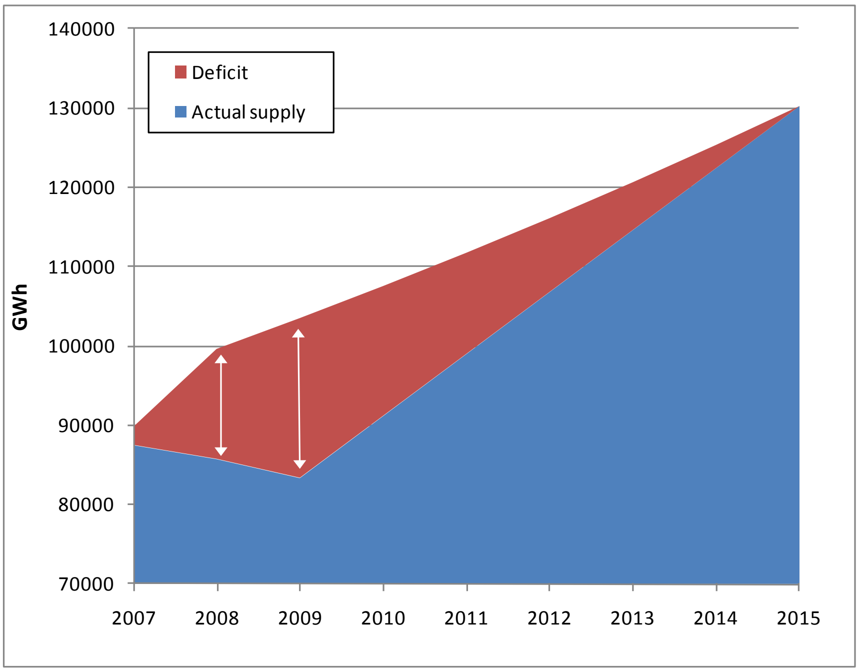


Figure 16: Pak-IEM approach to modeling load shedding

The amount of unmet demand in future years is a model input, and the analyst can control the rate at which the unmet demand must be satisfied. In the example above (which is the model Reference case), the deficit is set to be eliminated by 2015. The analyst can shorten or lengthen this period or change the rate of removal or amount of unmet demand in a period as sensitivities to the Reference case.

To ensure that the investment cost of removing the deficit in electricity supply is captured, the deficit is modeled as a "dummy" commodity, and forced into the base year demands. The commodity has to be forced using lower bounds, as the unmet demand is costed at a high level. The cost of load shedding was \$0.44 /kWh from the 1989 paper "Power Outages in the Industrial Sector of Pakistan." This has been adjusted to \$0.6 /kWh to put it on a \$2006 basis.

This commodity is shared across demand sectors based on their share of electricity consumption in the base year. As this commodity is removed (i.e. the problem starts to be addressed), the system has to respond to fill the energy gap, therefore requiring investment either in new generation capacity or other energy types that could meet the energy service demands.

G. Summary of Main Power Sector Data Sources

Table 21 lists the main data sources for the power sector.

Table 21: Summary of Data Sources for the Power Sector

Data Type	Data Source	Notes and Comments
Thermal / nuclear plant		
Public plant – PEPCO	See Table 15	
Public plant – KESC	See Table 17	
Private operated plant – IPPs	See Table 16	
Hydropower plant		
Plant characterization	See Table 18	

Data Type	Data Source	Notes and Comments
Non-hydro renewable generation		
Capacity and generation	Pakistan Energy Year Book 2007 (HDIP 2008)	Resource information for future years sourced from AEDB website
Transmission and distribution		
Losses	Pakistan Energy Year Book 2007 (HDIP 2008)	
Capacity	Based upon current installed power plant capacity	
Operating / investment costs	Data from ADB (2008)	
Load shedding	Data provided directly by PEPCO / KESC	See file *Power Sector Load Shedding & Captive Power Data.pdf* (PEPCO) and *KESC data sheet.doc* (KESC)
Future options		
Planned new build	List of future generation projects provided directly by PEPCO / KESC	See file *Response to Remaining Power Sector Issues 3-2-10.pdf* (PEPCO) and *KESC data sheet.doc* (KESC)
New technology options	Based on review of number of international sources, and Pakistan specific data	International data sources included IEA (2005b), AEO (2010), ETSAP information and data from European NEEDS model[34]

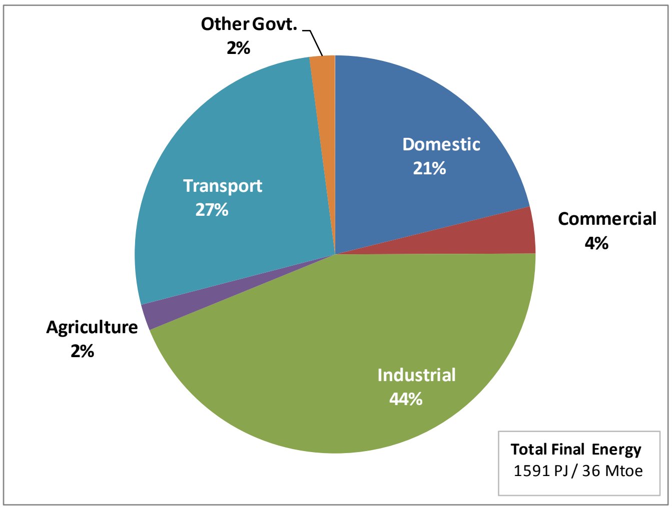
Some of the above sources were not publicly available, and were provided directly to the project team for use in Pak-IEM. A full listing of these files, and the data providers, is provided in Appendix 3. The EW holds all of these data files referred to.

[34] ETSAP (Energy Technology Systems Analysis Program) information can be found at ETSAP website – http://www.etsap.org/index.asp

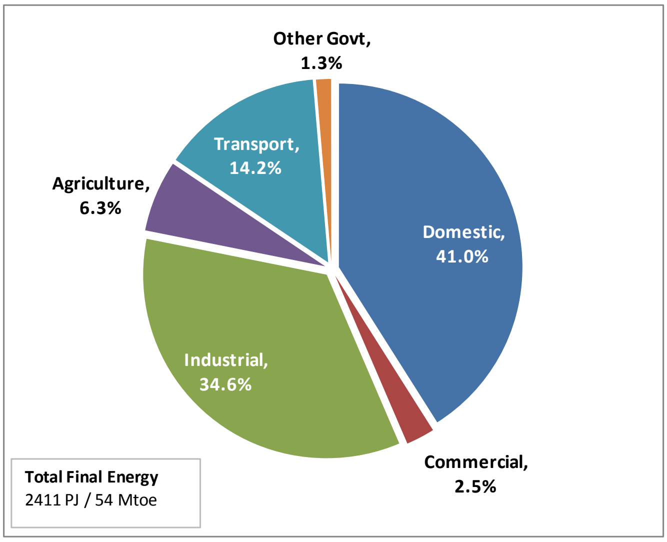
VI. DEMAND SECTORS

Demand sectors characterize the consumption of energy services across the economy, for example, for the provision of cooling and heating, transportation, and industrial production. In Pak-IEM there are five demand sectors – agriculture, commercial, industry, residential, and transportation. Demand sector energy consumption in Pakistan in 2006/07 is in the main based on estimates from the Energy Year Book (HDIP 2008). However, there are some significant differences between Energy Year Book sector estimates and those used in the model, due to the inclusion of biomass in residential and industry sectors, adjustments for black market diesel, and the re-allocation of diesel from transport to the agriculture sector.

The proportion of energy use across the different demand sectors, as presented in the Energy Yearbook, is shown in Figure 16(a), while the Figure 16(b) shows the allocation in Pak-IEM.



(a) Energy Yearbook sector shares



(b) Pak-IEM sector shares[35]

Figure 17: Final Energy Consumption by Sector, 2006-07

[35] Total energy in Pak-IEM is higher due to inclusion of estimates of biomass use in industry and black market diesel.

In total, as shown in Figure 17, final energy is 50% higher than that observed in the Energy Year Book. This is primarily due to inclusion of biomass in the residential (+650 PJ) and industry sectors (+75 PJ wood and 50 PJ bagasse) plus an increase of 10% of diesel (HSD) consumption due to black market sales.

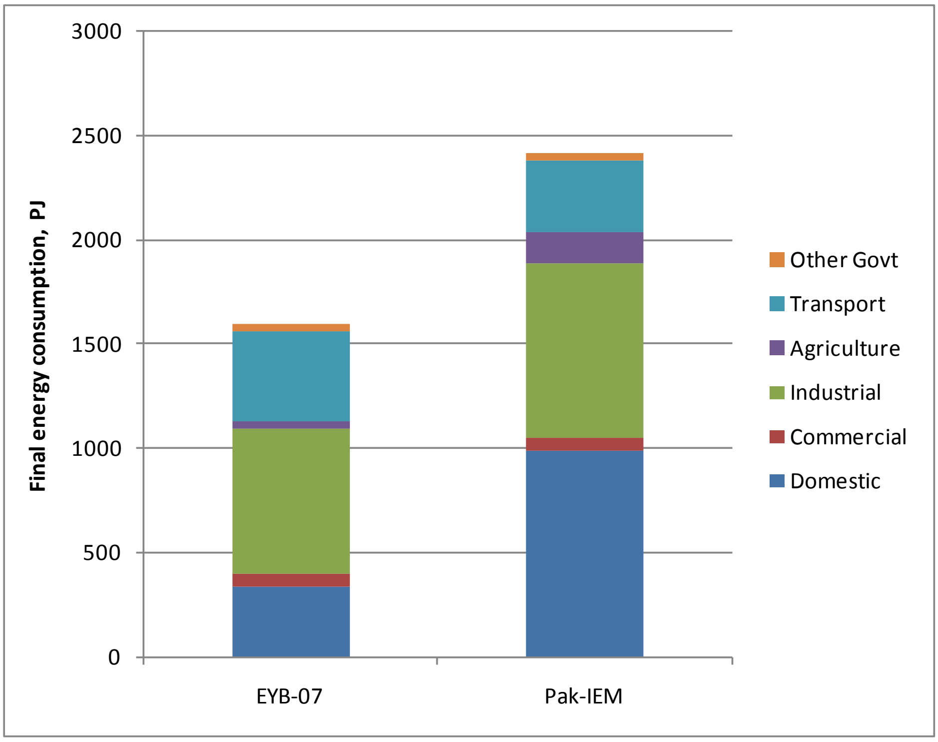


Figure 18: Comparison of Final Energy Consumption estimates between Energy Year Book 2007 / Pak-IEM

A. Modeling approaches

The sector final energy consumption values from the Energy Yearbook provide the basis for calibration of the model's start year. However, this sector-level energy consumption data has to be developed for the individual sub-sectors, and perhaps sub-groups, according to the nature of the different energy service activities performed within each demand sector, such as pumping and plowing (agriculture), lighting and space conditioning (commercial and residential), process heat and machine drive (industry), and passenger and freight transport (transportation). These energy services need to be developed as sub-sector demands, as each serves a unique (non-substitutable) demand and requires a different set of technologies (end-use devices) to provide those services.

It is important to distinguish that MARKAL/TIMES, unlike many other models, uses the concept of energy service demand, not final energy demand. This enables the model to evaluate fuel mix and device choices reflecting industry and consumer choices for meeting future service level. These energy service demands can be specified in whatever units are convenient (e.g., vehicle-miles traveled for transportation, lumens for lighting, BTUs for space cooling, etc.). In these cases, the end-use devices must be defined in terms that convert final energy carriers into these energy service units.

There are two general approaches used to develop the sub-sector level breakout for each of the demand sectors: top-down decomposition and bottom-up aggregation. Both approaches involve a number of steps, which are illustrated in Figure 18. The approach chosen for a particular demand sector depends on the data availability, and is discussed under each sector.

For most sectors, a top-down decomposition approach is necessary because the existing stock of end-use devices and the amount of fuel each consumes is not known. In this approach, decomposition shares are applied to the sector energy consumption totals to determine sub-sector totals for each fuel type, which are then further broken down into the individual end-use services, perhaps with some intermediate splits as well (e.g., residential into rural/urban, particular industries).

These shares are a straightforward mechanism employed to disaggregate the sector level fuel use to each sub-sector demand, though they often need to be determined by surveying or expert judgment. Data on sub-sector final energy consumption can be estimated from basic data such as number of households and final energy consumption per household. This data may also be estimated from general information on energy consumption patterns (e.g., per capita consumption) in similar countries in the absence of country-specific data.

For other sectors, shares are estimated using a bottom-up approach, based on technology stock and use/performance information to aggregate up to the sector energy consumption values. In this case the device details are aggregated and crosschecked against the sector energy balance. For Pak-IEM, the bottom-up approach has been employed for agriculture and transportation sectors.

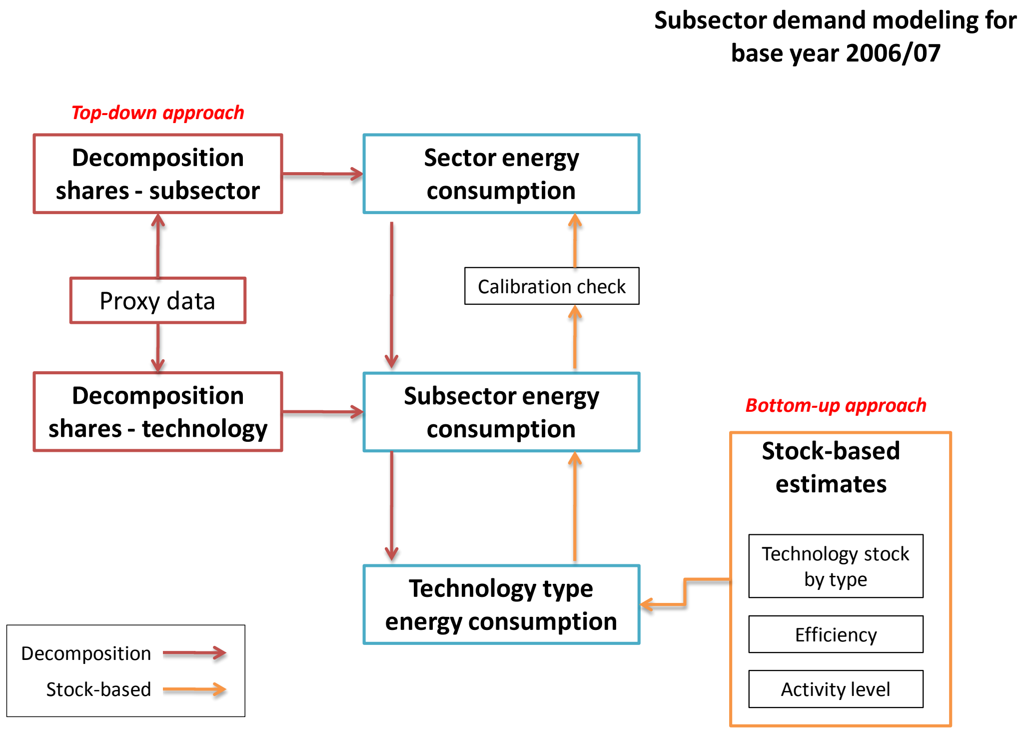


Figure 19: Bottom-up and Top-down Approaches for Demand Sector Modeling

For each demand sector the number of sub-sectors is based on the need to adequately model the energy system at the appropriate level of detail, when supported by data. An example of possible sub-sector detail might be commercial building types (which can be classified according to purpose (e.g., government, hospital, school, hotel, restaurant, and other commercial services) or size (e.g., large, small), or residential location (e.g., urban or rural) or household income class (e.g., low, medium, high). These additional breakdowns are important to consider and represent when the energy use patterns and/or policies to be examined warrant separation into these finer groupings. The goal is not simply to add detail, but rather to develop the level of detail that is supported by the available data and appropriate for the intended uses of the model. At the current time the commercial sectors are being modeled only at the aggregate sector level and residential simply split between urban/rural, with appropriate demand services (e.g., cooling/heating, lighting, refrigeration, cooking) until a more solid understanding of a finer breakdown is supported by the data, or developed by means of surveying. In particular, investigation is underway looking to further breaking down the residential sector according to income class, as the nature and expected growth of the demand for energy (and devices deployed) varies substantively according to income level.

For each of the demand services, information on the *demand timing* is required to properly distinguish the time-of-use of the demand for commodities such as electricity. The demand timing splits determine the amount of each demand service that must be satisfied in each season and time-of-day time-slice. In order to properly represent these patterns, data on daily and seasonal electricity consumption (and seasonally for gas) by end-use category is needed or needs to be derived / estimated. In particular, utility load curves by sector and by sub-sector would be ideal. Data on the effects of climate on daily and seasonal demands can be useful (that is, degree day information for the calibration and typical year). Data on industrial practices (e.g., shifts per day, seasonal activities) on daily or annual demands for electricity is also useful. However, to date only limited information on these fronts has been secured, and thus consideration needs to be given to surveying, particularly in the residential sector.

For certain sub-sectors where the demand is uniform throughout the year, which is often the case for industrial facilities that have continuous production, it is assumed that the demand follows the overall fractional split for season and time-of-day. However, if a demand typically does not follow those splits (e.g., residential lighting is mostly at night, residential and commercial space cooling mainly in the summer), then demand service timing splits need to be specified. An approach has been set up by the modeling team that allows for the calibration of demand fraction shares to accurately represent the daily and seasonal load curves in the model, as was discussed in Section II.C.

End-use technologies to meet the demands for energy services need to be fully characterized. Table 22 lists the main parameters that are needed for each device. These are considered in greater detail in each of the sector-specific sections.

Table 22: Technical Parameters for Characterization of End-Use Technologies

Characteristic	Unit	Comment
Technology Name		
Input Energy carrier		
Capacity	PJ/a	
Remaining life (existing)	Years	TIMES can also use the start year for existing devices
Lifetime (new)	Years	New devices
Efficiency	OUT/IN	
Investment cost	$M/PJa	New devices only
Fixed O&M Cost	$M/PJ	
Variable O&M Cost	$M/PJa	
Utilization factor	Annual	
Input share	Fraction	For duel-fuelled technologies
Output share	Fraction	For technologies providing more than one energy service e.g., heat pump providing heating and cooling, car doing short/long-distance driving

B. Agricultural Sector

Agriculture is one of the largest sectors of the economy in Pakistan, contributing 21.8% of GDP, and an even larger share of employment, providing an income for 44.7% of the total labor force (Pakistan Economic Survey 2008-09, GoP 2009). Due to the size of the sector, energy use is significant (over 6% of final energy consumed), even if agricultural production is relatively non-energy intensive. The main demands for energy include:

- Water pumping for irrigation
- Motive power provided by tractors and self-propelled field machinery for tilling, cultivating, and harvesting
- Tractor-based transport of goods

The model depicts the above demand services, plus a general "other" energy use category, primarily to capture unallocated electricity use (e.g., lighting, heating and cooling for storage buildings, etc.).

Energy use in agriculture

The sectoral energy use in the base year (2006/07) totals 34 PJ (based on EYB 2007), excluding any high speed diesel use, which is included in the Energy Yearbook transport sector estimates. Bottom-up estimates for Pak-IEM, based on technology stock data (ACO 2005), put agricultural HSD use at approximately 118 PJ, significantly increasing the energy consumption attributed to the agriculture sector (from 2% to over 6% of final energy).

Agriculture sector calibration approach

A bottom-up approach has been used to estimate energy use across the different agriculture sub-sectors, based on stock data of agricultural machinery, and typical annual usage. The basic approach is shown in Figure 19.

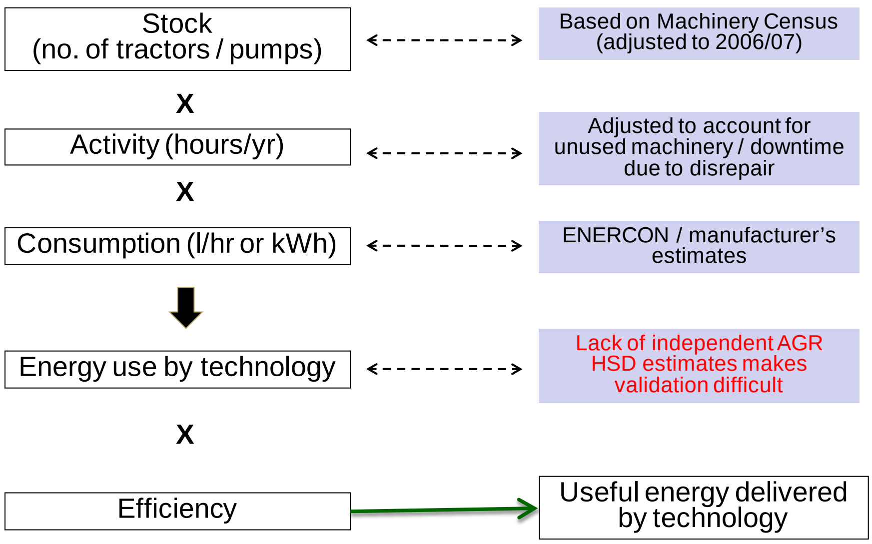


Figure 20: Approach to Bottom-up Estimation of Agriculture Sector Energy Use

The resulting estimates have been cross-checked against the Energy Balance values to ensure base year calibration. This calibration process has been undertaken in conjunction with the transportation sector, because the HSD used in agriculture is allocated to that sector in the Energy Yearbook. Useful demand estimates are then developed based on typical efficiencies and annual use of technologies.

The structure of the agriculture sector in Pak-IEM is shown in Figure 20, illustrating the use of fuels by different device types for the provision of agriculture energy services.

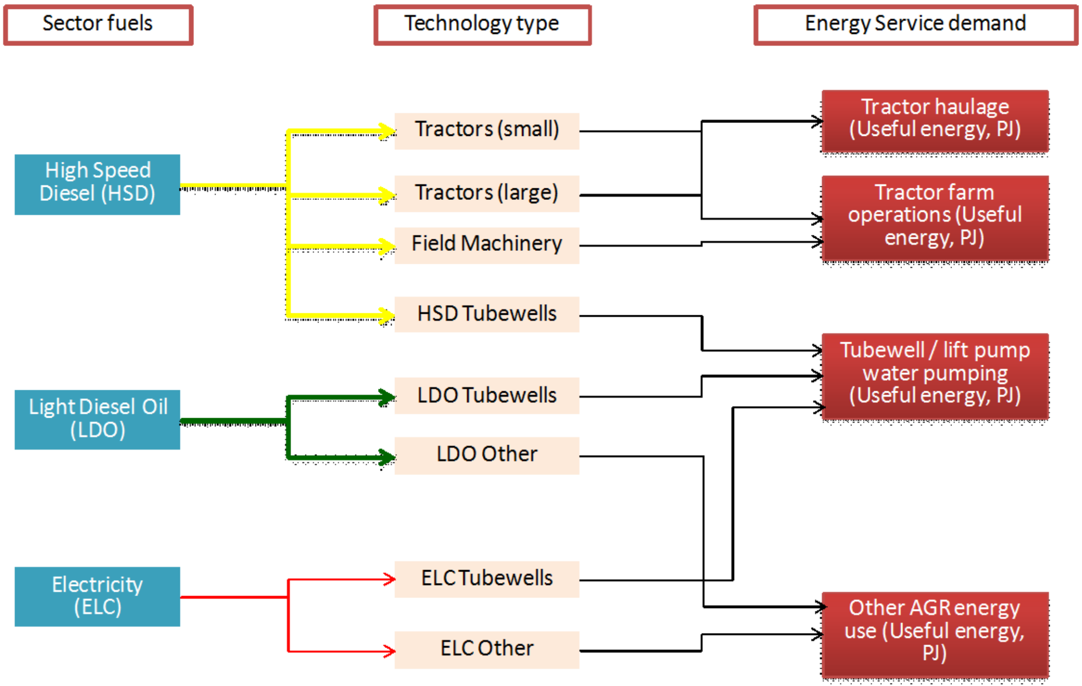


Figure 21: Agriculture Sector RES Diagram[36]

Sector technology characterization

The structure for this sector requires the following types of data:

- Technology stock data – tractors / irrigation pumps / other self propelled field machinery
- Stock activity levels / fuel consumption
- Characterization of existing end-use technologies

Technology stock data and utilization rates are presented in Table 23 and are sourced from the 2004 Machinery Census (ACO 2005). Fuel consumption in tractors is taken from ENERCON (1988), and has been validated based on personal communication with an industry expert.[37] Tubewell water pump consumption is based on Qureshi et al (2003), Bom and van Steenbergen (1997), and TERI (2006). Again, this information has been validated by industry experts.

[36] Based on discussions with experts at NARC, the use of tractors for water pumping has not been included. It is considered an old practice that is no longer common since the introduction of high-speed diesel pump sets.

[37] Personal Communication with sector expert, dated 08.03.09 (See file *Independent Expert TRACTORS 30-03-09.pdf*)

Table 23: Stock and Operating Assumptions for Agricultural Machinery

End-use technology type	Stock (000s)[1]	Hourly fuel consumption (l/hr)	Utilization
Small-medium tractors (<55 HP)	384	4.7	12%
Large tractors (>55 HP)	83	5.7	12%
Combines	5	10	8%
Tubewells / Lift pumps (using HSD)	668	2.4	6%
Tubewells / Lift pumps (using Light Diesel Oil)	165	1.5	6%
Tubewells / Lift pumps (using electricity)	97		11%

[1] Adjusted to 2006/07 basis

Tractor estimates have been validated by industry sales figures, and stock estimates. These have been used to make the adjustment of stock to a 2006/07 basis.[38] NTRC (2008) has also published "On the Road" estimates for tractors, which have not been used. They estimate around 878,000 tractors, which is significantly higher than the other sources of information used. NTRC are aware of these differences, and agree that Machinery Census estimates are the best to use.

Base year stock of combines was provided by experts at one of the August 2009 stakeholder meetings.[39]

Characterization of new technologies is based on the following sources:

- USAID[40] project to install energy efficient tubewells in South Punjab, cross checked against estimates in TERI (2006)
- Tractor investment costs provided by NARC[41]

Another important assumption for this sector is timing of demand for energy services that use electricity. Electricity consumption in this sector is primarily for tubewell operations, the timing of which is based on the overall seasonal pattern of consumption, as provided by PEPCO, and expert judgment in regard to the daily profile. The shares allocated to each season and day time slice are shown in Table 24.

Table 24: Season / Day Demand Shares for Agriculture Sector Electricity

Season	Season share	Day / Night	Day share*
Summer (S)	0.47	Day (D)	0.10
Intermediate (I)	0.25	Shoulder (S)	0.19
Winter (W)	0.28	Peak (P)	0.0
		Night (N)	0.71

* Day / Night shares are assumed to remain the same across all seasons

[38] Personal Communication with sector expert, dated 08.03.09 (See file *Independent Expert TRACTORS 30-03-09.pdf*).

[39] Data provided at Sector Task Force meeting in August 2009 (See notes from meeting in *Agricultural & Transport_subgroup_Summary_v03.doc*).

[40] USAID Energy Efficiency & Capacity Project, Islamabad, Pakistan.

[41] See file labeled *NARC Correspondance_Tractor&StoveCosts.doc.*

These shares can be used to calculate demand fractions for every time slice period. The summer night is the period when most electricity for pumping is required (35% of the annual total), as this is the hottest season and the time of day when water tends to be pumped.

Summary of agriculture data sources

Table 25 provides a summary of the key data sources being used in the agriculture sector.

Table 25: Summary of Data Sources for the Agriculture Sector

Data Type	Data Source	Notes and Comments
Stock data	Pakistan Machinery Census 2004 (ACO 2005)	Tractor stock validated by independent sector expert
Activity levels / utilization	Pakistan Machinery Census 2004 (ACO 2005)	
Fuel consumption	ENERCON (1988) NARC (Personal Communication) Pakistan Journal of Water Resources (2003) Energy for Sustainable Development (1997) Applied Engineering in Agriculture (1993) TERI (2006)	for tractors (validated by independent sector expert) for irrigation pumps (validated by independent sector expert)
Efficiency	ENERCON (1988)	
Time slice demand shares	PEPCO seasonal electricity consumption data	Expert judgement for day / night shares
Characterization of future technology options	NARC; National Energy Map for India (TERI 2006); USAID tubewell project	

C. Industry Sector

Energy use in industry

Industrial manufacturing constitutes the second largest sector in Pakistan’s economy, contributing around 18% to national GDP (GoP 2009). It is also the largest consumer of commercial energy, and accounted for 35% of final energy consumed in 2006/07.

Natural gas accounts for almost half of all energy consumed, while coal consumption accounts for approximately 25% (Figure 21). Cement and brick-making industries are the largest consumers of coal. The consumption values below include energy used for captive generation, which is not identified separately in the energy balance.

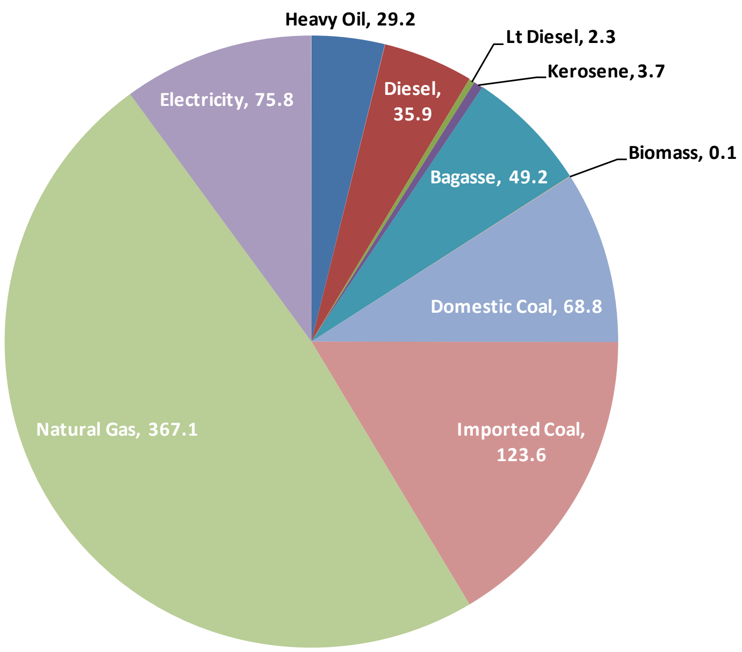


Figure 22: Industrial Sector Energy Consumption (PJ), 2006/07 (HDIP 2008)

The share of natural gas consumption across selected industries is shown in Figure 22. The textiles sector is by far the largest individual consumer, followed by iron and steel and fertilizer industries.

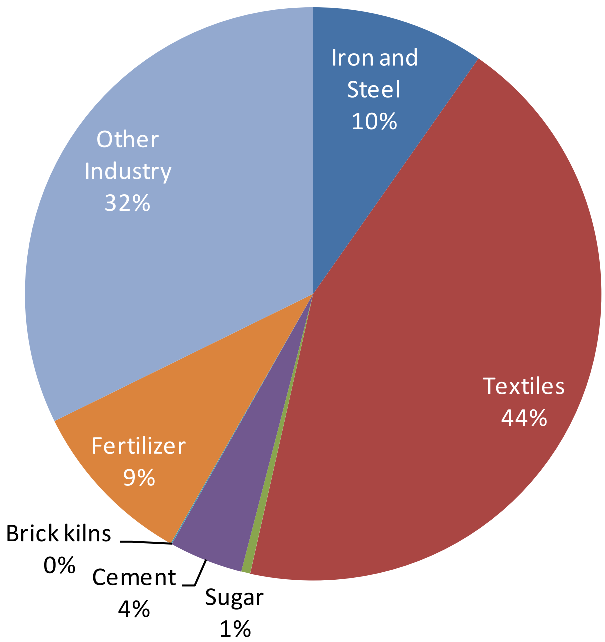


Figure 23: Industrial Sector Natural Gas Consumption (% PJ), 2006/07 (Source: SNGPL / SSGC)[42]

[42] Data from SSGC and SNGPL was provided directly for use in the project. The relevant files, listed in Appendix 3, are *Categ-det_Jul'06-Jun'07.xls* (SSGC) and *SNGPL Consumer Data 2007 and 2008.xls* (SNGPL).

Identification of the main industrial energy consumers provides a basis for deciding which sub-sectors to model individually, and thereby with process-step level detail. On this basis, the following industry sub-sectors were agreed for inclusion in Pak-IEM:

- Textiles
- Sugar
- Iron and Steel
- Cement
- Fertilizer
- Brick-making[43]

Other factors in determining the above sub-sector categories include availability of:

- Output statistics to relate energy use and production
- Sectoral future growth information
- Data to understand industrial processes within each sub-sector

All remaining sub-sectors are included in an "Other Industry" category, which accounts for the largest share of final energy consumption, at 34%. A review was undertaken of the paper and pulp, and glass industries but based on their aggregate energy consumption, it was decided not to model them as separate sub-sectors.

Approach to industry sector modeling

Figure 23 illustrates the basic approach to industrial sector modeling. Overall industrial energy consumption can be determined from the energy balance, while sub-sector consumption is estimated based on a range of sources, including data from the gas and electricity distribution companies (Table 26).

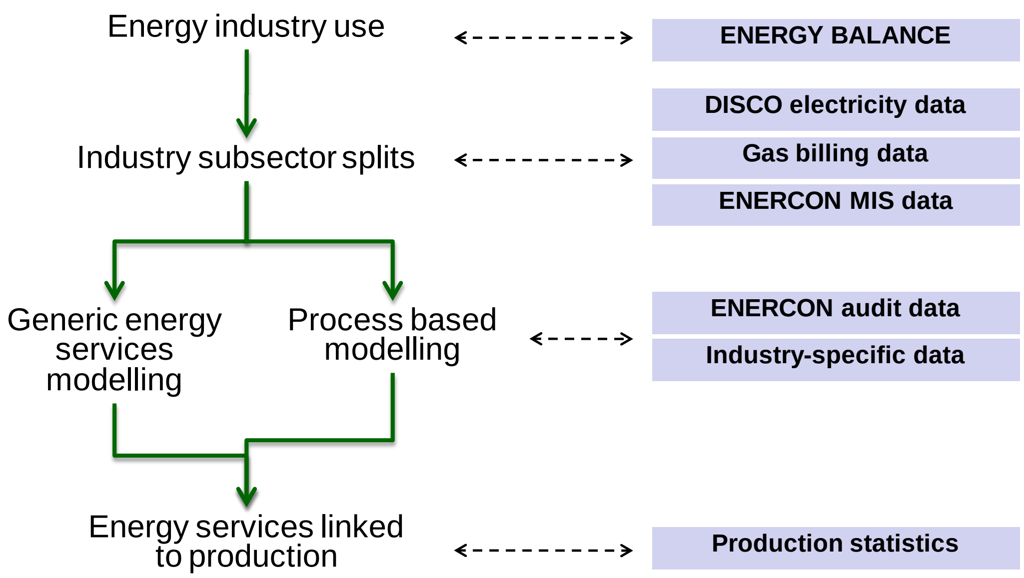


Figure 24: General Approach to Industry Sector Modeling

[43] Brick-making is modelled very simply, and as a separate sub-sector to track coal consumption.

Table 26: Sources of Data for Estimating Sub-sector Energy Consumption

Fuel type	Source / comments
Electricity (public supply)	PEPCO administered DISCOs / KESCO. Billing data available by sub-sector. Also provides seasonal load profile
Electricity (self-generation)	New survey: Sectors / equipment manufacturers surveyed by MEC, to assess installed capacity in-country UDI: Estimates based on capacity (UDI database), typical use patterns and efficiencies. Year of installation also from UDI Census of Electricity Establishments (CEE) 2005-06
Natural gas	Gas distribution companies. Billing data from SSGC and SGNPL
Heavy oil	ENERCON MIS. Based on plant-specific data from ENERCON database
HSD	ENERCON MIS. Based on plant-specific data from ENERCON database
Coal	Pakistan Energy Yearbook 07. Disaggregated in the Energy Balance
Bagasse	Pakistan Sugar Mills Association, ENERCON MIS

Once sub-sector energy consumption has been estimated, there is a need to know more specifically how energy is used to provide services and in different industrial process steps. There are two approaches that can be taken.

- Generic energy service modeling – Energy use is allocated to broad energy services (e.g., motive power and process heat) that are required in the manufacture of products.
- Process based modeling – A more detailed approach that requires good process-specific data. Individual technologies within the manufacturing process are characterized in terms of their efficiencies (unit output / unit inputs) and operating costs. For example, instead of generic technologies providing process heat in the iron and steel sector, specific process steps involving different technologies (e.g., blast furnace, re-heating, induction) are individually specified.

The Pak-IEM model uses a combination of the approaches, depending on the sub-sector and data availability. Finally, the energy services are linked to production; for every unit of production (e.g. tonne of sugar), “x” petajoules of energy services (e.g. process heat) will be required.

Approach to sub-sector modeling – Iron and Steel

The iron and steel sector in Pak-IEM is split into two sub-sectors – private sector independent producers who produce steel through melting and steel products in rolling mills, and the part public-owned large integrated steel works near Karachi, Pakistan Steel.

In the independent sector, steel melting is carried out using induction furnaces (approx. 140 plants) to produce ingots / billets for production of steel-based products. The main technology to produce required process heat is induction furnaces (with limited use of electric arc furnaces in Pakistan) using electricity. There is limited self-generation in this sector.[44] Another important independent sector is steel re-rolling. The main technology to produce required process heat is a re-heating furnace using fuel oil / natural gas.

Two key sources have been used to characterize the sector in the base year. The first is a presentation by Magna Steel whilst the second is data provided directly by Pakistan Steel Rolling Mills Association (PSRMA).[45]

Table 27: Key Data Assumptions for Steel Melting and Re-rolling Sectors

Sector	Steel Melting	Steel Re-rolling
Registered Units	140	200
Total Units	350-400	300-500
Base Year Production (Mt)	2.4	4
Electricity consumption (kWh)/ tonne output	800	130
Gas consumption (m3 gas) / tonne output		100

The structure of the independent **steel** sector in the model is shown below in Figure 24. There are two key technologies in the sub-sector – induction and re-heating furnaces. A third technology generically represents "other" energy consumption in unregistered units. Captive generation levels are considered to be extremely low in this sector, and therefore not modeled.

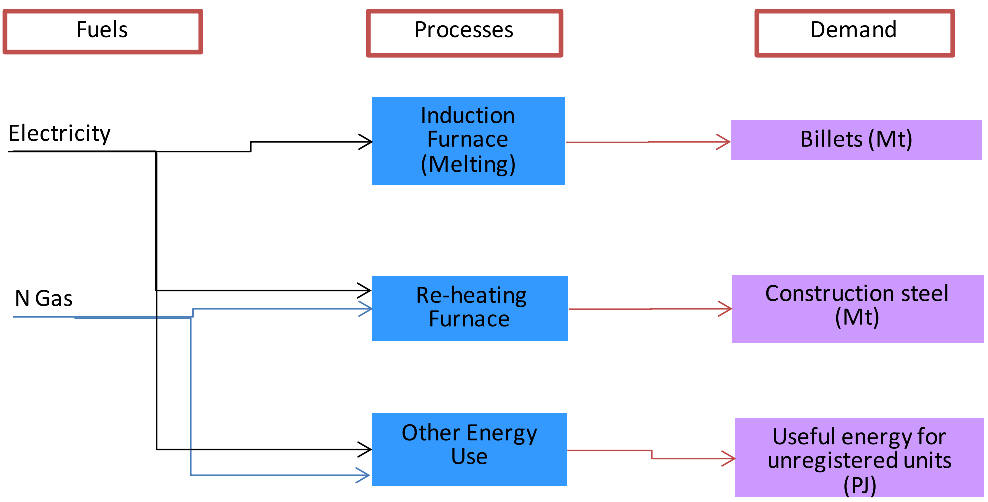


Figure 25: Reference Energy System – Iron and Steel (Independent Operators)

New technology options include new plant or energy efficiency opportunities across existing units. Energy efficiency potential is taken from recent analysis by Hagler Bailly (ADB 2009b). It is modeled through the use of a retrofit measure to ensure that only existing stock is included.[46]

[44] Pakistan Steel Melters Association website – http://steelmelters.com/

[45] Data sourced from files *Steel Sector Presentation Final on 10-8-09.ppt* (from Magna Steel) and *Pakistan Steel re-Rolling Mills Association.pdf* (see Appendix 3).

[46] Retrofit measures require the use of sophisticated user constraints, which can be found in model scenario file *Scen_REF-DMD.xls*.

The other sub-sector is the large integrated works Pakistan Steel Mill. It produces a range of iron and steel products through an integrated process, as illustrated in the RES diagram below.[47] Some aspects of the process have been simplified; for example, cold and hot rolling of products, and galvanizing are grouped into “Other” processes.

As discussed, this detailed process-based modeling requires detailed data, at the minimum production and energy consumption at each of the process stages, with associated operating costs. These data have been provided by Pakistan Steel,[48] and provide the basis for detailed modeling (see Figure 25 below).

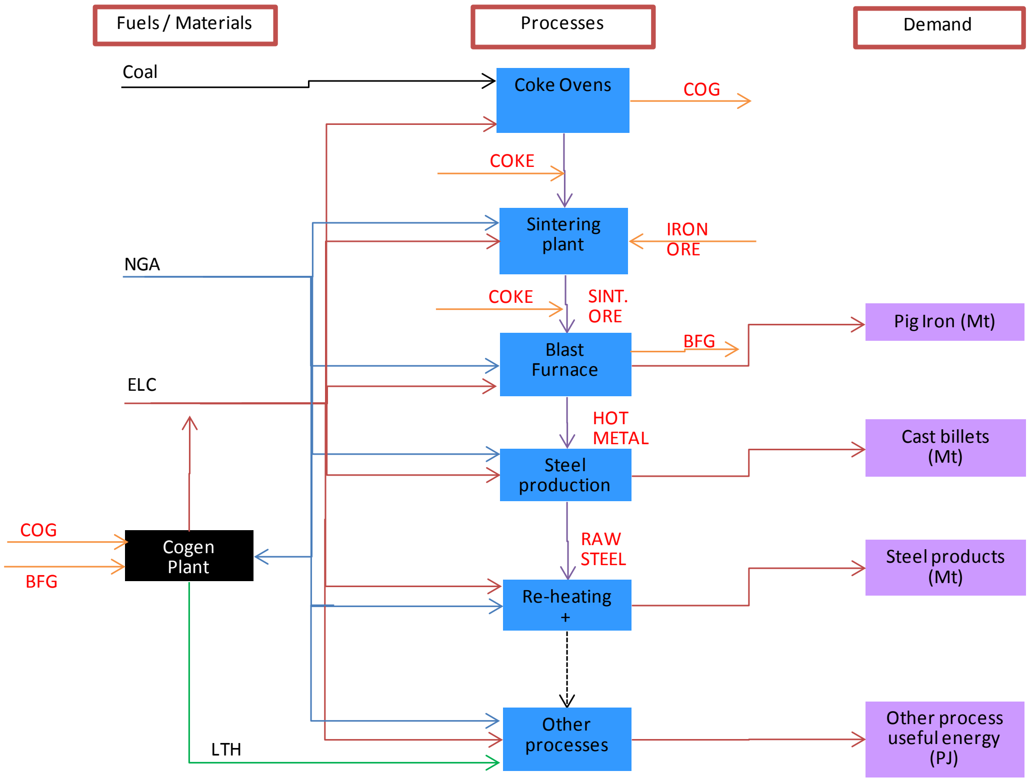


Figure 26: Reference Energy System – Iron and Steel (Pakistan Steel)

While the base year characterization is known, understanding what technical options can be considered in future years is more difficult, as such options should be site-specific. As Pak-IEM is further developed, it will be important to revisit this issue with the company, to better understand energy efficiency potential. Default new technology options have been included in the model for blast furnace (ETSAP technology factsheet[49]) and basic oxygen furnaces (TERI 2006), with other process steps costed relative to these core processes. However, in reality, it is likely that the plant will retrofit rather than re-built over time; therefore, further discussion with the industry is important.

Specific data for the above plant have not been published here to ensure confidentiality for this operator.

[47] Details of the integrated plant processes can be found on the Pakistan Steel website – www.paksteel.com.pk/

[48] Production and fuel consumption data provided in file *Pak Steel Data 12-2-2010.pdf*

[49] This can be found at ETSAP website - http://www.etsap.org/index.asp

Approach to sub-sector modeling – Textiles

The textile sector is one of the largest energy-using sectors in Pakistan, accounting for over 20% of industry final energy consumption. It is also a sector of significant economic importance, with Pakistan the fourth largest producer of cotton. In 2006-07, it accounted for over 60% of total exports ($6.6 billion), 46% of manufacturing output, and 38% of employment in the economy (GoP 2008).

The sub-sector can be divided into spinning, weaving, and finishing. Dyeing and printing, which are large energy users within finishing, could also be separated out. However, this would be heavily reliant on data availability. Spinning and weaving are large users of electricity primarily for motive power as well as for heating and ventilation.

There is a large non-mill textile sector in Pakistan; it has been decided that both this sector and the mill sector will be included in Pak-IEM because their respective energy use cannot be distinguished. No distinction has been made between mills undertaking specific processes and integrated mills.

The structure of the current sub-sector, shown in Figure 26, is generic, with general sub-sector energy services modeled rather than specific processes. Most of the assumptions concerning how much energy is used for production of yarn versus cloth, and at what efficiency, is based on expert judgment primarily from MEC. Detailed data was not sufficiently sourced during the project to allow for more detailed modeling, and this remains a priority for future development.

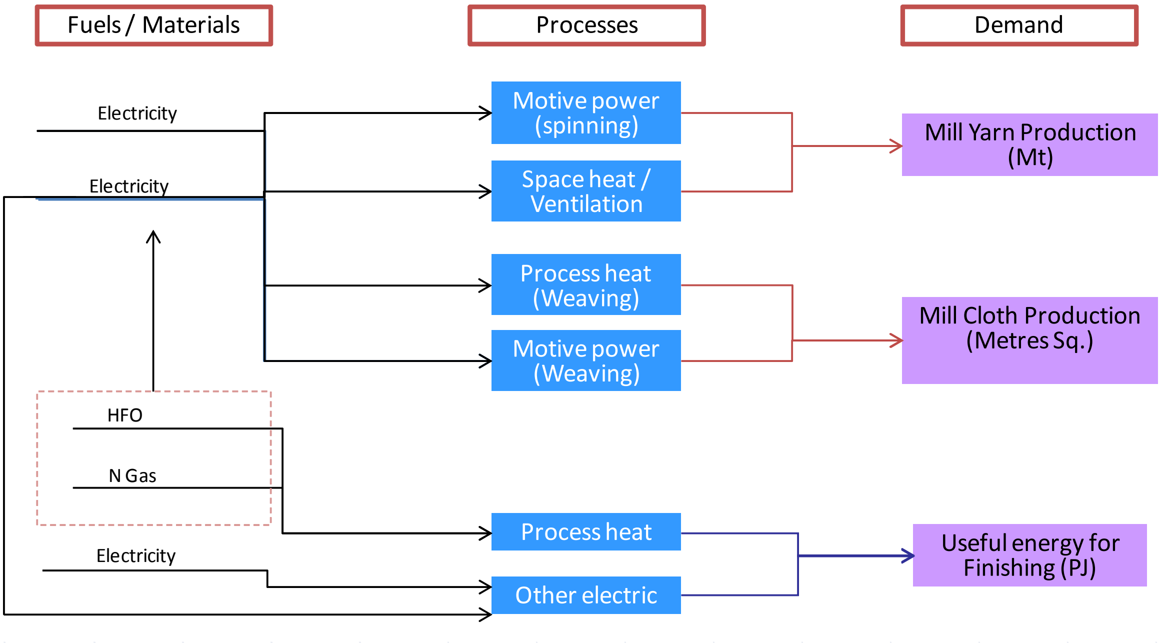


Figure 27: Reference Energy System – Textiles

Estimates of captive generation capacity are sourced from a survey of distributors under this study (for gas) and from the Platts UDI database (for oil-based generation). These sources are described in more detail in the later section. The capacity for the textile sector is estimated to be significant, at about 1.8 GW, the majority being gas.

Retrofit options are available from the recent Hagler Bailly energy efficiency analysis for ADB (2009b). These options retrofit existing stock, and allow for modeling of energy efficiency improvement. New technology options are less well characterized but take account of the relative cost of retrofit options.

Approach to sub-sector modeling – Cement

Pakistan currently has 29 cement plants with a combined production capacity of 37 million tons of cement, mainly Portland cement. In 2006/07, 22.8 million tons were produced. Due to their excess capacity, cement companies are exporting to Middle East, Africa, Afghanistan, and India. In the first nine months of FY08, exports increased by 114% to 5.1 million tons (expected to be 6.6 million tons for the full year) (GoP 2008).

Energy consumption in the cement sector is dominated by coal use in rotary kilns for clinker production. Most plants use a dry rather than wet process, a distinction which is important for understanding energy needs per unit of production.

The structure of the sector in Pak-IEM is relatively simple, and would probably be classed as generic energy services modeling, with no specific characterization of the different production processes – raw material preparation, clinker production, and cement grinding.

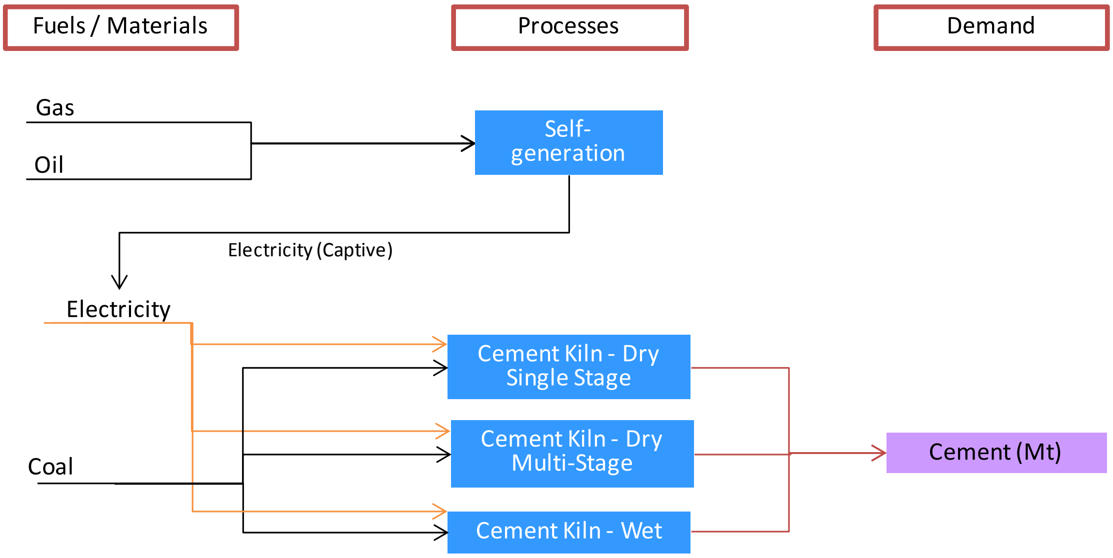


Figure 28: Reference Energy System – Cement

As shown in the above RES diagram, there are four main technologies; sector-based (captive) generation and three types of cement production – wet, dry single stage and dry multi-stage. Coal is the primary fuel used in the cement kilns; electricity constitutes a much smaller proportion of energy consumption in this sector. The production levels and coal consumption shown in Table 28 are from ADB (2009b), and provide the basis for splitting production and fuel consumption in the base year.

Table 28: Cement sector production and coal consumption, Million tonnes

Kiln Type	Production (Mt of cement)	Coal Use (Mt)	Coal use per t of cement (t)
Wet	4.08	1.26	0.309
Dry Single	5.18	1.37	0.264
Dry Multi	16.61	3.08	0.185

There are three new technology options in the cement sector.

- Two retrofit options, upgrade of wet process cement plants and dry single process cement plants to dry multi-stage. Data are sourced from the recent Hagler Bailly energy efficiency analysis for ADB (2009b).
- New build option, to install dry multi-stage plant, based on data from TERI (2006).

A significant amount of the electricity used in the cement sector is generated from captive generation. It has been estimated at around 300 MW based on fuel consumption (close to the aggregate capacity level from the UDI database of 270 MW). Some uncertainty surrounds the estimate of gas plant capacity, which is much higher than the MEC or UDI estimate). This is driven by the natural gas value for the cement sector from the Energy Year Book which is allocated entirely to electricity generation in the sector.

Three new technology options exist for captive generation. These include:

- Gas generation plant
- Oil generation plant
- Generation plant using waste heat recovered from cement kilns, and providing the opportunity for sale of electricity to the grid. [The data for the characterization of this plant is from a NEPRA determination document, for a particular plant considering this option.]

For captive generation new technology assumptions, see the relevant section below.

Approach to sub-sector modeling – Sugar

Sugar production energy requirements are largely met by the use of bagasse in cogeneration plants to produce electricity and steam. Steam drives much of the plant machinery, including some of the motive power requirements. The production is seasonal, occurring only during the summer cane harvesting period. The majority of the energy needs of this sub-sector are provided by the bagasse, which is the residue of the sugar cane after it has been crushed and its sugar extracted.

Modeling is based on the generic energy services approach, with process heat and electricity requirements coming exclusively from the cogeneration plant. During the off-season, other energy is needed for maintenance so most plants remain grid-connected.

The model has also been set up to allow for electricity supply to the grid. It also has a distilling process included, for the production of molasses, some of which is used for the production of ethanol, including fuel grade ethanol that could be used in the transport sector. In the base year, all of this fuel grade ethanol is exported although could potentially be used in the domestic transport sector. The structure of the different processes in the model is shown in Figure 28.

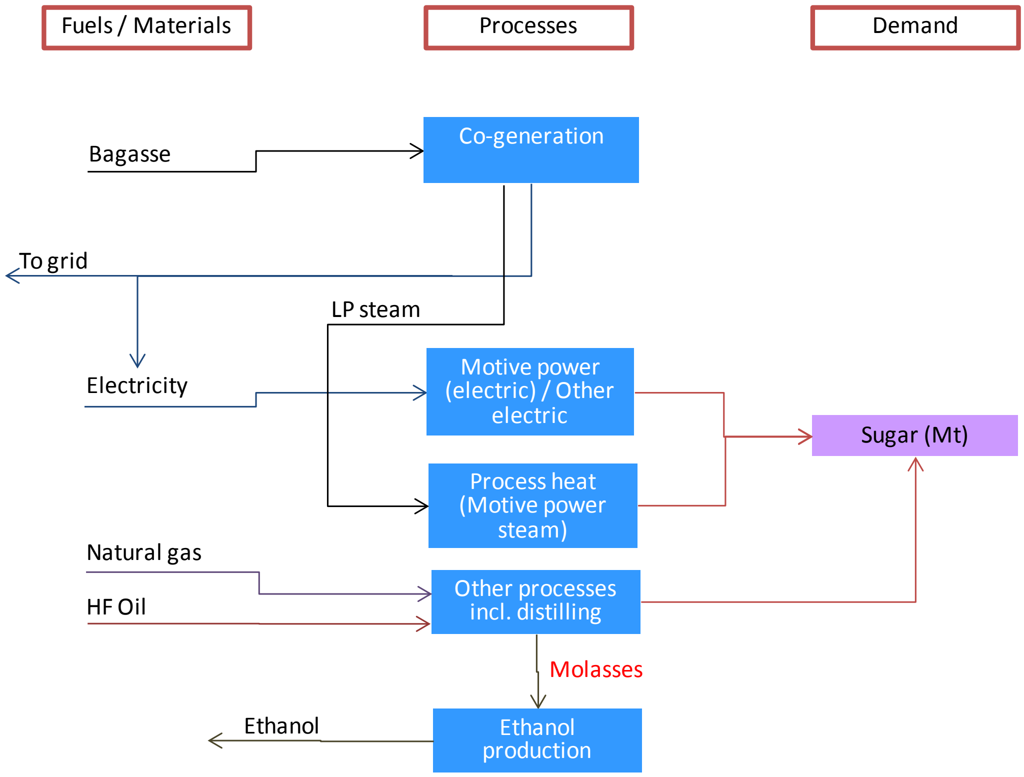


Figure 29: Reference Energy System – Sugar

Key assumptions and sources used for the base year characterization are provided in Table 29.

Table 29: Key assumptions used for sugar sector in Pak-IEM model

Data type	Million tonnes	Source
Sugar cane (SC) production	54.9	PSMA (2007)
Supply of SC to mills	40.5	PSMA (2007)
Bagasse for energy	8.6*	ENERCON MIS database
Sugar production	3.53	FBS (in GoP 2008)
Molasses production	1.91	PSMA (2007)
Ethanol production capacity	0.4	Dewan mushtaq Group**
Ethanol export	0.274	PSMA (2009)
Proportion of exported ethanol of fuel grade	13%	USDA Foreign Agricultural Service (2007)

* Cross checked against typical cane to bagasse ratios of 25% e.g. WADE (2004).

** Presentation on 'Overview of Sugar Manufacturing Sector of Pakistan' By Mian Kausar Hameed, COO - Sugar Operations, Dewan Mushtaq Group

The key new technology for the sugar sector is the retrofitting of existing cogeneration plants, to increase steam pressure and increase potential electricity generation for sale to the grid. Total additional power that existing plants can produce has been estimated by MEC at 655 MW. Costs and characteristics of new cogeneration plants are based on a NEPRA tariff determination document for a specific sugar mill looking at the sale of surplus electricity to the grid.

Approach to sub-sector modeling – Brick production

The brick production sector is relatively informal compared to other sectors, with numerous kilns around the country, proving bricks for local construction activities. The primary fuel used in these kilns is coal, the total of which is estimated in the Energy Year Book.

Data on technologies is sourced from the recent Hagler Bailly energy efficiency analysis for ADB (2009b). The majority of existing brick production uses Bull's Trench kilns, with a small percentage (5%) of Clamp kilns. There is significant scope for efficiency improvement, as illustrated below in Table 30.

Table 30: Brick Kiln Efficiencies (Source: ADB 2009b)

Kiln Type	kg/brick	Efficiency*
Vertical	0.1	1.47
Bull's Trench	0.19	1.00
Clamp	0.23	0.79

* Normalised against Bull's Trench kiln efficiency

New technology options are either new vertical kilns, or Bull's Trench and Clamp kiln being retrofitted with a vertical kiln.

Approach to sub-sector modeling – Fertilizer

The fertilizer sector is important to model as a separate subsector due to the high level of gas consumption, both as a fuel and a feedstock. Forty-six percent of industry gas consumption is used by the fertilizer industry, nearly 80% for feedstock. Gas for feedstock and fuel are separately modeled, with feedstock gas not being processed like gas used as a fuel.

This separation is also important to reflect different pricing of gas. The Government provides an indirect subsidy to fertilizer manufacturers by selling feedstock gas (80% of the raw material cost) at approximately 50% lower rates compared to the price for commercial users (GoP 2008). Data on differentiated sector prices is primarily sourced from the Energy Year Book (HDIP 2008).

The model also has a fertilizer import option, which comes into play when the price of gas rises significantly. The price of the imports is based on assumptions provided by the Pak-IEM Planning Team.

Timing of electricity demand by industry sub-sector

Based on PEPCO data, the demand for electricity by season is relatively flat, with limited seasonal variation. All sectors have a 24 hour shift pattern with the exception of sugar and the general *Other* industry category, which have 16-hour day shifts.

Captive power generation capacity in industry

An important aspect of the industry sector modeling is the captive power generation, which provides electricity for self-consumption across different industrial sub-sectors. Results of a survey of manufacturers / distributors of equipment undertaken by the project team suggest captive generation capacity of approximately 2.5 GW, almost 1.8 GW of which is in the textile sector (see Table 32 below).

The survey only covers gas fuel equipment as diesel and Heavy Fuel Oil (HFO) equipment installations are few, and run intermittently (as back-up) due to high fuel costs. Estimates from the UDI WEPP database[50] published by Platts are therefore used for the oil-based plants. Gas engines have a high investment costs; industry therefore strives for high utilization to ensure return on investment. The feasibility of installation only works if they perform base load duties; otherwise they are unlikely to be purchased.

The survey estimates far exceeds estimates from the previous source of information, the UDI WEPP database. The WEPP database puts total captive generation in Pakistan industry at 1.2 GW (250+ units), including the capacity of 0.7 GW for the sub-sectors shown in Table 31.

Table 31: Industrial Captive Generation Plants (Source: UDI WEPP, Platts)

Sector	Input fuel	Unit type*	Capacity (MW)	Unit number
Sugar Mill	BAG	ST	133.3	49
		ST/S	10.4	4
	OIL	IC	1.4	2
	UNK	ST	2	1
		ST/S	1.5	1
Sugar Subtotal			148.6	57
Cement	GAS	IC	49.5	3
	OIL	IC	226.0	38
Cement Subtotal			275.5	41
Pakistan Steel**	COG	ST/S	165	3
Textiles	GAS	GT/S	7.4	2
		IC	38.1	15
		IC/H	3.0	3
	OIL	IC	72.2	35
		IC/H	15.5	16
		ST/S	7.2	1
Textile Subtotal			143.4	72
Sector Total			732.5	173

* Unit type definition: ST-Steam turbine; ST/S-Steam turbine with steam sendout (cogen); GT/S-Gas turbine with steam sendout (cogen); IC-Internal combustion (reciprocating engine or diesel engine); IC/H-Internal combustion engine with heat recovery (cogen)

** Integrated works only; no independent sector operators included

50 UDI World Electric Power Plants Database (WEPP), Published by Platts (www.platts.com/)

Table 32: Captive generation capacity by Industry Sub-sector

(Results of MEC Ltd Survey)

		INDUSTRIAL SEGMENTS AND INSTALLED POWER IN MW												
NO	MANUFACTURER/ DISTRIBUTOR	TEXTILE	PETRO-LEUM	COMM-ERCIAL	HOSPITAL & PHARMA	STEEL & ENGIN.	CHEM-ICAL	FOOD	WOOD, PAPER& BOARD	CEMENT & CERAMICS	GLASS	IPP	SUGAR, FERT. RICE, OTHER	ROW TOTAL (MW)
1	GE JENBACHER	683	4	23	11	38	31	24	11	24	5	216	18	1087
2	CATERPILLER	741	31	47	6	11	1	2	0	25	8	16	9	896
3	WAUKESHA	228	105	2	1	14	2	9	3	NIL	11	NIL	4	378
4	DUETZ MWM													
5	GAUSCOR	61	0	2	3	4	3	17	2	0	0	0	0	92
6	KAWASAWI GAS TURBINE	3	3	2	0	28	0	0	3	0	0	0	0	38
7	TURBOMAC GAS TURBINE	77	0	0	2	0	11	0	0	0	0	0	8	98
A	TOTAL CAPACITY (MW)	1793	142	75	24	94	48	51	18	49	24	232	39	2497
B	DAILY OPERATING HOURS	24	24	12-14	14-16	18-20	24	16	24	24	24	24	24	
C	UTILIZATION FACTOR	0.87	0.87	0.65	0.70	0.75	0.80	0.75	0.70	0.75	0.75	0.87	0.75	

Additional information on captive generation has been sourced from the 2005-06 Census of Electricity Establishments (FBS 2007) and used for cross-checking model estimates.

Summary of industry sector data sources

Table 33 provides a summary of the current industry sector data sources.

Table 33: Summary of Data Sources for the Industry Sector

Data Type	Data Source	Notes and Comments
Sub-sector energy consumption		
Electricity consumption	PEPCO DISCO billing data	Note that this is used to derive shares between sub-sectors
Gas consumption	Sui Northern Consumption data Sui Southern Consumption data	See file *SNGPL Consumer Data 2007 and 2008.xls* See file *Categ-det_Jul'06-Jun'07.xls*
Other energy consumption	ENERCON MIS database	
Cement sector	EYB 2007 (HDIP 2008)	Cement sector totals sourced directly from EYB. Coal information provided directly by HDIP.
Captive generation		
Capacity / technology type	Project-based survey complimented by UDI WEPP database	Published by Platts. An industry-based review will compliment this.
Capacity by sector	Based on project team survey	
Iron and Steel sector		
Production data	Production and sales data for independent sector in Magna steel presentation. Pakistan Steel data provided directly.	Independent sector -see *Steel Sector Presentation Final on 10-8-09.ppt;* Pakistan steel – see *Pak Steel Data 12-2-2010*
Energy consumption (process level)	As per above	As per above
Technology characteristics	As per above	As per above
Textile sector		
Production data	All Pakistan Textile Mills Association (APTMA) website	http://www.aptma.org.pk/Statistics.asp
Energy consumption (process level)	ENERCON Energy Audit dataset	
Technology characteristics	ENERCON Energy Audit dataset	
Sugar sector		
Production data	Pakistan Economic Survey 2007/08; PSMA	PSMA providing data on cane production and supply to mills
Energy consumption (process level)	ENERCON Energy Audit dataset	
Technology characteristics	ENERCON Energy Audit dataset	
Cement sector		
Production data	Pakistan Economic Survey 2007/08	
Energy consumption (process level)	Energy Year Book 2007, ADB 2009b	
Technology characteristics	ADB (2009b)	

Engagement with trade association will be important for maintaining datasets in future years. Key associations are listed below in Table 34.

Table 34: List of Sector Associations

Sector	Web address
Pakistan Steel	http://www.paksteel.com.pk/
Pakistan Steel Melters Association	http://steelmelters.com
Pakistan Steel Re-Rolling Mills Association	
Pakistan Sugar Mills Association	http://www.psmaonline.com/psma/home.aspx
All Pakistan Cement Manufacturers Association	http://www.apcma.com/
All Pakistan Textile Mills Association	http://www.aptma.org.pk/

D. Residential Sector

The residential sector, like industry and transport, is one of the largest consumers of energy, accounting for 20% of total energy consumed. The published reports and data available to characterize the residential sector are either quite old, inadequate, or do not provide a consistent set of information that can be use to characterize these sectors and understand how energy is currently used.

Information describing the general energy supply situation is available from the Energy Yearbook, and distribution companies. However, important details are lacking when it comes to understanding time-of-use consumption patterns and the relative shares of energy utilized by end-use appliances, such as air conditioners, refrigerators, water heaters, lighting, etc. The last major surveying activity of the residential sector, the World Bank sponsored Household Energy Strategy Study was undertaken in the early 1990s (ESMAP 2003).

However, new research as part of the modeling analysis has enabled a reasonable characterization of energy use within this sector. This includes development of biomass estimates to ensure this important energy type for rural communities is captured, and survey-based activities to better understand the technologies on the market, and the stock in use.

Approach to residential sector modeling

The types of information needed for a proper characterization of the residential sector are illustrated in Figure 29. They include data on regional energy use patterns, demographic information to determine how the current energy use may change in the future, and a breakdown of the energy use patterns by end-use application. Energy demand should be defined according to useful energy requirements rather than final energy use, so that the impacts of fuel switching and end-use device efficiency can be factored into analyses of the sector.

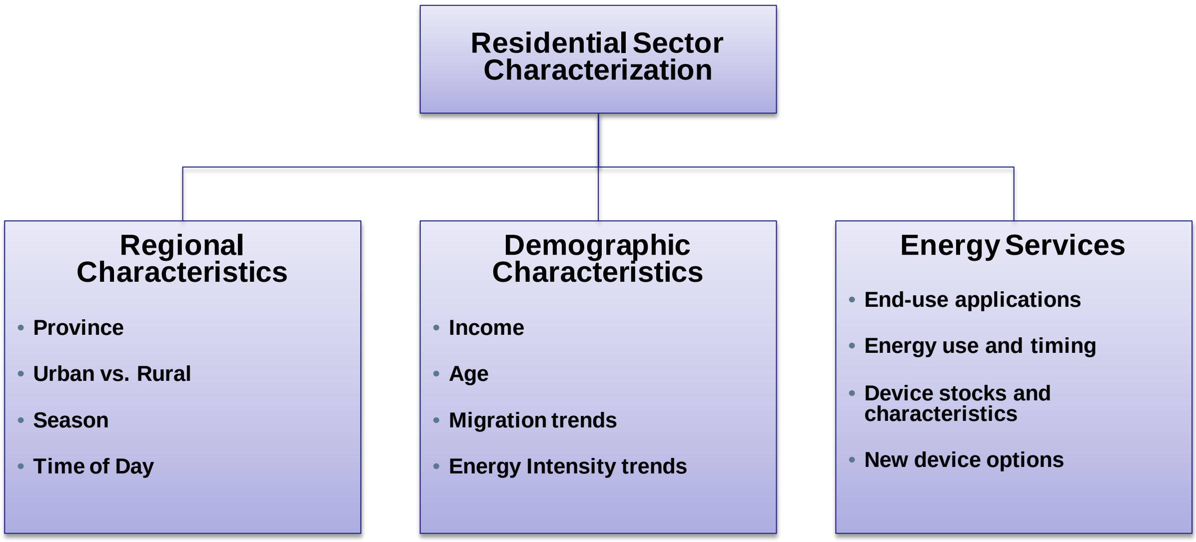


Figure 30: Information Needed to Characterize Residential Sector Energy Use

Due to a lack of up-to-date information for these sectors in Pakistan, a large surveying program has been proposed by the project team to be funded by USAID as part of their Energy Efficiency project. However, plans for this survey are currently on hold as the USAID project focused on activities with greater near-term impact.

In the absence of new survey data, development of this first version of Pak-IEM relied on a variety of existing and recent data sources, using these to develop a decomposition approach to residential sector modeling.

The approach for this sector is illustrated in Figure 30. It takes the following steps:

- Determining the number of urban and rural households
- Estimating the number of households in urban / rural areas using specific fuels
- Weighting the above household numbers to reflect differences in energy intensity
- Estimating shares to disaggregate the urban / rural energy consumption by energy service, based on a range of sources

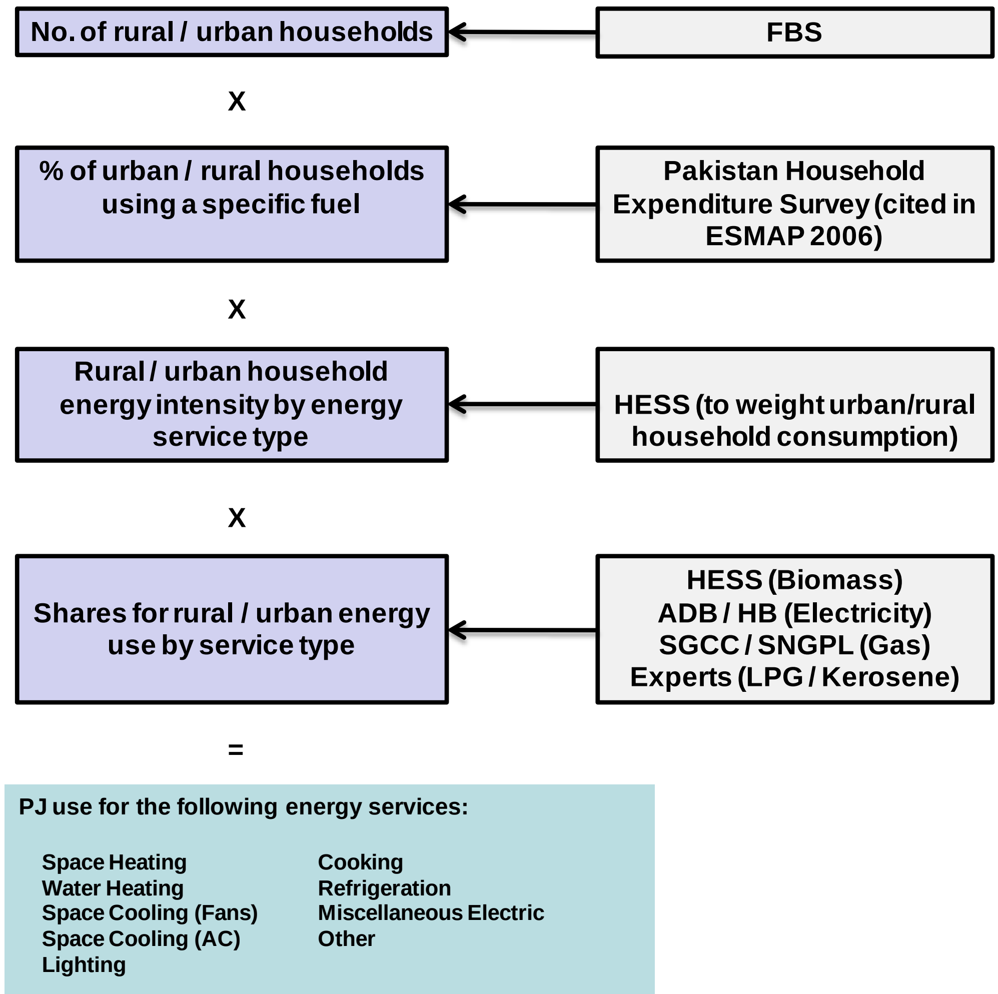


Figure 31: Approach to modeling the residential sector

In future versions of Pak-IEM, there is an intent to expand this approach to disaggregate rural and urban classes into income classes, if possible. The rural-urban distinction does reflect some of the differences in the type of consumption but not to the extent that an income group disaggregation would.

The differences in base year consumption levels between rural and urban areas as a percentage of overall energy consumption are shown in Figure 31 and Figure 32. The large amount of biomass use in the rural areas is particularly evident as is the current dominant energy for cooking services

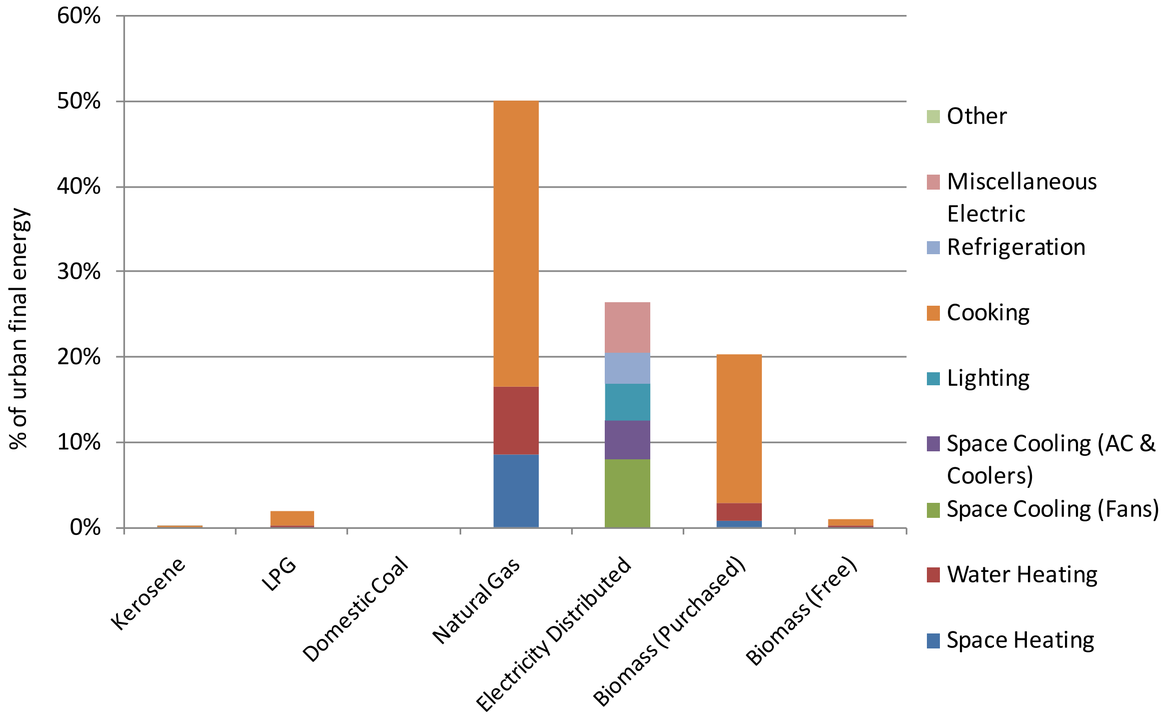


Figure 32: Shares of final energy consumption by type in the urban residential sector

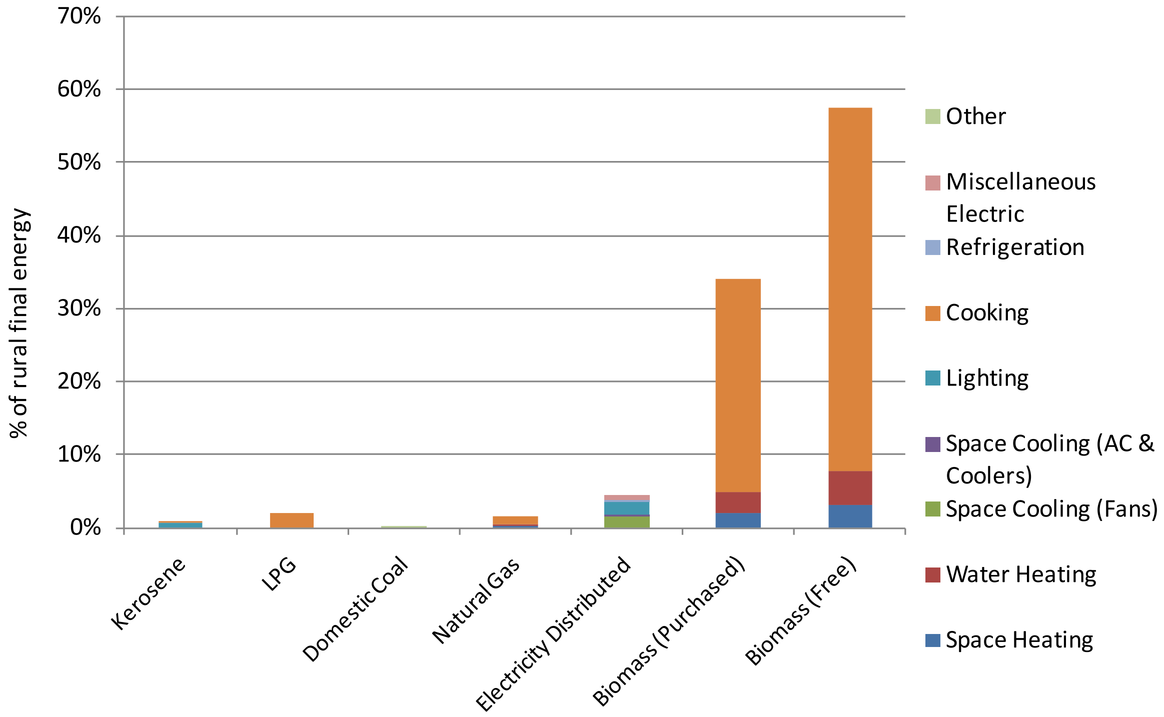


Figure 33: Shares of final energy consumption by type in the rural residential sector

Technologies used in the residential sector

The approach described so far allocates fuel consumption to different types of uses (cooling, heating, etc). The next step in constructing this sector was first, to understand the existing stock in the sector of appliances, and second, the new technologies that might be available for investment in later years in the model.

Significant assistance was provided by the Planning Team, in particular the Mechanical Engineering Department at the University of Engineering and Technology – Taxila (UETT), to help develop this dataset, particularly in the absence of other data. Much of the information to characterize the appliances was done based on UETT Taxila survey work, as shown in Table 35 below. Due to the surveys being focused on the Punjab region, a future priority will be to expand these survey activities across Pakistan.

Table 35: Data sources to characterize residential sector technologies

Data Parameter	Data Source
Appliance price	Residential Energy Survey UETT Taxila 2009 & 2010 www.metro.com.pk www.prices.pk
Avg. Power Rating (W) – for electric appliances	Residential Energy Survey UETT Taxila 2009 & 2010 www.metro.com.pk
Avg. Life(yrs.)	Residential Energy Survey UETT Taxila 2009 & 2010 Interviews and Local Market Survey 2010
Avg. Use/day	Residential Energy Survey UETT Taxila 2009 & 2010 http://www.gallup.com.pk/
Annual maintenance cost	Interviews and Local Market Survey 2010 Residential Energy Survey UETT Taxila 2009 & 2010
Stock of appliances by type	Estimating Residential Electricity Demand Responses in Pakistan's Punjab(Theresa Chaudhry), The Lahore Journal of Economics, 15: Special Edition: Papers and Proceedings of the Sixth Residential Energy Survey UETT Taxila 2009 & 2010 OWNERSHIP OF DURABLES IN PAKISTANI HOUSEHOLD (results released on: July 30, 1999) http://www.gallup.com.pk/

Data on lighting technologies, including existing stock, their costs and potential, is sourced from ADB (2009b). For new technologies, the US NEMS model has been used to provide information on more advanced technologies.

The type of technologies considered are shown in the RES diagram below, illustrating the type of energy used (on the left) and the energy services provided (on the right).

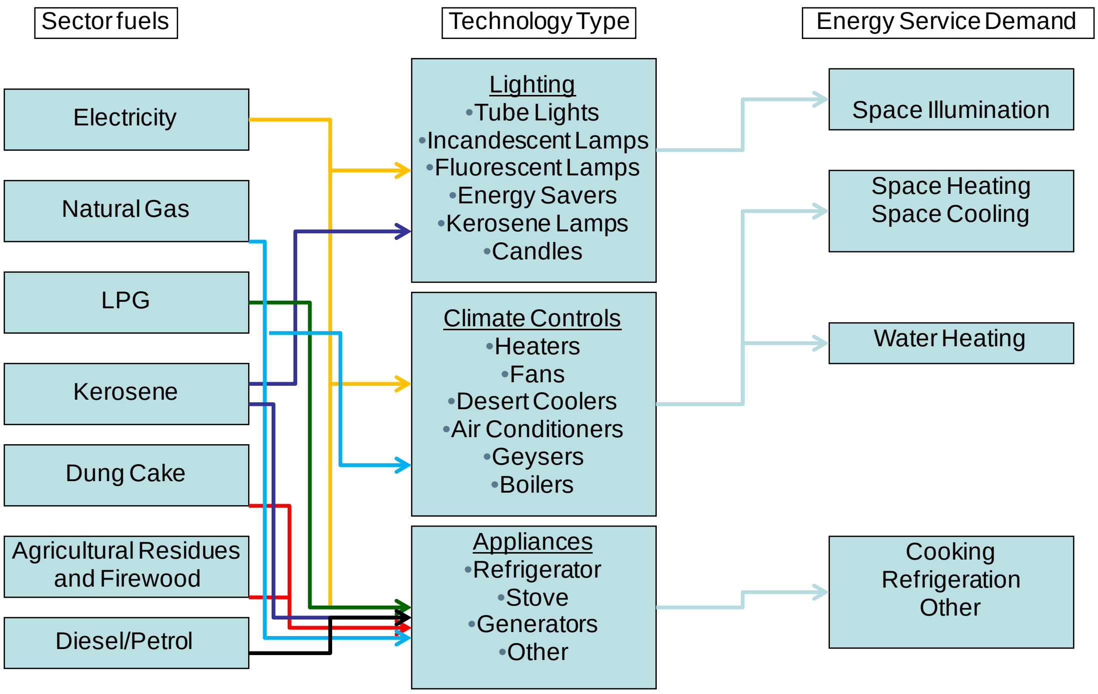


Figure 34: Residential sector RES Diagram

Temporal patterns of demand in the residential sector

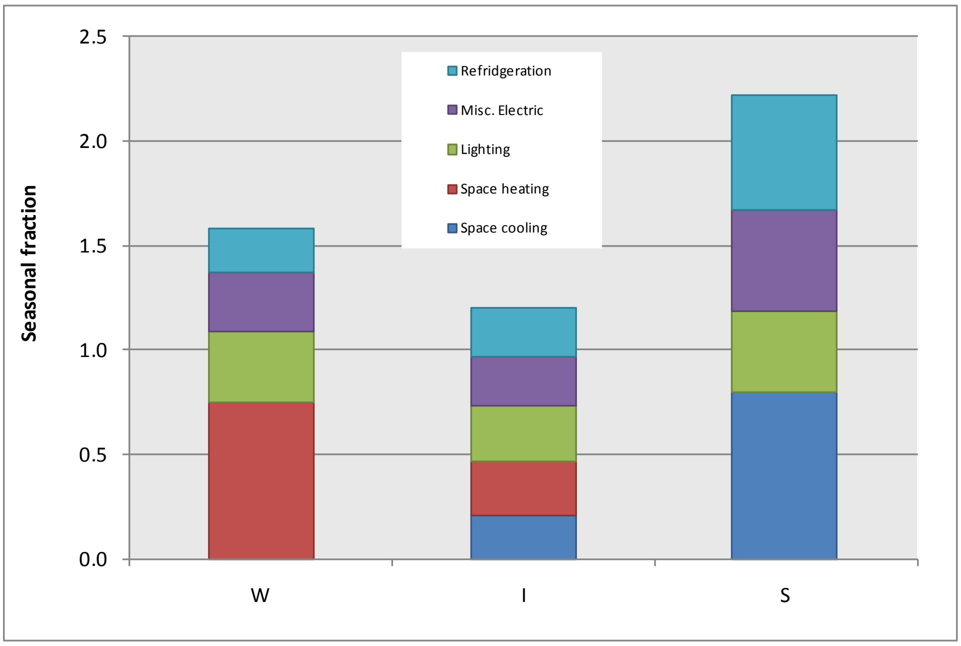
In Pak-IEM, the demand for energy services is tracked at a sub-annual level, reflecting that heating is required most during winter periods and air conditioning during the summer. For those commodities that are characterized sub-annually (gas seasonally and electricity across periods of the day), their supply has to match the temporal patterns of demand.

Demand fractions (COM_FRs in the model) have been calculated, primarily with electricity in mind, which allocate annual demand for an energy service across the different timeslices in the model. This has been done by calibrating the temporal profile of demand with the electricity load curve, using hourly load data from PEPCO and KESC (as described in section II.B).

Therefore, at the aggregate level, it is clear how much electricity is demanded in a given timeslice for all sectors. In addition, due to seasonal demand data, the level of demand in the residential sector by month is also known. The most difficult information to source is what the difference in demand is for a specific energy service within a specific sector. This information has primarily been sourced from a survey[51] by UETT and from expert judgment from stakeholders and the wider Planning Team.

Figure 34 illustrates the survey information on energy service demand by season (as defined in the model). Using these data and other information, the resulting timing of demand profiles for space cooling and space heating can be seen in Figure 35. These profiles also apply to gas supply, which is seasonally-defined commodity.

[51] UETT Taxila conducted an energy survey for the residential sector in Punjab, consisting of about 35 questions regarding life style, income group, and electricity consumption by different categories of end-use devices; data from utility bills was also collected. The sample size was 1,300 households, of which 41% were rural and 59% were urban. Income group information was also collected but not used here.



* Above shares based on UETT survey are fixed at the aggregate level to seasonal data provided by PEPCO. This figures shows the higher demand in summer (S) relative to other seasons, and the relative contributions by energy service demand

Figure 35: Season fractions for electricity demand in residential sector across different end-use applications

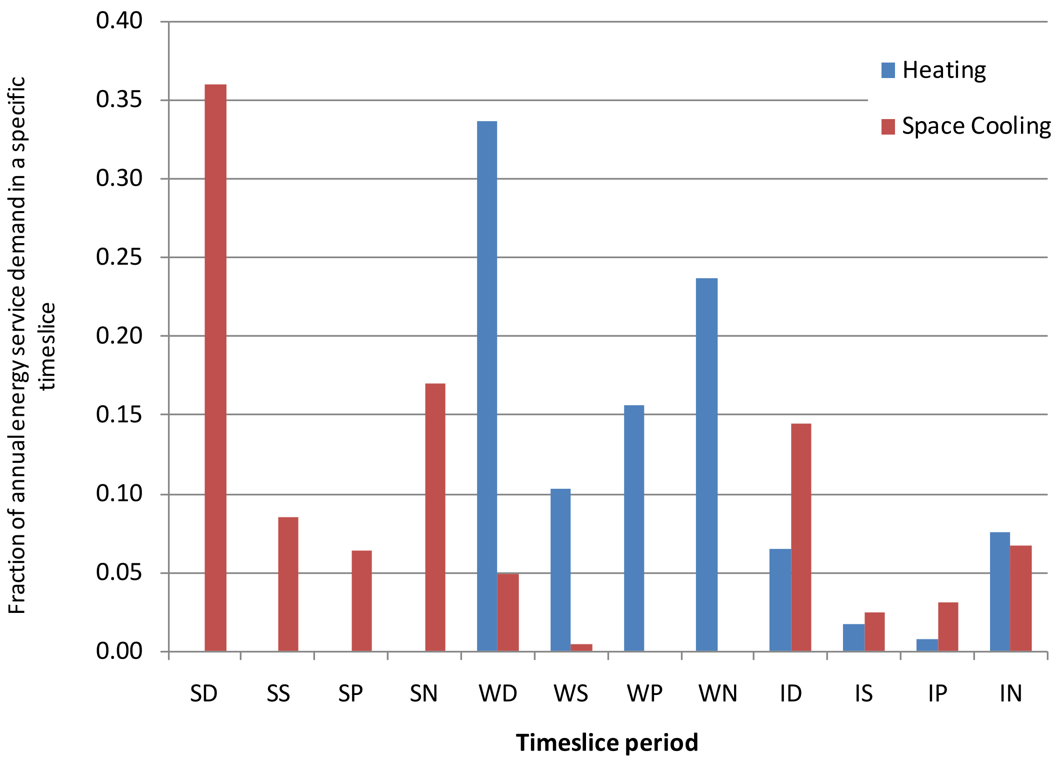


Figure 36: Timing of Demand Profiles in Residential Sector by space heating and cooling

Residential sector data sources

A range of data sources have been used for this sector, and are listed in Table 36 below

Table 36: Summary of Data Sources for the Residential Sector

Data Type	Data Source	Notes and Comments
Household use of fuels	Household expenditure survey 2001 (as cited in ESMAP 2006)	
Relative energy intensity of urban / rural households	HESS (ESMAP 1993)	
Fuel shares by energy service type	HESS (ESMAP 1993) SGCC / SNGPL ADB (2009b)	Seasonal profile used to identify gas demand for different energy services Electricity shares
Technology data	See Table 35 Also US NEMS data, ADB 2009b	

E. Commercial Sector

The commercial / Other Government (including Military) sector takes a similar approach to that employed for the residential sector, but as a single aggregate sector (no urban / rural split). The shares of energy by end-use demand category are currently formed on the basis of expert judgment, as are the timing of demand profiles.

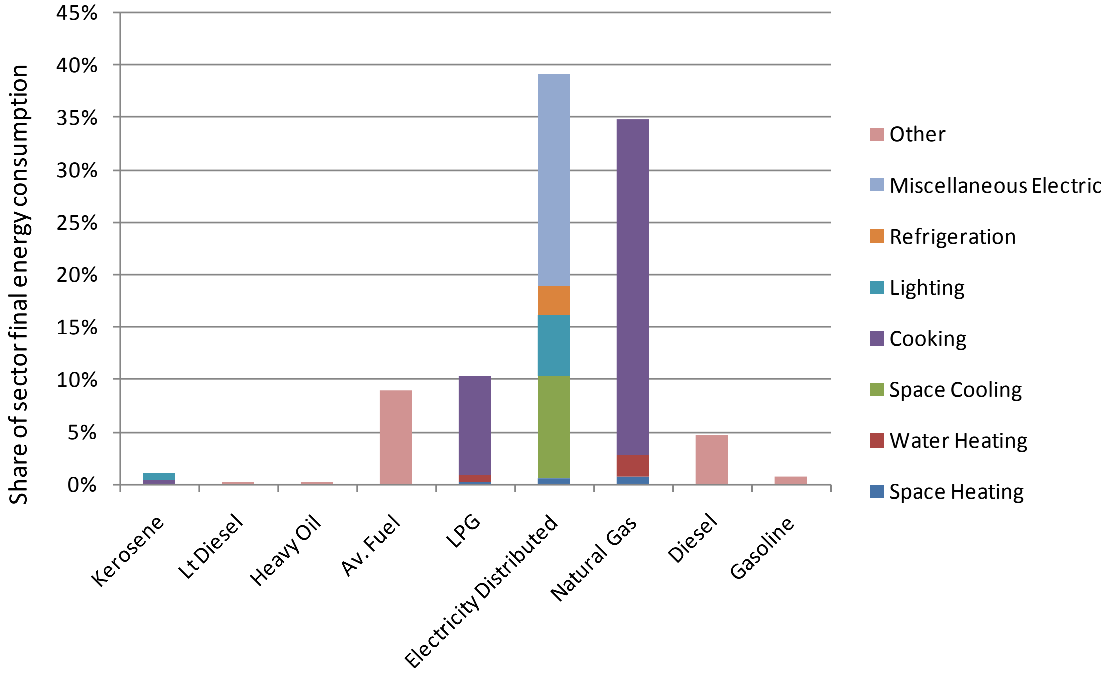


Figure 37: Shares of final energy consumption by type in the commercial sector

Energy use is dominated by gas and electricity. Transport fuels are considered to be used in Government vehicles, although these have been allocated to "Other."

Due to the lack of in-country data, information on different technologies is sourced from the US NEMS model.

The current lack of data means that many of the assumptions in this sector will continue to be based on expert judgment – and potentially some very limited surveying activity. Although not ideal, the concerns over the strength of the data are less because this sector is actually a relatively small user of energy (6% of final energy consumption as per the Energy Year Book 2007). However, as there is a real potential for energy saving, and this is a growing sector, better characterization of the sector is desirable. Further discussion of areas for development can be found in section VIII.

F. Transportation Sector

The transportation sector includes various forms of transport for passengers and freight in Pakistan. Table 37 provides the sub-sector splits in the model between road and non-road transport vehicles, many of which provide both passenger and freight transport.

Table 37: Transportation Sub-sectors in Pak-IEM

Sub-sector	Vehicle type / Mode
Road transport [1]	
Passenger	Cars
	Taxis
	Buses
	Mini-buses
	Three wheelers
	Two wheelers
Freight	Trucks
	Vans
Non-road transport	
Passenger	Rail electric
	Rail diesel
Freight	Rail diesel
Non-differentiated	Aviation
	Shipping

[1] Road transport sub-sectors determined on the basis of vehicle stock statistics

Energy use in transport

Transport energy use in the base year (2006-07) is sourced from the Energy Year Book (HDIP 2008). Figure 37 illustrates the split of total energy used in the transport sector, which totals 348 PJ. The sector is dominated by high speed diesel consumption. The figure excludes the HSD that has been allocated to the agricultural sector, which the Energy Year Book includes in the transport energy consumption totals.

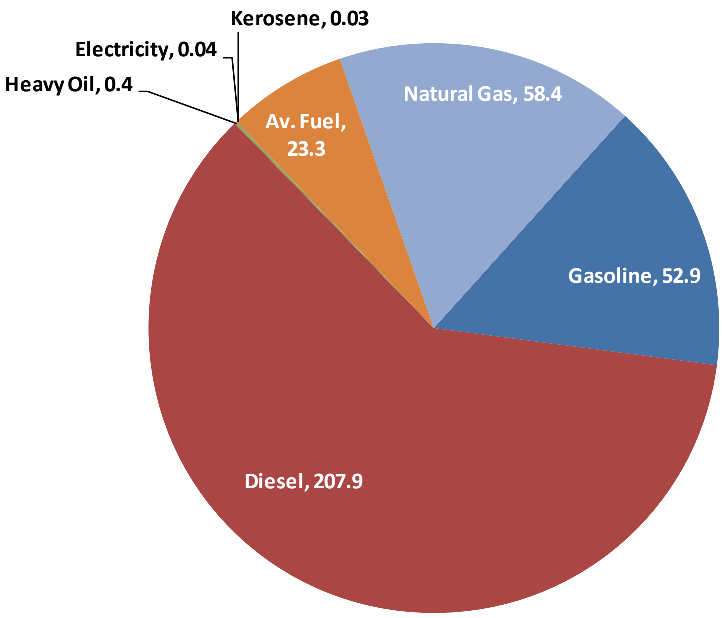


Figure 38: Fuel Consumption (PJ) in the Transport Sector, 2006/07 (HDIP 2008)

Table 38 shows the HSD balance from the Energy Yearbook and how it has been allocated in the model. The bottom-up estimates (in Pak-IEM) for agriculture combined with transport suggest a shortfall of 35 PJ, which we assume to be diesel imported on the black market. The assumptions used in our bottom-up estimates require further scrutiny by experts to ensure that this surplus relative to the Energy Yearbook is representative. Discussions to date suggest that there is a significant amount of cross-border smuggling; therefore a 10% surplus may be a reasonable estimate.

Table 38: HSD Energy Balance (PJ) for 2006/07, and Allocation in Pak-IEM

Energy Yearbook 2007		
Production	Refining output	150
	Import	185
	Export	-2
	Bunkers	-0.2
	Total available to system	**333**
Consumption	Industry	36
	Transport	294
	Agriculture	0.5
	Other	3
	Total consumed	**333**
Pak-IEM consumption estimates		
	Agriculture	118
	Transport	208
	All other sectors	42
	Deficit (assumed to be Black Market Diesel, 11% of EYB total)	35

Transport sector modeling approach

Although the high level energy use in the transport sector is known from the Pakistan Energy Year Book, understanding energy use by road vehicle type and mode requires bottom-up estimation using stock information, and various associated technical parameters – notably efficiency and activity (e.g. annual vehicle km). The basic approach is shown in Figure 38. The resulting estimates are cross-checked against the energy balance values to ensure base year calibration. Useful demand estimates are then developed based on vehicle occupancy (passengers) or load (freight).

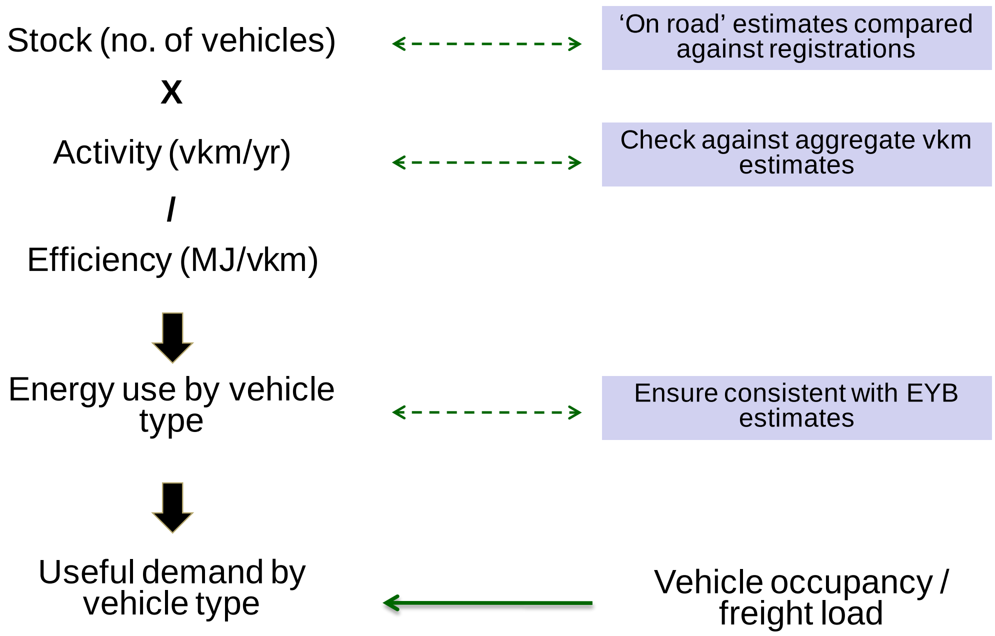


Figure 39: Approach to Bottom-up Estimation of Energy Use in Road Transport Sector

Based on the above approach, Figure 39 and Figure 40 show the Reference Energy System structure of the passenger and freight transport sub-sectors, respectively. These RES diagrams show how the sector fuels can be used by different vehicle types for the provision of the various transport sector energy service demands.

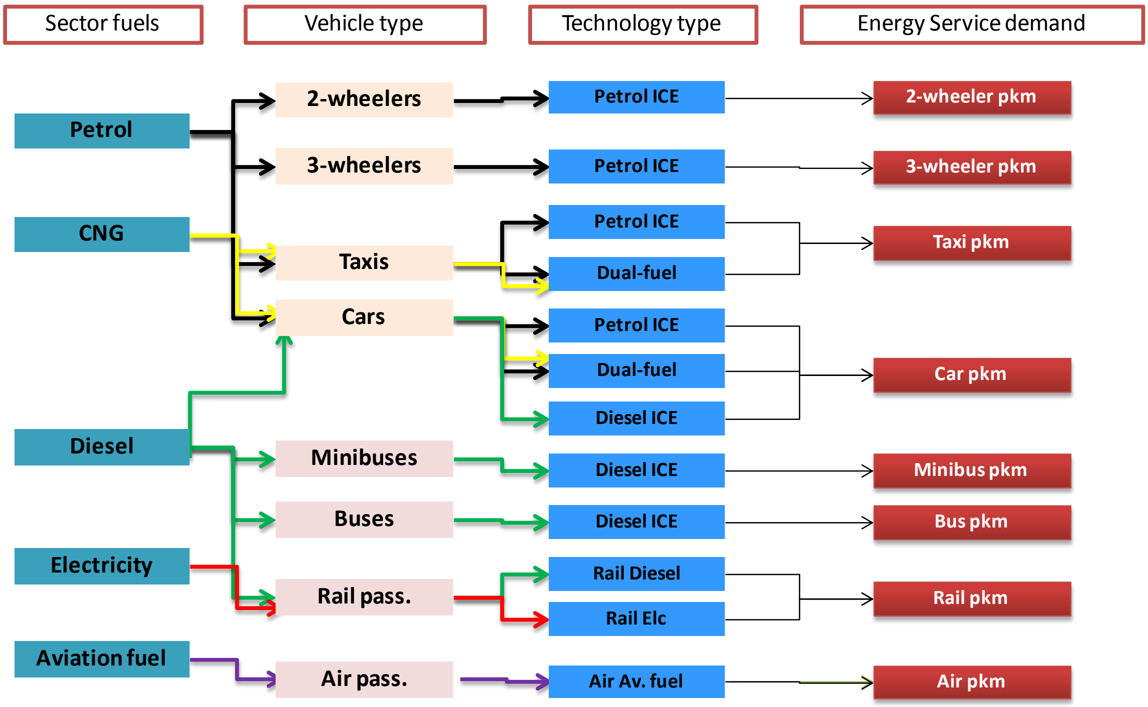


Figure 40: Pak-IEM Transport Sector RES Diagram – Passenger Vehicles

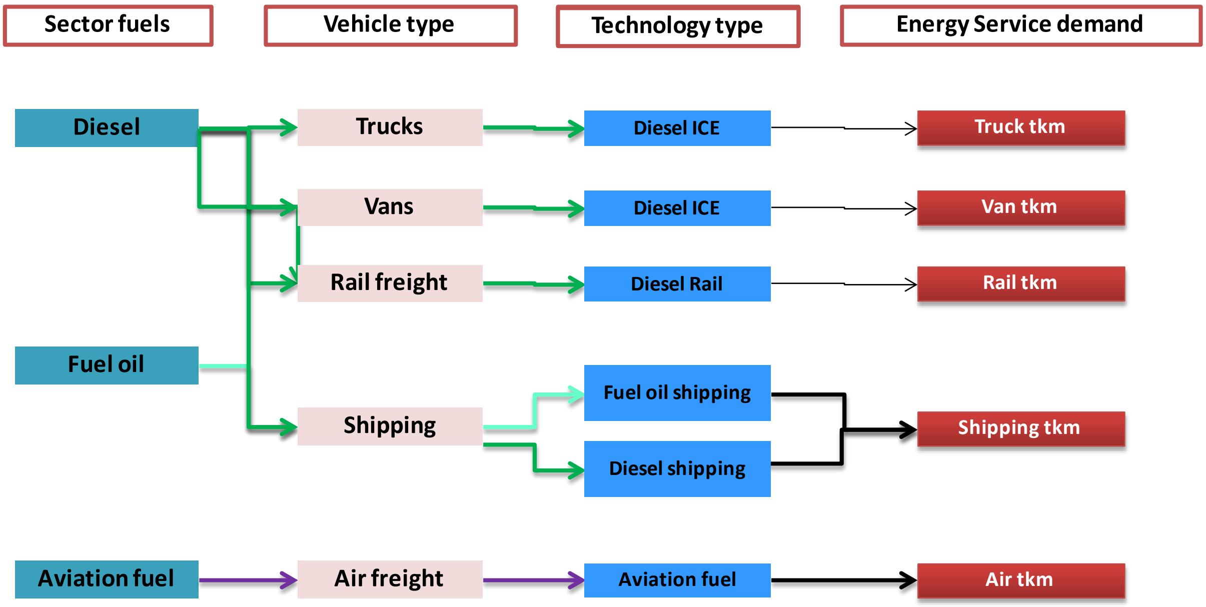


Figure 41: Pak-IEM Transport Sector RES Diagram – Freight Vehicles

Sector data requirements and sources

The approach presented earlier in this section requires the following types of data:

- Vehicle stock data
- Stock activity
- Characterization of existing vehicle technologies

The focus of the data requirements presented here are for base year modeling. Table 39 lists the main data requirements for different transport technologies.

Table 39: Parameters Required for Characterization of Transport Sector Technologies

Characteristic	Unit	Comment
Vehicle type		
Existing stock	Number	
Annual distance travelled	Km/yr	
Input energy carrier		
Average occupancy	Passenger/vehicle	
Remaining life (existing)	Years	TIMES can also use the start year for existing vehicles
Lifetime (new)	Years	New vehicles
Efficiency	passenger-km/PJ or tonne-km/PJ	
Investment cost	$/vehicle	New vehicles only
Fixed O&M Cost	$/vehicle/a	
Variable O&M Cost	$/vehicle/km	
Capacity factor	1	
Input share	Fraction	For dual fuel vehicles
Output	passenger-km	Calculated (not data)

Vehicle stock

Table 40 provides estimates of vehicle stock, which are sourced from "On the road" estimates provided by NTRC (2008).

Table 40: Vehicle Stock Statistics, 2006/07 (NTRC 2008) and Fuel Split Assumptions

Vehicle type*	000s vehicles	Diesel / Petrol splits	CNG conversions (petrol / CNG split)
Buses	108.4	1/0	
Cars	1872.2	0.15/0.85	82% (0.02/0.98)
Trucks	182.1	1/0	
Vans	148.9	1/0	
Two-wheelers	4463.8	0/1	
Three-wheelers	79.0	0/1	

Vehicle type*	000s vehicles	Diesel / Petrol splits	CNG conversions (petrol / CNG split)
Taxis	119.1	0.05/0.95	80% (0.04/0.96)
Minivans	173.7	1/0	
Other	38.5		
Total	7185.8		

* NTRC tractor estimates have not been included; they are dealt with in the agriculture sector

An alternative dataset of stock is also published by FBS (2008). Significant efforts have gone into understanding which is the most appropriate dataset to use. We have used the NTRC estimates, as we believe these provide the most accurate estimates of vehicles actually on the road. According to NTRC, they use records from regional excise and taxation departments so as to estimate not simply registered vehicles but those actually being used.

FBS have clarified what they believe to be the differences between the datasets – FBS data on road transport includes only those vehicles which are registered with the excise department while NTRC figures are based on a survey which includes three categories of vehicles: (i) registered with excise department, (ii) exempted to registration from excise department, and (iii) smuggled vehicles running on roads.[52] This explanation appears to make sense, given that the NTRC estimates are higher at the aggregate level. However, for specific road vehicle categories, FBS stock estimates are higher but not for others.

No official source on the split between diesel and petrol vehicles has been identified. The estimates are therefore based on expert judgment and a paper by ENERCON (2003). Compressed Natural Gas (CNG) vehicles in 2006/7 were estimated at 1.4 million vehicles (OGRA 2008),[53] and all assumed to be petrol-vehicle conversions. (This value has been cross-checked against other sources, notably the Hydrocarbon Development Institute of Pakistan). Currently, conversions are assumed to be only on car / taxi vehicle stocks, with expert judgment on petrol / CNG usage splits for converted vehicles.

CNG conversions have taken off significantly in recent years due to the price differential between CNG and petrol. These vehicles have been set up as dual-fuelled vehicles in the model, allowing for fuel switching depending on price.

There has been a recent emergence of CNG vehicles across other vehicle types (rickshaws, buses) – e.g., the government of Punjab has mandated that all public-transport vehicles will use CNG by 2007.[54] However, these are in the stock numbers post-2006/7 so do not feature in the base year.

Stock activity and technology characterization

A range of different technology assumptions are required to characterize different vehicles, notably vehicle efficiency, annual activity and load / occupancy. These have been used to develop the bottom-up estimates of energy use by vehicle type. The primary source of data is an ENERCON paper (2003), shown in Table 41. NTRC (2005) provides a comparable dataset with similar assumptions.

[52] Based on personal communication with FBS.

[53] Estimate of 1.55 million on IANGV website, www.iangv.org, (Accessed 2nd April 2009, 14.00); (NB. Website also has time series information on numbers of CNG vehicles that may help inform future trends).

[54] PakCNG.com, www.pakcng.com/cng_info.asp; (Also see www.cng.com.pk/index.html for additional information.)

Table 41: Efficiency and Activity Assumptions for Different Vehicle Types, ENERCON 2003; Lifetime and Occupancy Values Sourced from NTRC (JICA 2006b)

Vehicle type**	Size	Fuel	Activity (km/yr)	Efficiency (mvkm/PJ)	Life (Years)	Occupancy / Load
Taxi cabs	Small	Gasoline	32,500	403	12	3
		CNG	32,500	400	12	3
Buses	All	Diesel	50,400	109	10	45
Minibuses	All	Diesel	50,400	305	10	17
Trucks	All	Diesel	50,400	97	12	3 (ton)
Motor cars	Medium	Gasoline	12,600	314	12	2
		Diesel	12,600	377	12	2
		CNG	12,600	315	12	2
	Large	Diesel	12,600	226	12	2
Vans	All	Diesel	28,000	305	10	0.5 (ton)
Motorcycles	All	Gasoline	10,000	1531	10	1.4
Rickshaws	All	Gasoline	40,000	349	10	2

** Includes jeeps / pickups, classified as large cars

New transport technologies

A range of new technologies have been included in the model for road transport, and are shown in the Box below.

Cars (in Pak-IEM, cost / efficiency factors relevant for all LDVs) INCLUDED: Conventional ICE Diesel / Gasoline Advanced ICE Diesel / Gasoline Hybrid Diesel / Gasoline Electric Vehicle Flex-ethanol (fuel sugar cane derived) CNG EXCLUDED: Hydrogen ICE / Fuel cells TO BE CONSIDERED IN FUTURE MODEL VERSIONS: Small cars (e.g. Tata) Non-technical options (driving behaviour etc) Blending biofuels in mainstream fuels (in upstream sector)	**Buses** (in Pak-IEM, cost / efficiency factors relevant for minibuses) INCLUDED: ICE Diesel Hybrid Diesel Electric CNG EXCLUDED: Fuel cell TO BE CONSIDERED IN FUTURE MODEL VERSIONS: Non-technical options (driving behaviour etc)
Trucks INCLUDED: ICE Diesel Diesel hybrid EXCLUDED: Hydrogen ICE / Fuel cells TO BE CONSIDERED IN FUTURE MODEL VERSIONS: Hybrid electric / CNG (these are in the UK model although not sure if serious options) Non-technical options (driving behaviour etc, better maintenance, reducing unnecessary weight)	**2 wheelers** INCLUDED: ICE Gasoline (2-stroke / 4-stroke) 3 wheelers INCLUDED: ICE Gasoline (2-stroke / 4-stroke) Gasoline Hybrid Electric CNG CNG Hybrid

The technology assumptions by road vehicle type are discussed in turn below.

Cars

Conventional technology

These technologies represent current vehicles on the market; future improvements in ICE technologies are incorporated in the advanced technology type.

The capital cost of diesel / gasoline cars are taken from the NTRC published VOC study (2005). All other technologies are factored against the costs of these vehicles, and the basic efficiency values.

Advanced technology

These options include improvements to vehicle powertrain systems that improve overall efficiency. For the purposes of the model, non-engine improvements (e.g. aerodynamics, material weight) will be assumed to be incorporated in these vehicles – and other future technologies.

Current year cost differential and efficiency improvements are based on IEA (2008). Future efficiency improvements out to 2050 (of 20-25%) are based on IEA (2005), and cross checked against IEA/WBCSD SMP Model (2004).

Hybrids

These are vehicles that incorporate an electric motor, running off a battery that recharges while the gas engine is being used and also through regenerative braking. The electric motor is used whilst the vehicle is moving slowly or cruising, and power requirements are less. This combination allows for a much more efficient use of the internal combustion engine, allowing it to operate steadily at near-optimal loads. (Hybrid technologies can be categorized into partial or full hybrid systems; only generic (no distinction between series or parallel) full hybrid system used in model).

The cost increase for hybrids is based on IEA (2008), as is the typical efficiency improvement of between 46-48%. Future cost reductions are based on improved and more cost-effective battery technologies. Efficiency improvements in future years are based on Ricardo estimates, as cited in UKERC (2007).

Plug-in hybrid vehicles (PHEVs)

These vehicles allow charging from the grid rather than the internal recharging system, and therefore improve energy use per KM. The main challenge is battery range and cost.

Capital costs are again based on IEA (2008), and a battery range of 50km (12.5 kWh battery storage). These decrease significantly in future years, by 35-40%, driven by improvements to battery technology (IEA 2008, IEA 2005). Efficiency of electric mode is based on UKERC (2007), assuming 10% less efficient than full electric vehicles due to additional weight of gasoline / diesel engine, reducing to 5% in later years. Efficiency of an electric vehicle is assumed to be four times greater than gasoline car (current year) and by up to five times in 2050 (UKERC 2007, IEA 2005/2008). The improvement in future years is partly due to better regenerative braking technology. The efficiency of the vehicle when using diesel / gasoline engine is slightly lower (5%) than that of the advanced engine technology (as described above).

Electric vehicles

These vehicles have no internal combustion engine, relying entirely on an electric system. Again the main challenge is battery range and cost. There is a view (ETP 2008) that the success of PHEV will determine the timing of electric vehicles, and their full commercialization.

The vehicles have costs 20% higher (in current year) and 10% higher in 2050 than PHEVs due to an assumed higher travel range of 100 km, rising to 270 km by 2050 (UKERC 2007, IEA 2005). Efficiency estimates are described in the PHEV section above.

Flex-ethanol 85

These vehicles can use up to 85% ethanol, and are seen in widespread use in countries such as Brazil. The ethanol supply in Pakistan is likely to be derived from sugar cane (although this will be influenced by the price of sugar, which has recently been at an all-time high).

Efficiencies are assumed to be the same as advanced gasoline vehicles in future years. Based on information in UKERC 2007, a small increment ($200) on capital costs is assumed relative to cost of a gasoline car.

CNG

Efficiency factors for new CNG vehicles track the estimates for advanced gasoline vehicles, scaling for a 5% reduction (IEA/WBCSD 2004).

Vehicle O&M costs

O&M costs are modelled relatively simply. There are two elements (represented as fixed costs as we assume that each vehicle by category travels the same distance in a year):

- Servicing and general maintenance (including replacing tires) and
- Parts replacement e.g. batteries in electric vehicles

Other options

Another option relevant to the transport sector that will be characterized in the upstream sector is blending plant, to allow for small proportions of biofuel (probably ethanol from sugar cane) to be introduced into the gasoline supply.

There is also the potential for a small vehicle option (e.g. Tata) and non-technical options (slower driving, proper maintenance). These will be further discussed in consultation with Pakistan transportation sector experts.

Hydrogen-based vehicles have not been considered as an option for the model due to the small likelihood of these technologies being commercially available in the model timescales, and the significant infrastructure requirements.

Two- and three-wheelers

For new two-wheelers, the options are divided into:

- 2-stroke (Assume that most of current stock are 2 stroke), and
- 4-stroke

Electric-powered two-wheelers are another option that could be included, although for the time being this has been omitted (subject to further discussion). TERI (2006) also has hydrogen ICE engine technologies; however, hydrogen-based technologies have been omitted from the model.

Data for these technologies have been sourced from TERI (2006). In considering the co-benefits of specific technologies, it is also worth mentioning the significant benefits that 4-stroke engines have in reducing air quality pollutant emissions, as compared to 2-stroke engines.[55]

For three-wheelers, the options identified and data are sourced from TERI (2006). A 4-stroke diesel technology was also listed, so some discussion with local counterparts to decide on whether this is also necessary to include.

Buses

ICE Diesel

The efficiency of conventional diesel buses is taken from the base year technology, and improved based on LDV ICE efficiency improvements over time. Capital costs are assumed to remain constant. Note that the cost of buses is very low from NTRC (2005), making the

[55] For further information, see PCFV, Cleaner motorcycles: Promoting the use of four-stroke engines, Kjaer Group / Partnership for Clean Fuels and Vehicles (PCFV),UNEP.

application of mutlipliers for efficiency and cost increase / reduction problematic. For example, costs of a 40+ seat bus are ~USD 90,000. In the international literature, costs are generally compared to diesel buses at around USD 250-300,000.

Hybrid Diesel (HEVs)

Hybrid electric buses are assumed to be 40% more efficient than conventional diesel buses, based on their use in major cities in the UK / USA (Transport for London, US Department of Transportation (DoT) 2005). The rate of future efficiency improvement is based on hybrid cars.

Cost estimates (based on the same sources) put HEV at 60% more than conventional buses for UK and US sources. This is based on US experience, with costs of between ~USD 450-500,000 (EESI 2007) and in the UK, costs of USD 350-400,000 (UKERC 2007). One factor explaining the variation will be the number of buses ordered at any given time, resulting in economies of scale.

TERI (2006) suggests ~USD 200,000, at 3.4 times the cost of a conventional bus. This is the factor that is being used in the model, to account for the very low cost of a conventional diesel bus. Future cost reductions are linked to reduced battery costs (as per light vehicles).

Electric buses

Efficiency estimate (1kWh/km) based on UK information (DfT 2005). Future efficiency improvements based on those cited in UKERC 2007. Cost estimates again based on UKERC 2007, based on the assumed battery range of vehicle (200km in 2008, increasing to 300 km post-2020). Future cost reductions linked to reduced battery costs (as per light vehicles).

CNG buses

The fuel economy of a CNG bus is considered to be 25% less than a conventional diesel bus (US DoT 2005, EESI 2007). Capital costs are assumed to be 1.5 times higher than a conventional bus (TERI 2006).

<u>Trucks</u>

ICE Diesel

This technology represents efficiency improvements that could be realized for ICE technologies in future years. The IEA (2008) ETP publication is used as the basis for efficiency improvement in new vehicles: - 20% by 2030, and 30% by 2050 (for non-OECD regions). This efficiency improvement is based on IEA ETP baseline efficiency improvement; potential could be higher depending on:

- Engine/drivetrain efficiency improvements, e.g. advanced higher-compression diesel engines
- Truck weight reduction
- Aerodynamic improvements
- Low-rolling resistance tyres
- More efficient auxiliary equipment, such as cabin heating/cooling systems and lighting

It would appear that there may be significantly greater potential in Pakistan than other countries for reducing truck weight / improving aerodynamics. Local information is therefore needed to further understand potential in future years.

Hybrid Diesel

Hybrid drivetrain technology has been included as an option, involving adding a motor/battery system to significantly improve urban cycle operation. Clearly, efficiency is dependent on urban versus inter-city transport; the IEA put the efficiency improvement range between 25-45%. Cost reduction is a function of changes predicted in the LDV vehicle category.

Summary of transport sector data sources

A summary of transport sector sources is provided in Table 42.

Table 42: Summary of Data Sources for the Transport Sector

Data Type	Data Source	Notes and Comments
Road transport		
Existing vehicle stock	Motor Vehicles on Road by Region 2006-07, (NTRC 2008)	Registration data from FBS also reviewed but not used
Activity by vehicle type	Fuel Efficiency, Vehicular Emissions and Pollution Control in Pakistan (ENERCON 2003)	
Fuels consumed and efficiency (l/km) by vehicle type	Fuel Efficiency, Vehicular Emissions and Pollution Control in Pakistan (ENERCON 2003)	
Vehicle life / Occupancy	Pakistan Transport Plan Study (JICA 2006)	
Operating costs	Vehicle Operating Costs using HDM – VOC Version 4.0 (NTRC 2005)	
Characterization of future technology options	IEA ETP (2008), IEA (2005), IEA/WBCSD (2004), National Energy Map for India (TERI 2006)	See references in previous section
Non-road transport		
Rail	Pakistan Railway Statistics Handbook 2006/07	
Aviation	Pakistan Oil Report 2006-07	
Shipping	Pakistan Oil Report 2006-07	

VII. DEMAND PROJECTIONS

A. Overview

Useful energy demand projections, or the demand for energy service, are a critical input to any MARKAL/TIMES model, as the model will identify the least-cost configuration of the energy system that will satisfy these demands. For Pak-IEM, modeling the future evolution of the energy system requires projecting the future demand for energy services using suitable demand drivers (e.g., GDP, population, energy intensity, etc.). The drivers for each energy service demand are those that most directly impact its potential growth, and the relationship (e.g., elasticity) between each driver and the associated energy service demand must also be established. Finally, any external factors affecting the demand growth (e.g., autonomous energy improvement) also need to be determined. Table 43 identifies both the primary energy service demand drivers by sector and some additional factors affecting the growth of that sector or sub-sector. Most of these additional factors have not been incorporated into the current demand projections for Pak-IEM because sufficient data is not available. These factors could be incorporated into future versions of Pak-IEM if suitable data can be developed.

Table 43: Energy Service Demand Drivers by Sector

Sector	Demand	Primary Drivers	Additional Factors
Agriculture	Agricultural energy services (pumping / tractor activity)	Sector GDP Energy service elasticity	Increased pumping due to climate change Changes in farming techniques (e.g., tilling, fertilizer use)
Commercial/ Public Sector	Buildings energy services	Sector GDP	Growth of service and government sectors Decommissioning of existing building stock Building standards for new construction
Industry	Industrial product output	Sector GDP Construction levels Sub-sector specific drivers (e.g. agricultural output for fertilizer sub-sector)	Sector structural change (e.g. new ventures, re-tooling etc) Changes in management practices
Residential	Household energy services	Population, urbanization, Electrification rate, Household energy intensity vs. GDP/Cap Income	Occupancy / demographic issues, including income levels Changes in existing housing stock Building standards for new dwellings Climate issues (temperature rise)
Transport	Passenger and freight demand by transport mode	GDP Income	Vehicle choice Occupancy rates Public transport development – modal shift

The Pak-IEM demand projection workbook has been developed and contains projections for GDP growth by sector, population growth, urbanization rates, and household size for urban and rural families leading to projections of urban and rural households. All data is sourced from official GoP sources where available. The demand projection workbook is described in more detail in the *Pak-IEM Final Report: Volume III – User's Guide*.

B. Primary Demand Drivers

Reference case GDP growth rates were based on the official GoP targets, as shown in Figure 41. The 2007-2030 aggregate average annual GDP growth rates for this Reference (REF) case is 5.6%, and the actual GDP growth is shown in Figure 42. Medium (MED) and Low (LOW) GDP growth projections were prepared by the Planning Team based on adjustments to the GDP component growth rates, an shown in Table 44. The MED aggregate average GDR growth rate for 2007 to 2030 is 5.0%, and the similar growth rate for the LOW GDP scenario is 4.2%. As shown in Figure 43 overall GDP growth rate was kept constant for all scenarios between 2030 and 2045, and the sectoral GDP growth rates were adjusted to accomplish this.

Year	Agriculture	Industry	Services	GDP (fc)
2010	3.8	1.7	3.9	3.3
2011	3.9	4.2	4.5	4.3
2012	4.0	5.0	5.2	4.9
2013	4.1	5.9	5.9	5.5
2014	4.1	6.8	6.6	6.1
2015	4.1	7.6	7.1	6.6
2016	4.1	8.0	6.9	6.6
2017	4.1	8.2	6.8	6.6
2018	4.1	8.5	6.4	6.5
2019	4.1	8.8	6.3	6.5
2020	4.0	10.0	5.5	6.4
2021	4.0	10.0	5.1	6.2
2022	4.0	10.0	4.8	6.1
2023	3.8	10.0	4.7	6.1
2024	3.6	10.0	4.5	6.0
2025	3.5	10.0	4.4	6.0
2026	3.2	9.8	4.3	5.9
2027	3.0	9.6	4.4	5.9
2028	3.0	9.4	4.2	5.8
2029	3.0	9.2	4.2	5.8
2030	3.0	9.0	4.2	5.8
Average	**3.7**	**8.2**	**5.2**	**5.9**

Figure 42: Official GoP GDP / Sectoral Growth Targets

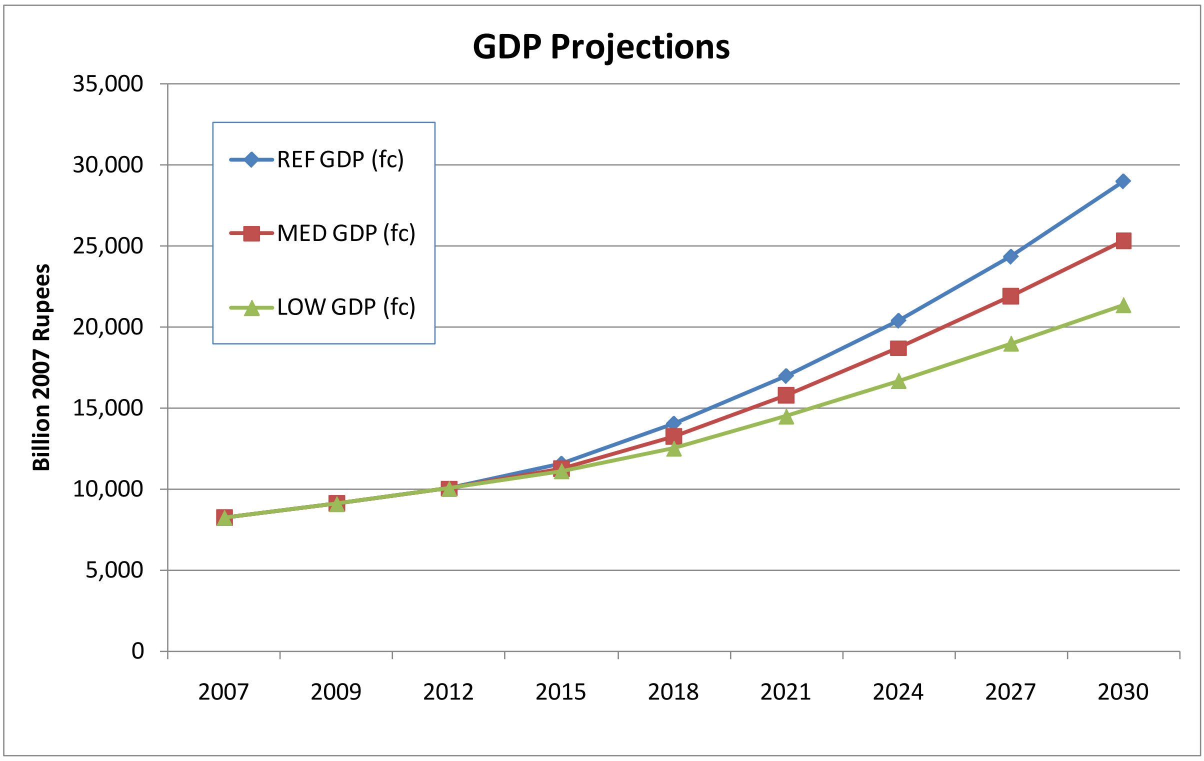


Figure 43: Reference, Medium and Low GDP Growth

Note that all the GDP growth scenarios have a significant increase in the Industry GDP contribution, and that this sector also shows the most significant decrease in the MED and LOW growth projection scenarios.

Table 44: GDP Growth Rates Components for Medium and Low Projections

AGRICULTURE	2007	2009	2012	2015	2018	2021	2024	2027	2030
MED Growth rate	2.60%	3.80%	3.80%	3.90%	4.00%	3.80%	3.60%	3.00%	2.75%
LOW Growth rate	2.60%	3.80%	3.60%	3.70%	3.80%	3.50%	3.25%	3.00%	2.50%

INDUSTRIAL	2007	2009	2012	2015	2018	2021	2024	2027	2030
MED Growth rate	5.30%	1.70%	5.00%	7.00%	8.00%	8.50%	8.00%	7.50%	7.50%
LOW Growth rate	5.30%	1.70%	5.00%	6.00%	6.50%	6.00%	6.00%	6.00%	6.00%

COMMERCIAL	2007	2009	2012	2015	2018	2021	2024	2027	2030
MED Growth rate	5.77%	3.92%	3.60%	5.34%	5.65%	4.94%	4.36%	3.90%	3.77%
LOW Growth rate	5.77%	3.92%	2.75%	3.09%	4.62%	4.58%	3.84%	3.05%	3.11%

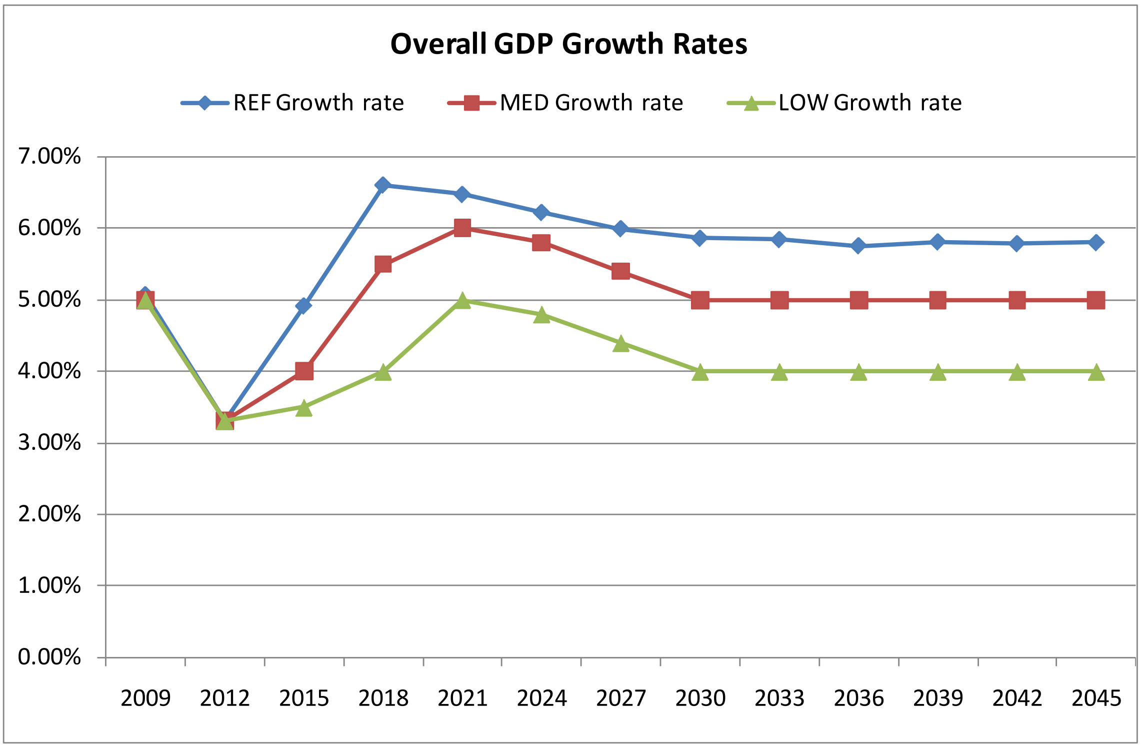


Figure 44: Overall GDP Growth Rate Projections

Figure 44 provides a breakdown of the relative sectoral GDP shares for the three demand projection scenarios. Of interest is the relative share of industry sector relative to services and agriculture. Note that the economic share of commercial and services is much greater than its share of the energy use. Also, note that the industry share of GDP grows dramatically in all the demand scenarios.

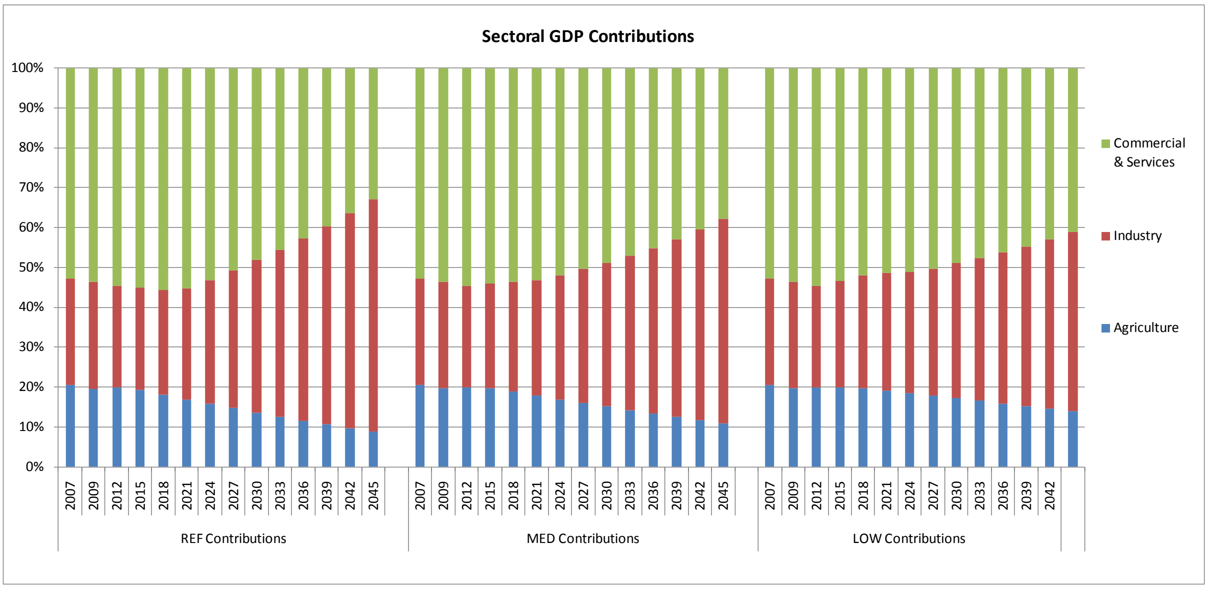


Figure 45: GDP Sectoral Contributions for Reference, Medium and Low Projections

The projections for population growth were taken from the draft Population Policy 2010 report.[56] As depicted in Figure 45, the overall population in Pakistan is expected to grow from 158 million in 2007 to 243 million in 2030. The share of rural population is expected to change from 66% in 2007 to 50% in 2030, and the average household size is expected to drop for both urban and rural households.

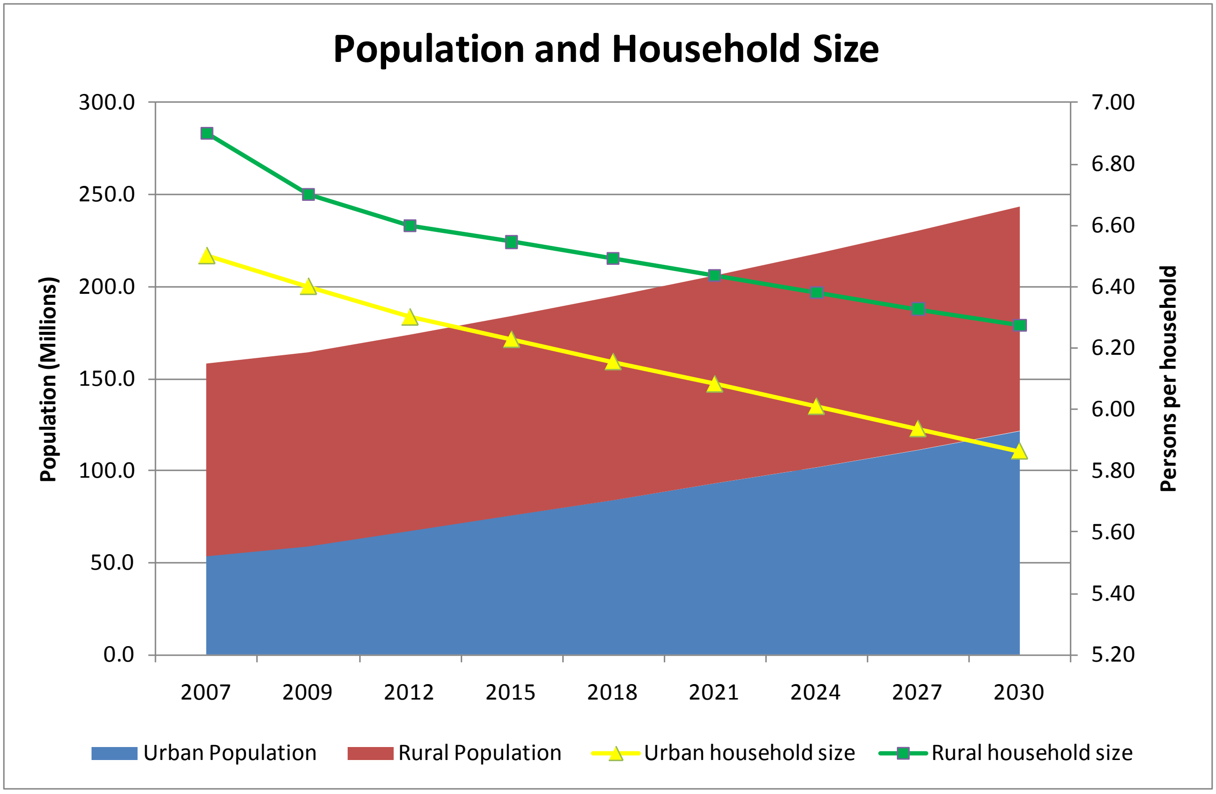


Figure 46: Projections of Popuation and Household Size

C. Demand Projections by Sector

4. Agriculture

The agriculture sector energy service demands are developed for the following end-use applications. All demands are in units of PJ.

- Water pumping
- Tractors – Haulage
- Tractors – Farm Operations
- Other Use

The agricultural component of GDP growth is the principal driver for this sector, and each end-use sector is related to the GDP growth through an elasticity factor, which is defined as the percentage change in energy consumption divided by the percentage change in GDP growth. The elasticity factors are either zero or negative, which if zero means that energy use grows at the same rate as GDP grows, or if negative means that energy use grows more slowly than GDP growth. The elasticities are used to calculate factors that when multiplied by the GDP growth gives the effective energy growth. The agricultural sector elasticities are

[56] National Population Policy – 2010, Ministry of Population Welfare, Islamabad, Jan 18, 2010.

based partly on expert judgment as well as data from the Energy Yearbook that was used to calculate a historical elasticity factor for the entire sector, which was -1.05%.

Table 45: Agricultural Sector Energy/GDP Elasticity Factors

Demand	Energy/GDP Elasticity Factor (Overall change in energy use relative to GDP growth)
Water Pumping	- 0.5% per annum (11% less energy growth by 2030 relative to GDP growth)
Farm Operation	- 0.75% per annum (16% less energy growth by 2030 relative to GDP growth)
Haulage	- 1.0% per annum (21% less energy growth by 2030 relative to GDP growth)
Others	- 0.5% per annum (11% less energy growth by 2030 relative to GDP growth)

Given the agricultural sector GDP demand driver, the base year useful energy demands, and the energy/GDP elasticities, the actual projections for the agricultural sector demands are shown in Figure 46.

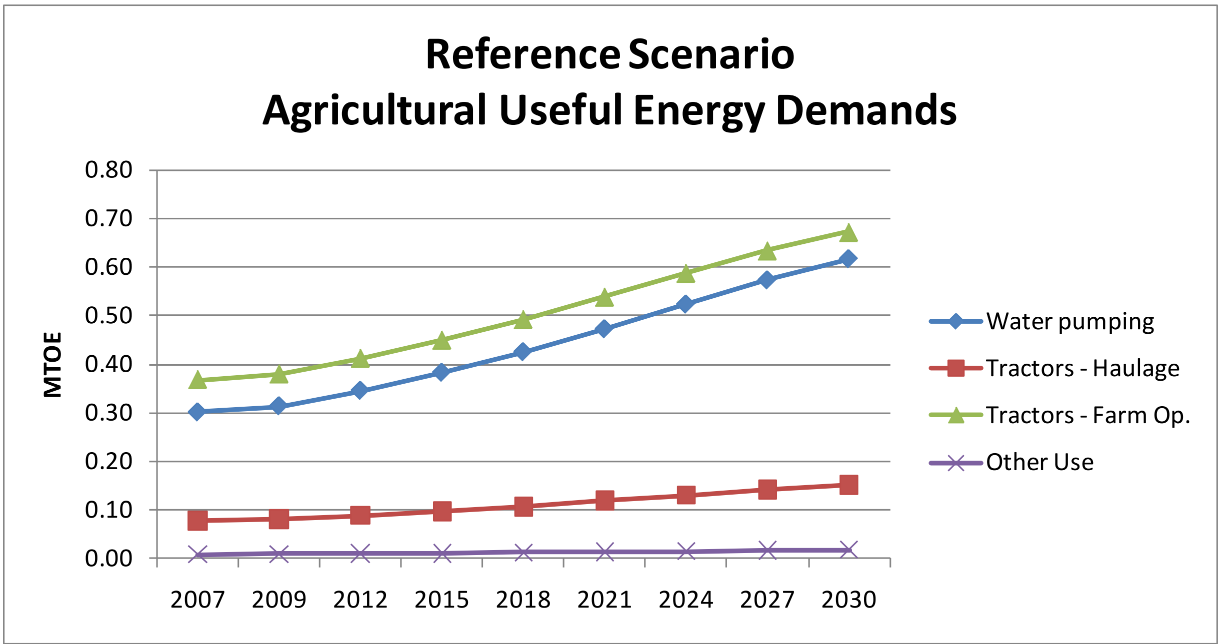


Figure 47: Agricultural Sector Useful Energy Demands

5. Commercial

The commercial sector energy service demands are developed for the following end-use applications. All demands are in units of PJ.

- Space Heating
- Water Heating
- Space Cooling (Fans and AC)
- Lighting
- Refrigeration
- Electrical Appliances
- Other

The services component of GDP growth is the principal driver for this sector, and each end-use application is related to the GDP growth through an elasticity factor, which is defined as the percentage change in energy consumption divided by the percentage change in GDP growth. The elasticity factors are either zero or negative, which if zero means that energy use grows at the same rate as GDP grows, or if negative means that energy use grows more slowly than GDP growth. The elasticities are used to calculate factors that when multiplied by the GDP growth gives the effective energy growth. The commercial sector elasticities are based on expert judgment.

Table 46: Commercial Sector Energy /GDP Elasticity Factors

Demand	Energy/GDP Elasticity Factor (Overall change in energy use relative to GDP growth)
Space Heating	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)
Water Heating	-0.75% per annum (16% less energy growth by 2030 relative to GDP growth)
Space Cooling (Fans and AC)	No change relative to GDP
Lighting	-0.5% per annum (11% less energy growth by 2030 relative to GDP growth)
Refrigeration	No change relative to GDP
Electrical Appliances	No change relative to GDP
Other	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)

Given the commercial sector GDP demand driver, the base year useful energy demands, and the energy/GDP elasticities, the actual projections for the commercial sector end-use demands are shown in Figure 47.

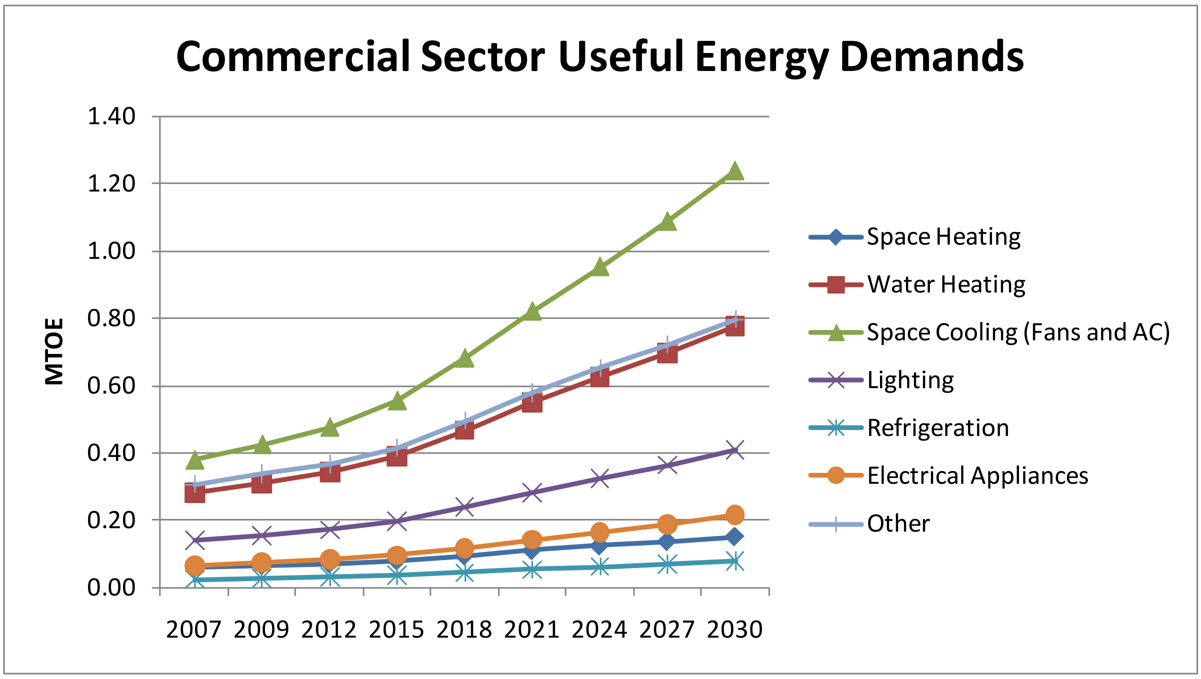


Figure 48: Commercial Sector Useful Energy Demands

6. Industry

The industry sector demand projections are developed according to the following categories. Most of the demands are expressed in activity units, such as million tons (Mt), while a few are expressed in PJ, and one is expressed in billion square meters (Bm2).

Sub-sector demand category	Units
• Textiles Yarn production	Mt
• Textiles Cloth production	Bm2
• Textiles Garment production	PJ
• Sugar production	Mt
• Cement production	Mt
• Iron and Steel Integrated Pig Iron	Mt
• Iron and Steel Integrated Cast Billet	Mt
• Iron and Steel Integrated Steel Products	Mt
• Iron and Steel Integrated Other Processes	PJ
• Iron and Steel Independent Billets (Independent)	Mt
• Iron and Steel Independent Construction steel	Mt
• Iron and Steel Independent Other (Independent)	PJ
• Brick kilns	PJ
• Fertilizer production	Mt
• Other industry	PJ

The industrial component of GDP growth is the principal driver for many, but not all of the industry sub-sectors. Because of the diversity of the various industry sub-sector demands, each uses a slightly different approach to the demand projection, which is described below. In addition, because of the different units employed, only the relative demand growth for the various industry sub-sectors are shown in Figure 48.

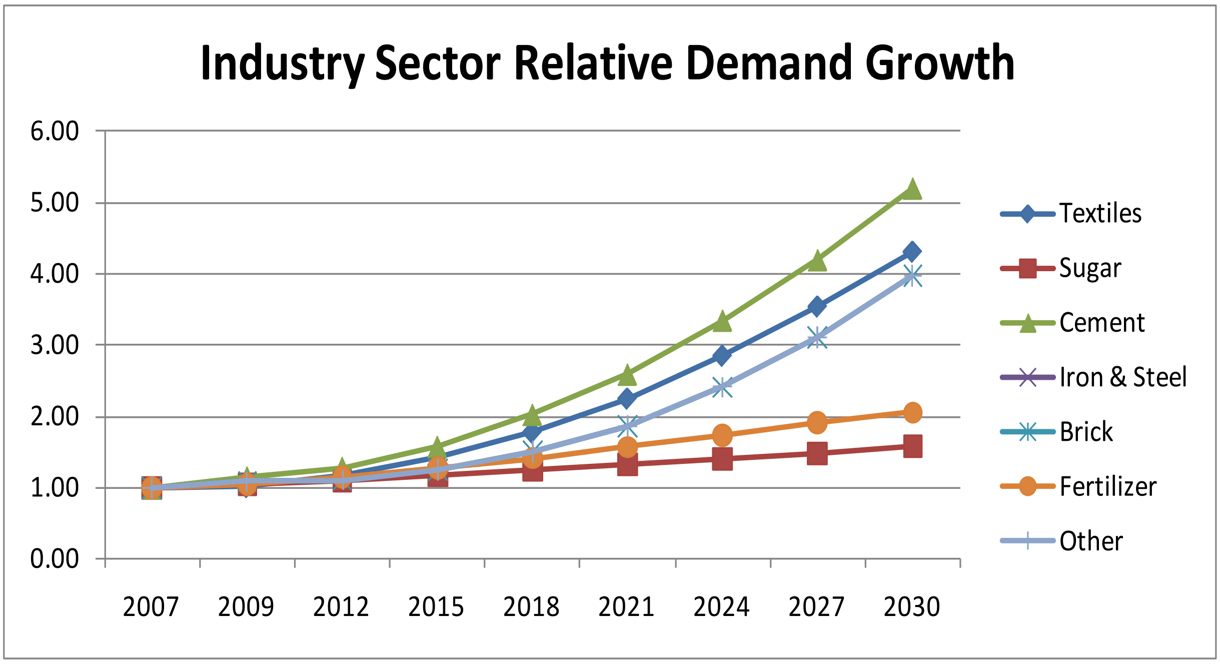


Figure 49: Industry Sector Relative Demand Growth

The drivers and elasticity factors used in each industry sub-sector are summarized in Table 47 and discussed in the sub-sections below.

Table 47: Industry Sub-sector Elasticity Factors

Demand	Driver	Energy/GDP Elasticity Factor (Overall change in energy use relative to GDP growth)
Textiles	Specific growth factors for yarn (5.1%), cloth (7.7%) & garments (6.4%) based on 2010 Economic Survey data. See Table 48)	
Sugar	Sugar Cane Production growth of 2%	
Cement	Construction component of GDP	Variable (See Table 49)
Iron & Steel	Industrial GDP	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)
Brick	Construction component of GDP	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)
Fertilizer	Agricultural GDP	-0.5% per annum (21% less energy growth by 2030 relative to GDP growth)
Other	Industrial GDP	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)

a) Textiles

The textile sub-sector energy service demand is ***not*** developed using the industry sector GDP growth as the driver. Because of the importance of this sub-sector and because of the international competitive factors that strongly influence its growth, it was decided to develop independent growth factors for each segment of the textile sub-sector based on data from the 2010 Economic Survey. Those growth factors are shown in Table 48 and are given in REF, MED and LOW. The growth rates for each textile industry segment and demand scenario were developed based on near-term issues as well as expected long-term trends.

Table 48: Textile Industry Component Growth Rates

Textile Industry		2009	2012	2015	2018	2021	2024	2027	2030
Yarn Production	REF	1.38%	3.50%	5.00%	6.00%	6.00%	6.00%	6.00%	6.00%
	MED	1.38%	2.00%	3.00%	4.00%	4.00%	4.00%	4.00%	4.00%
	LOW	1.38%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%
Cloth Production	REF	5.03%	6.00%	8.00%	9.00%	9.00%	9.00%	8.00%	7.00%
	MED	5.03%	5.50%	6.00%	6.00%	7.50%	7.50%	6.00%	5.00%
	LOW	5.03%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	4.00%
Garment Production	REF	-4.57%	1.00%	2.00%	3.00%	4.00%	5.00%	5.00%	5.00%
	MED	-4.57%	0.00%	1.00%	2.00%	3.00%	3.00%	3.00%	3.00%
	LOW	-4.57%	-1.00%	0.00%	1.00%	1.00%	1.00%	1.00%	1.00%

b) Sugar Production

The sugar sub-sector energy service demand is developed using the projected growth rate in sugar cane production[57] as the principal driver – and limitation on growth in the sub-sector. No elasticity factor or other factor was used. The report gives 2.5% growth potential, but for Pak-IEM this projection was moderated to 2% per annum.

c) Cement production

The cement sub-sector energy service demand is developed using the industry sector GDP growth as the principal driver, a construction sub-component elasticity, and a cement energy use elasticity factor (defined as the percentage change in energy consumption divided by the percentage change in GDP growth), which is based on review of cement sector trends in the 2010 Economic Survey.

Historically, the construction-related GDP growth relative to the industrial GDP growth was found to be highly variable, but the long-term average elasticity is zero, meaning that the construction component of industry GDP growth grows at the same average long-term rate as industry as a whole. Regarding the energy to GDP elasticity, the current trend toward cement exports is supporting strong near-term growth, but this trend is not expected to last for the long term. Therefore, the elasticity factor was varied over time (See Table 49) to allow for adjustment in this trend.

[57] Potential of Bagasse Based Cogeneration in Pakistan, Dr. Khanji Harijan, Dr. Mohammad Aslam Uqaili & Dr. Mujeebuddin Memon, World Renewable Energy Congress (WRECX) Editor A. Sayigh © 2008 WREC.

Table 49: Cement Industry Energy / GDP Elasticity

Cement Industry	2009	2012	2015	2018	2021	2024	2027	2030
Energy / GDP Elasticity	2.00%	2.00%	1.00%	0.00%	-1.00%	-2.00%	-2.00%	-2.00%

d) Iron and Steel

The steel sub-sector energy service demand is developed using the industrial component of GDP growth as the principal driver, and an energy use to GDP elasticity factor (defined as the percentage change in energy consumption divided by the percentage change in GDP growth). An elasticity of -1%, based on expert judgment, was used for the period up through 2030. While there are seven process-level demand for iron and steel, they are linked and so use the same values for the sub-sector elasticities.

e) Brick Kilns

The brick kiln sub-sector energy service demand is developed using the industry sector GDP growth as the principal driver, a construction sub-component GDP elasticity and a brick kiln energy use elasticity factor (defined as the percentage change in energy consumption divided by the percentage change in GDP growth). An elasticity of -1% was used, which is based on expert judgment. Historically, the construction-related GDP growth relative to the industrial GDP growth was found to be highly variable, but the long-term average elasticity is zero, meaning that the construction component of industry GDP growth grows at the same average long-term rate as industry as a whole.

f) Fertilizer

The fertilizer sub-sector energy service demand is developed using the agricultural component of GDP growth as the principal driver, and an elasticity factor (defined as the percentage change in energy consumption divided by the percentage change in GDP growth) of -0.5%, which is based on expert judgment.

g) Other Industry

The Other industry sub-sector energy service demand is developed using the industrial component of GDP growth as the principal driver, and an energy use elasticity factor (defined as the percentage change in energy consumption divided by the percentage change in GDP growth) 0f -1.5%, which is based on expert judgment.

7. Residential

The residential sector energy service demands are developed for the following end-use applications for both urban and rural households. All demands are in units of PJ.

- Space Heating
- Water Heating
- Space Cooling (Fans and Coolers)
- Space Cooling (AC)
- Lighting
- Cooking
- Refrigeration
- Miscellaneous Electric
- Other

The residential sector energy service demands are primarily driven by the growth in households, which are divided into urban and rural categories and further classified according to whether they are connected to the electricity grid. The projected number of electricity customers (households) is shown in Figure 49 for both urban and rural areas. For urban areas, the percentage of connected households is projected to go from 98% in 2007 to 100% in 2012. For rural areas, the number of connected households starts at the 2007 level and grows in proportion to the growth in rural population with additions for village electrification and migration from un-electrified areas to electrified villages. Rural households start at 81% electrified in 2007 and grow to 91% electrified in 2030.

Two other significant drivers to residential energy demand are the percentage of households with air conditioners and the percentage of households with refrigerators. Figure 49 shows the aggregate annual growth rate of these two major appliances for both urban and rural households. Households with refrigerators are expected to grow at an annual rate of 6% for urban households and 4% for rural households. Households with air conditioners are expected to grow at an annual rate of 6% for urban households and 3% for rural households.

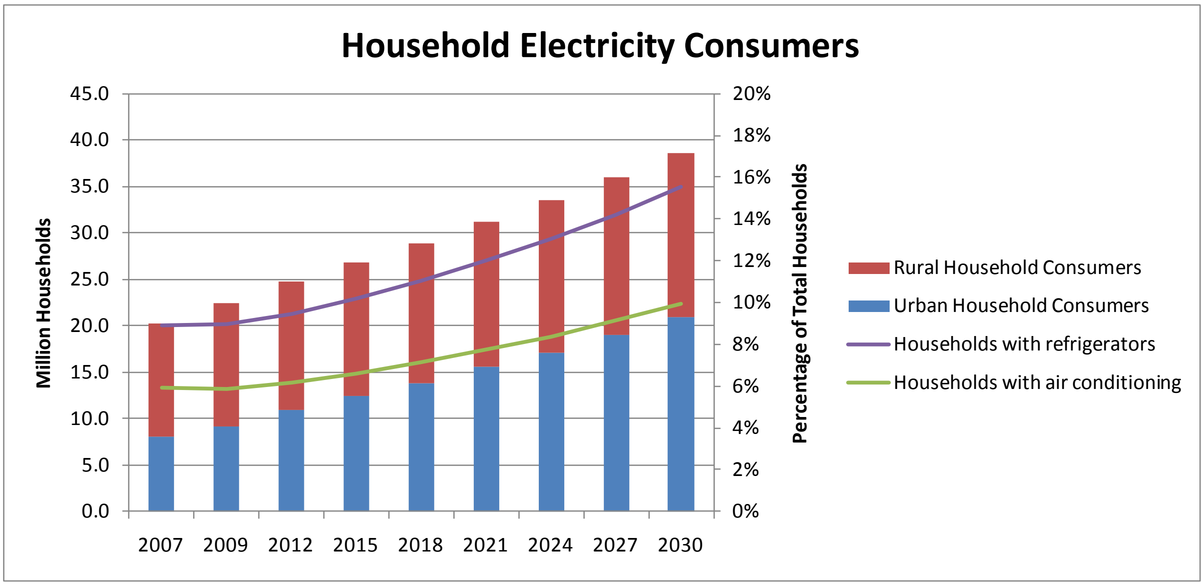


Figure 50: Number of Urban and Rural Electricity Consumers

For each end-use application, the average household energy use, as shown in Table 50, is determined from the disaggregation of the energy balance data combined with the urban/rural household data. As GDP in Pakistan grows, per-household energy use is projected to grow, and data developed by the World Resources Institute[58] was used to calculate the per capita energy intensity increase as shown in Figure 50, which shows the relationship between energy use per capita and GDP per capita.

[58] EarthTrends (http://earthtrends.wri.org) Searchable Database Provided by the World Resources Institute (http://www.wri.org): Energy and Resources – Energy Consumption: Residential energy consumption per capita.

Table 50: Average Household Energy Use in 2007

Demand	Average Household Energy Use in 2007 (kgoe)	
	Urban	Rural
Space Heating	42.7	67.0
Water Heating	145.7	76.9
Space Cooling (Fans and Coolers)	51.6	39.2
Space Cooling (AC)	16.5	3.6
Lighting	45.7	42.8
Cooking	542.4	581.4
Refrigeration	22.8	6.4
Miscellaneous Electric	22.3	12.0
Other	10.6	14.1

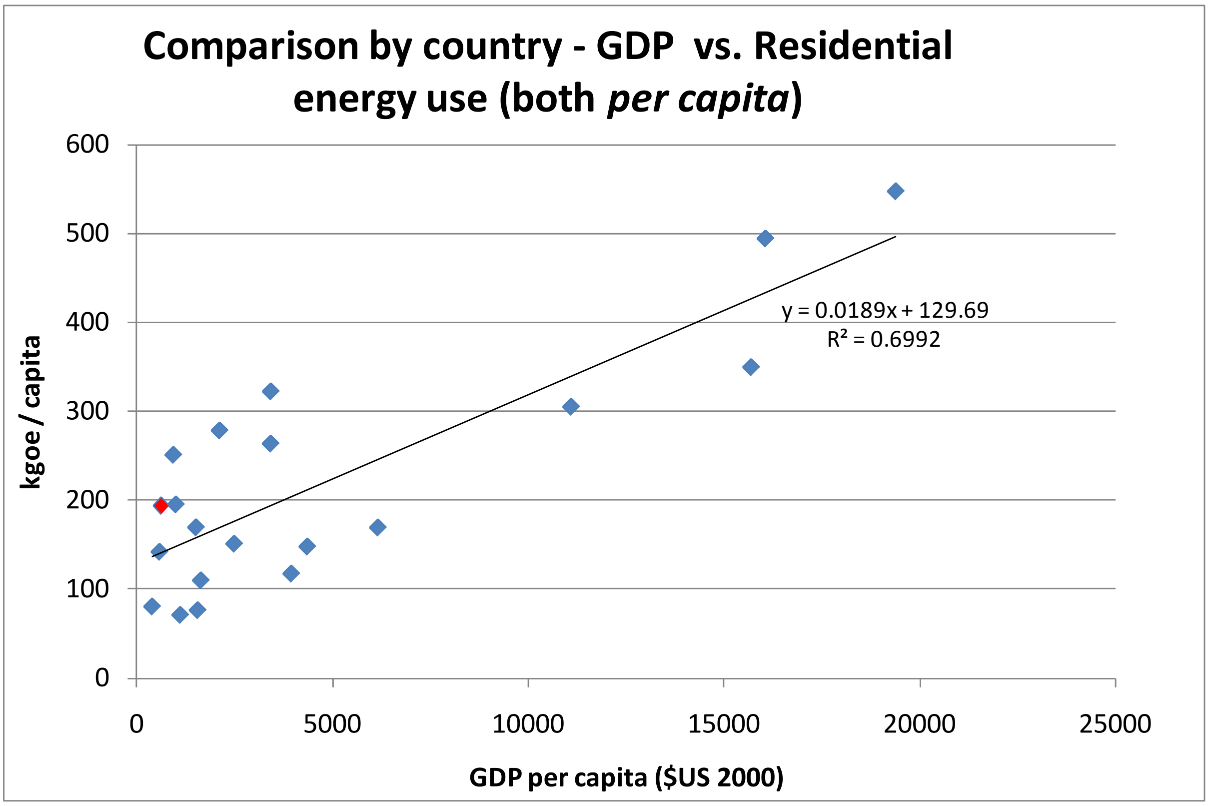


Figure 51: Comparison of Energy Use per GDP for Pakistan and Other Countries

The urban and rural household base year final energy demand for each end-use application is the calculated from the projected per capita energy use values multiplied by the relevant household population. To determine useful energy consumption at the end-use application level for both urban and rural households, the energy balance data was disaggregated – first by fuel type and then by end-use fuel share – so that typical device efficiencies could be estimated and applied to calculate useful energy demands.

The energy balance data was first apportioned between urban and rural households based on PSLM[59] data on percentages of households consuming various fuels. The relative energy use for urban and rural households is take from HESS[60] data to calculate the fuel shares between urban and rural households, which when multiplied by the energy balance data gives the urban and rural fuel use. This process is illustrated in Figure 51.

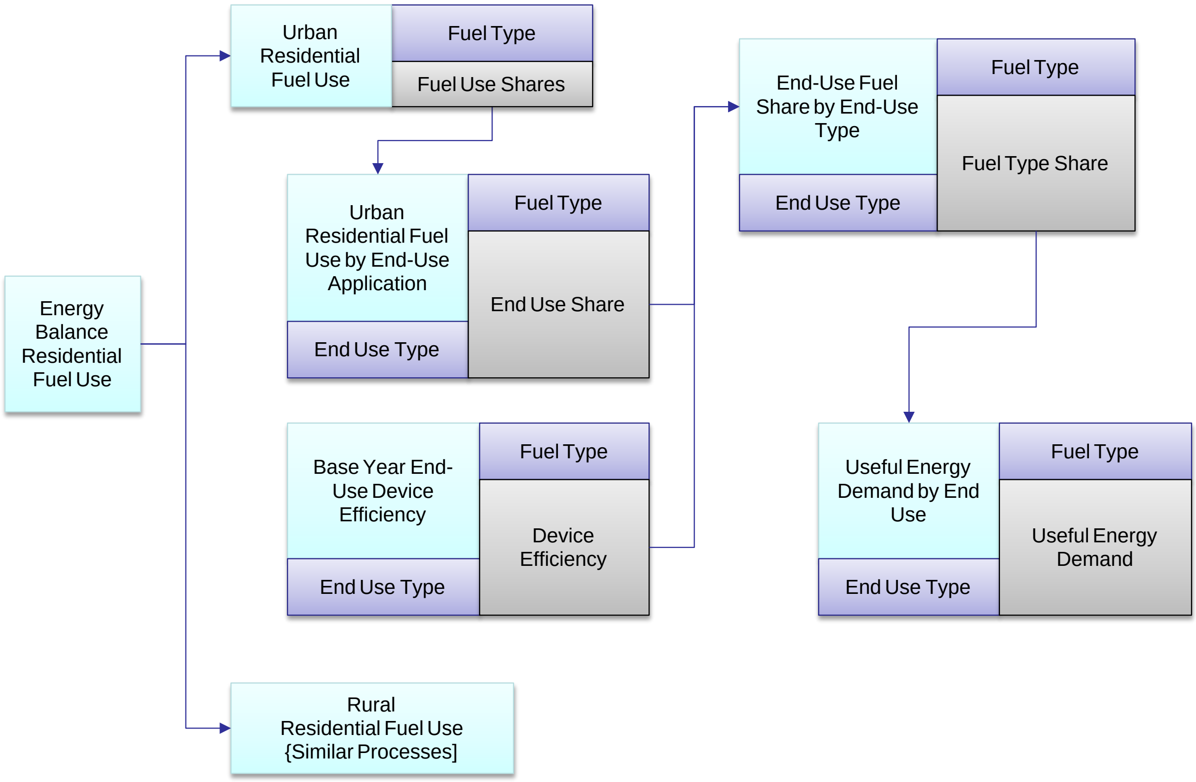


Figure 52: Diagram of Useful Energy Demand Development

The energy consumption shares by end-use application are calculated based on the fuel shares and energy consumption totals by end-use application. The base year efficiency value for typical devices by application and fuel type were based on expert judgment and were used to calculate useful energy consumption by end-use and fuel type. The urban and rural useful energy demands for each end-use application are shown in Figure 52 and Figure 53, respectively.

[59] Pakistan Social & Living Standards Measurement Survey PSLMS 2006-07.

[60] Pakistan Household Energy Strategy Study, Household Energy Demand handbook for 1991, The World Bank.

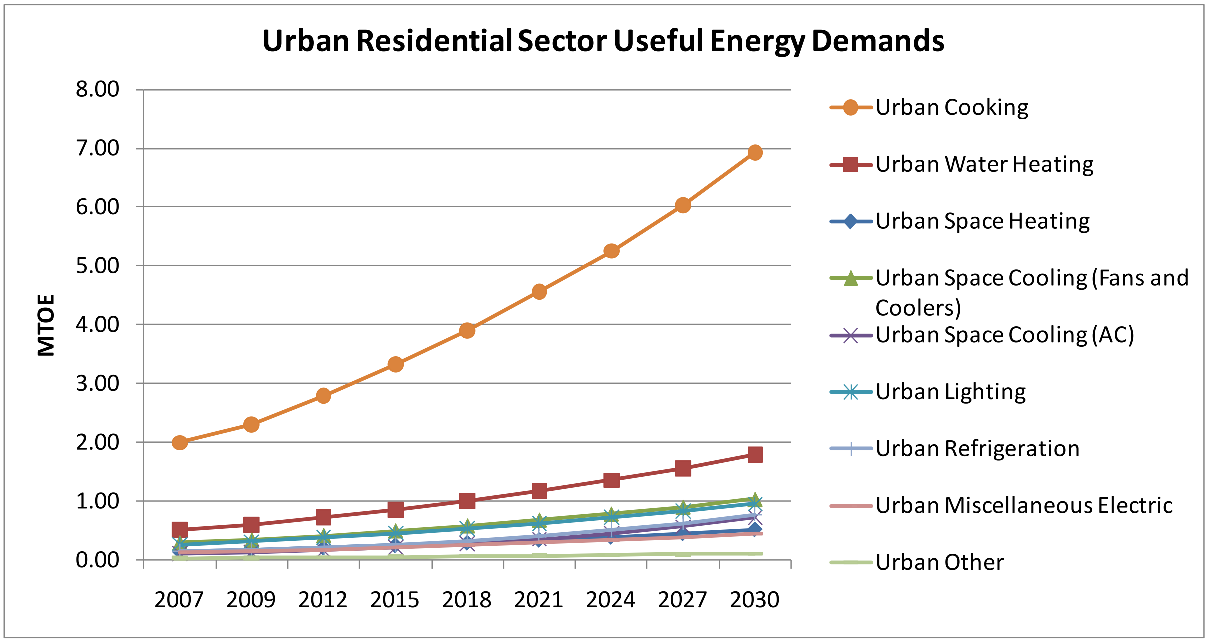


Figure 53: Urban Residential Sector Useful Energy Demands

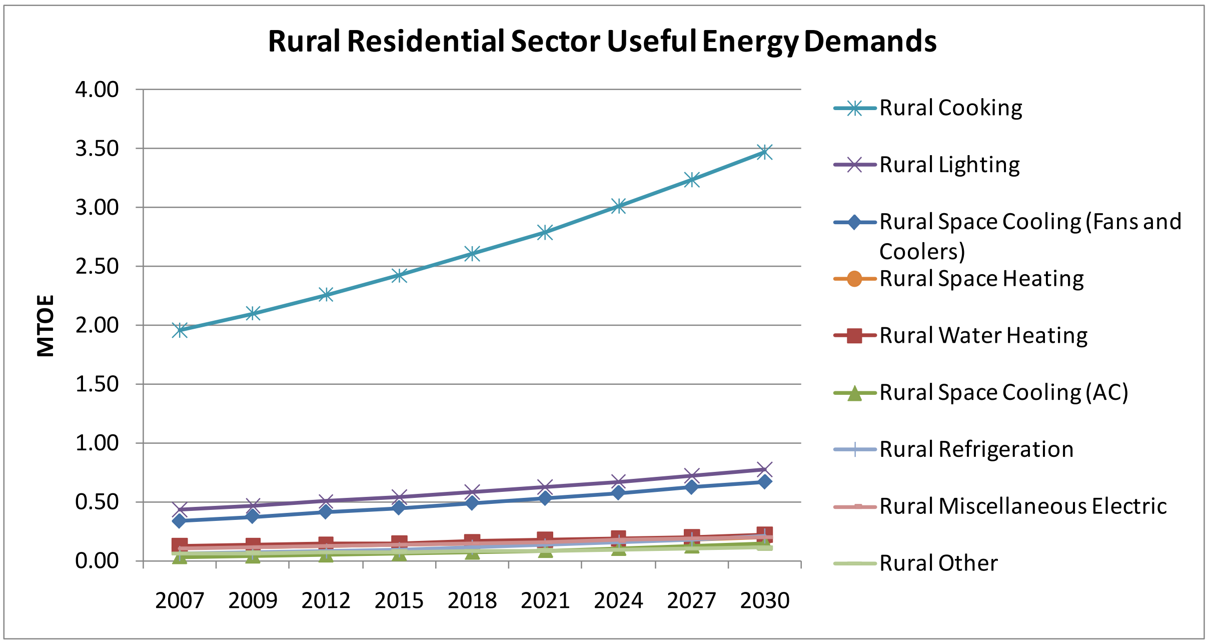


Figure 54: Rural Residential Sector Useful Energy Demands

8. Transport

The transport sector energy service demands are developed for the end-use applications listed below. There are two sub-categories of demands: passenger transport and freight transport. Most of the passenger transport demand is expressed in million passenger kilometers (mpkm) except for aviation, which is in PJ. Most of the freight transport demand is expressed in million ton kilometers (mtkm) except for shipping, which is in PJ.

Passenger transport	**Units**
• Buses	mpkm
• Cars	mpkm
• Two-wheelers	mpkm
• Three-wheelers	mpkm
• Taxis	mpkm
• Minivans	mpkm
• Rail Passenger	mpkm
• Aviation	PJ
Freight transport	**Units**
• Trucks	mtkm
• Delivery Vans	mtkm
• Rail Freight	mtkm
• Shipping	PJ

Overall GDP growth is the principal driver for this sector, and each sub-sector is related to the GDP growth through an energy use / GDP elasticity factor, which is defined as the percentage change in energy consumption divided by the percentage change in GDP growth. The Pakistan Transport Plan Study[61] was the principal reference used to calculate the elasticity factors. Table 51: Passenger Transport Energy /GDP Elasticity Factors provides the energy use / GDP elasticities used for the passenger transport sub-sector demand, and Figure 54 shows the resulting passenger transport demand level and shares. The per capita passenger transport demand goes from 3500 km/yr in 2007 to 6500 km/yr in 2030 with most growth happening for cars and two-wheelers.

Table 51: Passenger Transport Energy /GDP Elasticity Factors

Demand	Energy/GDP Elasticity Factor (Overall change in energy use relative to GDP growth)
Buses	-1.5% per annum (29% less energy growth by 2030 relative to GDP growth)
Cars	No change relative to GDP
Two-wheelers	-0.5% per annum (11% less energy growth by 2030 relative to GDP growth)
Three-wheelers	-0.5% per annum (11% less energy growth by 2030 relative to GDP growth)
Taxis	-0.5% per annum (11% less energy growth by 2030 relative to GDP growth)
Minivans	-1.5% per annum (29% less energy growth by 2030 relative to GDP growth)
Rail Passenger	No change relative to GDP

[61] Pakistan Transport Plan Study, JICA 2006.

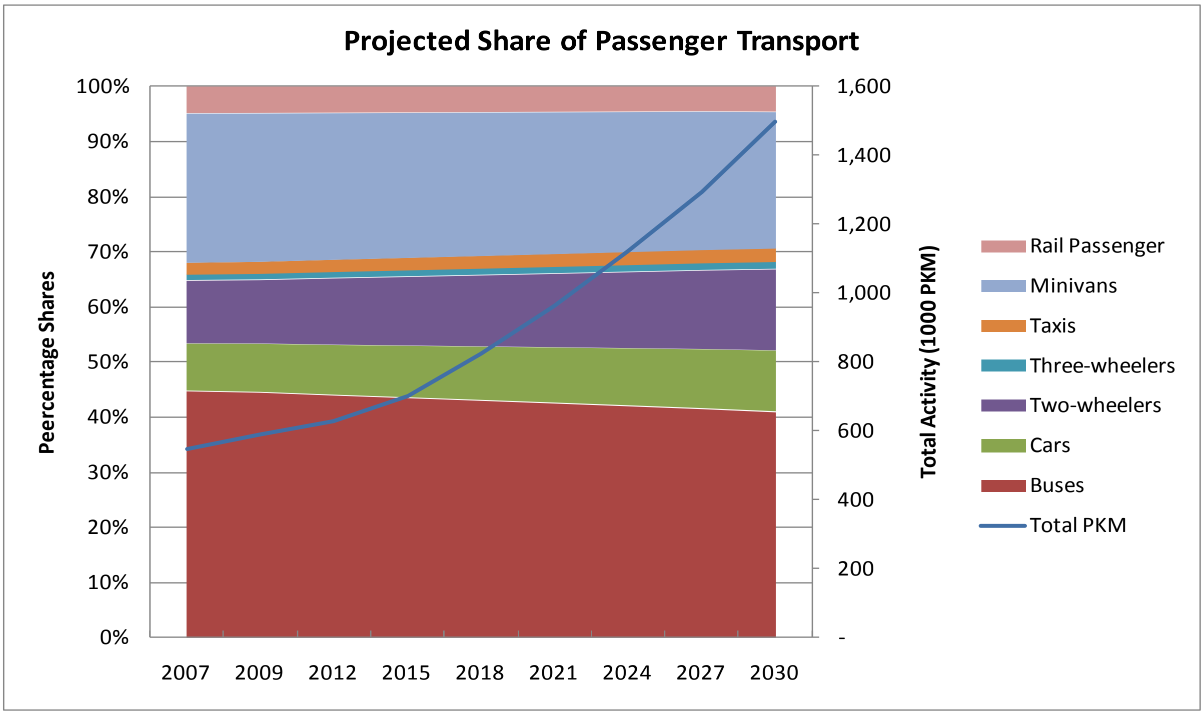


Figure 55: Passenger Transport Demand Projections

The Pakistan Transport Plan Study[62] was also the principal reference used to calculate the elasticity factors for freight transport. Table 52 provides the energy use / GDP elasticities used for the freight transport sub-sector demand, and Figure 55 shows the resulting freight transport demand level and shares. The freight transport demand increases by a factor of 2.5 between 2007 and 2030 with freight rail showing an increasing share over time.

Table 52: Freight transport Energy /GDP Elasticity Factors

Demand	Energy/GDP Elasticity Factor (Overall change in energy use relative to GDP growth)
Trucks	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)
Delivery Vans	-1.0% per annum (21% less energy growth by 2030 relative to GDP growth)
Rail Freight	No change relative to GDP
Aviation	Increase by 1.0% per annum (21% less energy growth by 2030 relative to GDP growth) & 1.2% Autonomous Efficiency Improvement factor
Shipping	-0.5% per annum (11% less energy growth by 2030 relative to GDP growth)

[62] Pakistan Transport Plan Study, JICA 2006.

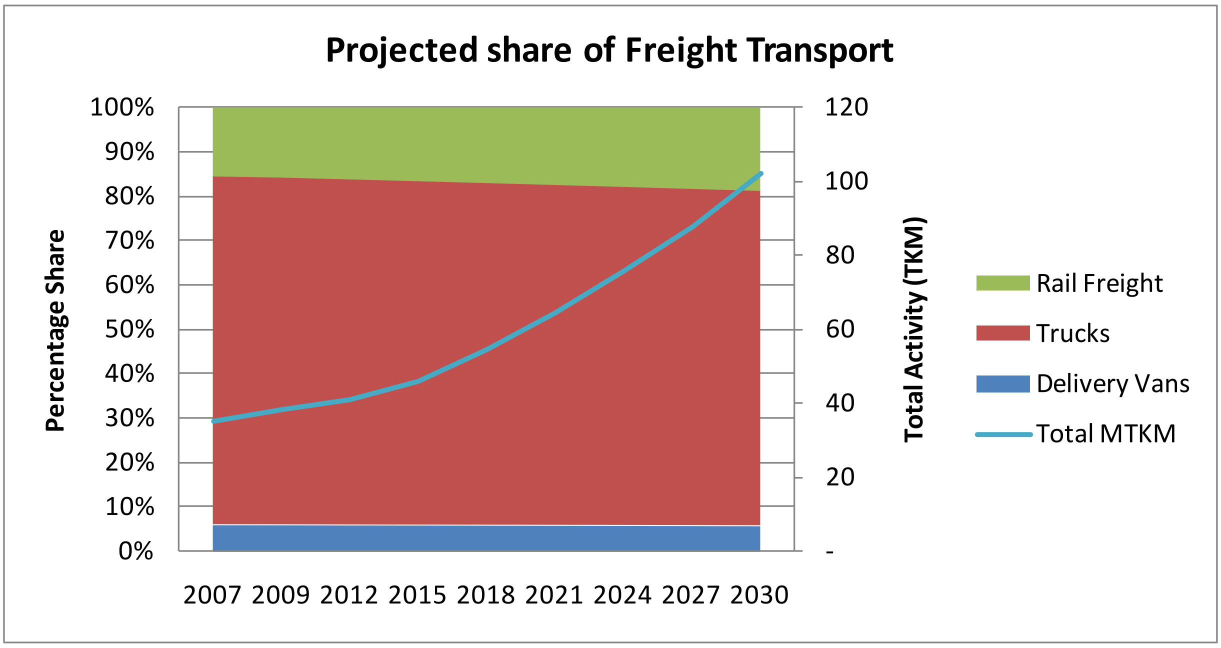


Figure 56: Freight Transport Demand Projections

VIII. Base Year Calibration

The Pak-IEM model has been calibrated so that it reflects the published energy balance as published in the Energy Year Book 2007. The goal of the calibration is to match the total energy supply, electricity generation, and energy consumption by fuel type across the entire energy system. This calibration is important, as it ensures that the energy system in the base year closely represents the ground reality, as reflected in the energy statistics. The first year of the model also needs to be properly calibrated because the base year energy service demands derived from the energy balance provide the seed for the demand projection drivers.

The User Guide describes the process (or mechanics) of checking the base year calibration so that is not repeated here. Four specific metric have been checked:

- Primary energy production
- Final energy consumption
- Power sector consumption / production
- Temporal electricity demand profile

Current calibration checks show that both primary energy production and final energy consumption in the model base year vary less than 0.2% from what is reported in the Energy Year Book.[63] The power sector fuel consumption is also subject to checking; this varied only slightly from the published statistics by 0.5% due to small levels of under consumption by gas plants. Note that these calibration checking metrics (described in the User Guide) are not exactly the same as the standard primary and final energy tables, as they have been specifically set-up for calibration checks.

An important aspect of the electricity system that has been subject to some calibration work to get a reasonable representation in Pak-IEM is the electricity load curve. The load curve is calibrated using data from both PEPCO and KESC systems. To replicate this in the model, the timing and level of all of the individual sector demands at an aggregate level must match the reported data.

Figure 56 shows the load curves in 2006/07 for each of the three seasons, showing demand for electricity (in PJ) in each hour. The dashed lines represent the model output and the solid lines, the actual reported data from KESC / PEPCO. There is currently a reasonable match in the model concerning shape of the curve and level of demand. However, some improvements are needed to better calibrate summer night demands, and improve the summer peak representation.

[63] See worksheet *Calibration* in model workbook *PakIEM_EnergyBalance-2007* for additional information.

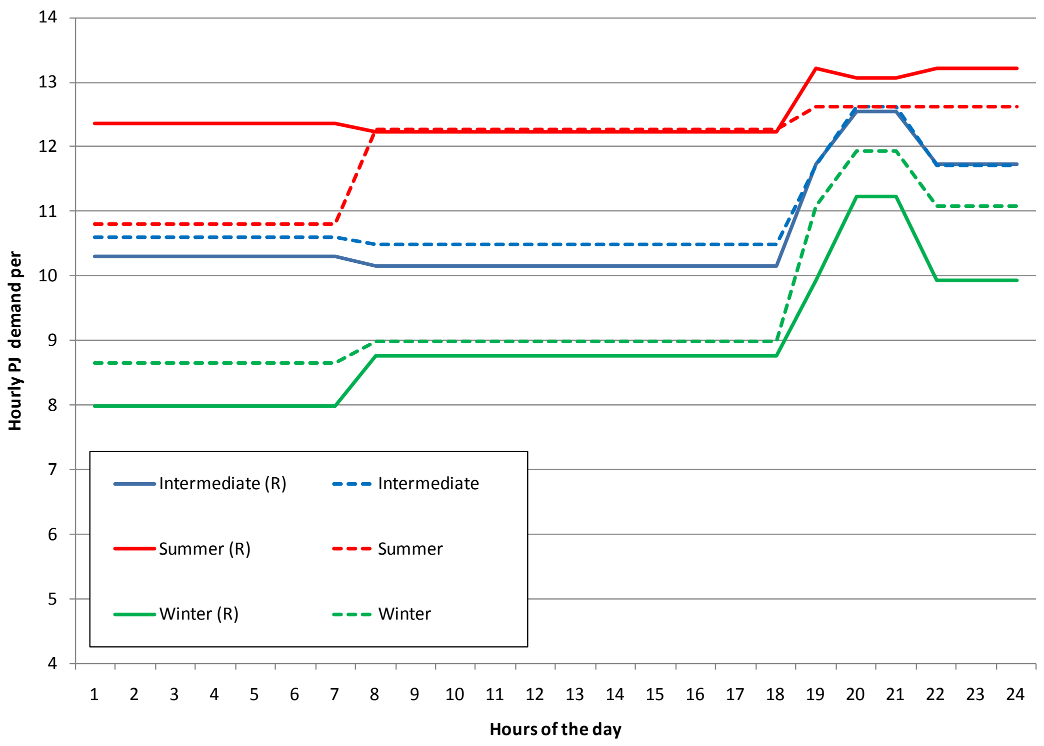


Figure 57: Reported load curve values versus model outputs

While other metrics have been subject to checking, namely carbon emissions, these have not been introduced systematically into the calibration process. This should be done as part of future model development.

IX. AREAS FOR FURTHER MODEL DEVELOPMENT

This first version of Pak-IEM provides significant analytical capability for assessing Pakistan's different energy policy issues. However, like with all models, there are potential areas for improvement, both structural and with respect to data availability. This section of the report outlines the areas for improvement although does not definitively state what should be the priorities; this is to be determined by the Planning Team, and their Advisory Committee.

Cross-cutting model enhancements

- Development of model regions, to provide additional insights into regional energy issues and policy options
- Track investments made by public / private sector in the model so that different constraints can be put on the different financial flows
- Explore alternative objective function formulations
- Increased use of economic constraints to control technology uptake through higher technology specific discount rates, representing barriers. These could replace the more rigid UC share constraints used in the model.

Potential improvements by sector are described below.

Resource supply

Issue	Description
Tight gas resource	The resource is included in the model but further work is required to develop extraction cost estimates, and timing of resource availability.
CCS transport and storage	The structure is set up in the model but further assessment of storage potential and costs is needed.
Gas network	Gas network expansion costs need further review, particularly the use of cost data provided as investment per KM (see DG GAS data file *Response of DG Gas 4-10-2010.pdf.*
Gas processing	Gas processing technologies (cost and processing efficiency) could be added if data can be obtained.

Refinery sector[64]

Issue	Description
Potential further development of existing refinery characterization	This is based on information provided by different refineries, relating to future upgrades and the costs of oil transportation. An obvious improvement would be to differentiate crude transport costs depending on the crude input mix (based on domestic region), taking care that these were not already included in the operating costs.

[64] The notes of the July Refinery Sector Task Force Meeting suggest that it would not be a priority to enhance Refinery to multi-stage and that a single block representation suffices. At the September meeting, there was no real support for developing API representation by crude type. At the present time, there is not the data to model this anyway.

Power sector

Issue	Description
Discrete investments	To increase use of discrete investment, a list of plants need to be identified for inclusion, and the permitted discrete investments. This also applies to specific investments in the resource supply sector e.g. import gas pipelines, refineries, LNG terminals, etc.
Additional transmission costs	Power plant that require additional transmission network due to their probable location should be identified and costs estimated. The structure has been set up in the model.
T&D system upgrade	Further development of options for upgrade of existing network could be considered. KESC has provided information on options for reducing losses and T&D investment costs (see file *KESC's Response 23-9-10.pdf*).
Electricity prices	Further assessment of electricity prices in different timeslices, considering whether load curve data used needs to be reviewed to ensure peak period prices.

Residential / Commercial sector

A significant need for the residential and commercial sectors is improved data to better characterize the level and timing of fuel use types for different energy services. This is needed for different income groups in the residential sector and sub-sectors for the commercial sector. In addition, a better understanding of the types of technologies used is also important.

No significant work has been done on these issues since the HESS study. A large-scale survey to better underpin the data assumptions in the model for these sectors is seen as a major priority.

Specific issues pertinent to the residential sector are listed below:

Issue	Description
Income classes	Further disaggregation of urban / rural into income classes.
Uptake of AC	Information on recent trend in uptake of AC needed, and data on future trends.
Biomass substitution	Consideration of rate of switching away from biomass needed for rural / urban households.
Future energy intensity	Estimates needed of changing household energy intensity over time.
Timing of device use	Further review of current timings used in model – based on load curve calibration.
Backup generation	Percent of households w/ gensets and amount (time) of use.

Industry sector

Further engagement with the industry sector is important for the further improvement of the model. In particular, the textile sector, one of the most important economic sectors in Pakistan, requires additional development, with greater engagement with the sector.

Specific areas for further model development are listed below:

Issue	Description
Textile sector characterization	Improved understanding of the sector composition and technology stock. In addition, further information on the evolution of the sector could be important to capture – to understand future energy needs / technology uptake.
Fertilizer sector development	This sector only tracks different types of natural gas use (fuel vs feedstock). If deemed important, the structure of this sector could be further detailed
Other industry	This “catch all” sector is relatively large. Further consideration should be given to further break out of other sectors

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XI. APPENDICES

Appendix 1. Model Naming Conventions

This section describes the naming convention guidelines that are being used in the Pak-IEM model.

1. Demand sectors

The five major demand sectors use the following names.

- Agriculture (AGR)
- Commercial (COM)
- Industrial (IND)
- Residential (RSD)
- Transportation (TRN)

The sub-sectors in each of these sectors begin with the first letter of the sector name, and the next 2-4 characters identify the various end-use services within the sector, or in the case of industry, the specific sub-sector.

2. Commodity Names and Descriptions

The names for the core energy carriers (NRG) and materials employed in the model are listed in Table 53. For most commodities a root identifying the nature of the fuel (e.g., BIO, COA, ELC, GAS, OIL), then qualified by the form or particular instance of the fuel.

Table 53: Core Names of Energy Commodities

Core Name(s)	Resource
GASRAW	Raw Gas
GASNGL	Gas Liquids
GASASS	Assoc. Gas
GASNGA	Processed Natural Gas
OILCRD	Oil Crude
OILGSL	Gasoline
OILHSD	Diesel
OILHFO	Heavy Oil
OILKER	Kerosene
OILLDO	Lt Diesel
OILNAP	Naptha
OILAVG	Av. Fuel
OILLPG	LPG
COAD	Domestic Coal
COAI	Imported Coal
RNWHYD	Hydro
RNWSOL	Solar
RNWWIN	Wind
NUC	Nuclear
ELCC	Electricity Connected
ELCR	Electricity Remote
HTH	High-temp
BIOWDF	Wood (Free)
BIOWDP	Wood (Purch.)
BIODNF	Dung (Free)
BIODNP	Dung (Purch.)
BIOCRF	Crop Residues (Free)
BIOCRP	Crop Residues (Purch.)
BIOBAG	Bagasse

For sector fuels, six-letter commodity names have the first three letters removed and replaced by the sector label. Three- or four-letter names simply have the sector label added e.g. INDCOAD. The exception is ELCC / ELCR which would become for example INDELC.

Three other types of commodities are used in Pak-IEM: DEM (demands), ENV (environmental indicators, emissions in Pak-IEM), and MAT (materials).

The list of demand sectors (DEM commodities in TIMES) is provided below. The general rule is that the first letter will denote the sector, while the following letters will identify the energy service being provided or product being produced. In the residential sector, the second letter also denotes the sector, distinguishing between urban and rural.

Table 54: Names of DEM Commodities

DEM Name	Description
AOE	Agriculture Other Use
ATF	Agriculture Tractors - Farm Op.
ATH	Agriculture Tractors - Haulage
AWP	Agriculture Water pumping
CA	Commercial / Other Govt - Electric Appliances
CC	Commercial / Other Govt - Space Cooling
CH	Commercial / Other Govt - Space Heating
CK	Commercial / Other Govt - Cooking
CL	Commercial / Other Govt - Lighting
CO	Commercial / Other Govt - Other
CR	Commercial / Other Govt - Refrigeration
CW	Commercial / Other Govt - Water Heating
FTP	Fertilizer
IBK	Brick kilns
ICTP	Cement
IIS	Iron and Steel
IOT	Other Industry
ISGP	Sugar
ITXC	Textiles Cloth production
ITXG	Textiles Garment production
ITXY	Textiles Yarn production
RRA	Residential Rural - Space Cooling (AC)
RRC	Residential Rural - Space Cooling (Fans and Coolers)
RRH	Residential Rural - Space Heating
RRK	Residential Rural - Cooking
RRL	Residential Rural - Lighting
RRM	Residential Rural - Miscellaneous Electric
RRO	Residential Rural - Other
RRR	Residential Rural - Refrigeration
RRW	Residential Rural - Water Heating
RUA	Residential Urban - Space Cooling (AC)
RUC	Residential Urban - Space Cooling (Fans and Coolers)
RUH	Residential Urban - Space Heating
RUK	Residential Urban - Cooking
RUL	Residential Urban - Lighting
RUM	Residential Urban - Miscellaneous Electric
RUO	Residential Urban - Other
RUR	Residential Urban - Refrigeration
RUW	Residential Urban - Water Heating
T2W	Transport - Two-wheelers
T3W	Transport - Three-wheelers
TAV	Transport - Aviation
TBU	Transport - Buses
TCA	Transport - Cars
TMV	Transport - Minivans
TRF	Transport - Rail Freight
TRP	Transport - Rail Passenger
TSH	Transport - Shipping
TTR	Transport - Trucks
TTX	Transport - Taxis
TVN	Transport - Vans

The emissions being tracked in Pak-IEM include CO2, NOX and SO2. All are tracked at the sector level, and labeled, XXXCO2 e.g. INDCO2. Materials flows are still being finalized in the model; corresponding commodity names will be listed in subsequent Pak-IEM model reports.

3. Technology Names and Descriptions

Technology name rule definitions are described in Table 55, where the Technology type refers to the TIMES set designation.

Table 55: Naming Conventions for Technologies

Technology type	Description	Naming Convention
IRE (inter-regional exchange)	Resource supply technologies, providing energy to a region	• 3 letters – IMP, EXP or MIN • 6 letters – Full commodity Name • Indicating region or other information
PRE	Energy processes converting energy from one form to another	
	Refineries	• 'P' for process technology • 3 letters – 'REF' for refineries • 4 letters – Refinery name abbreviation • 2 letters – 00 for existing, 'N' or 08 for new
	X Processes (Dummy process technologies to track sector fuels in all end-use sectors)	• 'X' • 3 letters – 3 letter sector name • 3 letters – 3 letter commodity name • 2 letters – '00'
ELE	Electricity generation technologies	**Existing Tech** • ET,ER,EH to denote thermal, renewable or CHP • 6 letters – Full commodity Name (for thermal plant • 6 letters – Technology type (for renewable plant • 3 letters – Plant Name (abbreviated) **New tech** • ET,ER,EH to denote thermal, renewable or CHP • 3 letters – Technology identifier • 3 letters – Fuel identifier • 'N' to indicate new
DMD	Demand devices that are a subset of PRE that consume energy to meet the demand for energy services	• Starts with single letter to denote sector • 2 letters denoting energy service being provided • 3 letters denoting fuel consumed • Final letter 'E' to denote existing or 'N' to denote new

There are exceptions to the rules in the above table, but in general they hold across the majority of technologies.

Appendix 2. Model Templates

The templates constitute structured Excel workbooks that contain all the data embodied in Pak-IEM, from original data sources reference material, to the various component declarations and characterization required for a TIMES model. Each workbook is organized along these basic lines, taken from the power sector workbook. A fuller discussion of the workbooks can be found in the *Pak-IEM Final Report: Volume III – Users' Guide*.

Template Guide	
Name	**Description**
RES	Reference energy system diagram
ReviewComments	Table to input comments based on template review
Commodities	Definition of commodities used in sector (Model load table)
Processes	Definition of processes used in sector (Model load table)
Existing_PP	Model load table, characterising end use technologies across different subsectors
Sector_Grid	Model load table, characterising grids (and associated EFF losses)
Sector_Fuels	Model load table, characterising technologies that track sector fuel consumption
Emissions	Model load table, with subsector emission factors for CO2, NOx (BY only) and SO2 (BY only)
NTDC_ElecMtkData	Data from NTDC (2008), Electricity Marketing Data (Power System Statistics)
PEPCO_Therm	Data provided directly from PEPCO on thermal plants
PEPCO_HydelProd	Data provided directly from PEPCO on seasonal hydro generation
KESC_Therm	Power plant information provided directly by KESC
PakEYB2007-ELECT	Power sector information from EYB 2007
PakEYB2007-Renewable	Renewable generation information from EYB 2007
NEPRA_HydroCosts	Hydro O&M costs (calculated by MEC based on NEPRA tariff determination)
NEPRA_ThermalCosts	Thermal plant O&M costs (calculated by MEC based on NEPRA tariff determination)
Nuclear PP	Information on nuclear generation existing plants
Conversion	Energy conversion units
Currency	Currency exchange and deflator values [to be included]
Legend	
Status information	
Overview / Model declarations	
Model load sheets	
Primary data sheets (used in load	
Miscellaneous	

The complete set of templates constituting the Reference scenario are listed in Table 56. In addition a series of policy scenarios (prefixed with Scen_Pol-) complete the initial Pak-IEM model dataset.

Table 56: Pak-IEM Reference Scenario Workbooks

Model Template	Description
Base Year Templates	**Characterize sectors in the base year only**
VT_PAK_SUP	Resource Supply Sector
VT_PAK_ELC	Power Generation Sector
VT_PAK_AGR	Agriculture Sector
VT_PAK_COM	Commercial Sector
VT_PAK_RSD	Residential Sector
VT_PAK_IND	Industry Sector
VT_PAK_TRN	Transport Sector
SubRes	**Characterizes technology options for future years**
SubRES_NewTechs	New technology database
Demands	**Future demands by energy service type**
DEM_PIEMRef	Demand projection drivers (plus supporting data)

Model Template	Description
DEM_PIEMLow	Demand projection drivers (plus supporting data) – Low growth
DEM_PIEMMed	Demand projection drivers (plus supporting data) – Medium growth
Dem_Alloc+Series	Driver allocation to specific drivers
Scenario files	**For implementing scenarios, or introducing additional model parameters that cut across different BY templates**
Scen_REF-FR	Demand FRs to characterize timing of demand (plus supporting data)
Scen_REF-DMD	Set-up to control fuel and technology shares in end use sectors
Scen_REF-ELC	Scenario to ensure power plant operation, introduce build rates and model load shedding
Scen_SectorPrices	Sector fuel prices (to undertake financial approach

Appendix 3. List of unpublished sources

In this appendix, all of the data files sent directly by data providers and used in the model have been listed. As these are not published sources in the main, they have all been provided electronically to the Energy Wing (EW) / Planning Team, categorized by sector (as shown below). These files reside in the Sources folder on the Pak-IEM FTP site established for this project.

Sector	Data Provider	Data	File Name	Date provided	Sent to IRG by
Resource Supply	DGPC	Supply by field to 2035	Long term Oil Projections-DGPC.xls		EW
	DGPC	Supply by field to 2035	Long term Gas Projections-DGPC.xls		EW
	DGPC	Estimate of tight gas reserve	Response of DGPC 7-10-2010.pdf	Letter dated 7th October 2010	EW
	DG Minerals	Supply by field to 2015	Long term Coal Projections.xls		EW
	NARC	Biomass potential estimates	Biomass resource-Munir.jpg		MEC
		Oil pipeline information			
Gas Supply	SSGC	Pipeline cost estimates	SSGC pipeline estimates 14-02-10.doc		
	DG Gas	Pipeline utilization, based on information provided by SSGC / SNGPL	Letter & Data from DG Gas.pdf	Letter dated 26th May 09	EW
	DG Gas	Costs of grid expansion	Response of DG Gas 4-10-2010.pdf	10.10.08	Mr Latif (EW)
	SSGC	Monthly consumption data by sector	Categ-det_Jul'06-Jun'07.xls (Industry) Comm_2006-2007-1.xls (Commercial - unused in model)		EW

Sector	Data Provider	Data	File Name	Date provided	Sent to IRG by
			Domestic-overall-fy0708.xls (unused in model) SLAB WISE Domestic CONSUMPTION 2007-08.xls (unused in model)		
	SNGPL	Monthly consumption data by sector	SNGPL Consumer Data 2007 and 2008.xls Slabwise Breakup of Domestic Consumers.pdf (unused in model)		EW
	ISGS	Information on timing and costs of gas import pipelines	ISGS's Response 28-9-10.pdf	10.10.08	Mr Latif (EW)
Oil Refining	Attock Refinery		PIEM Refinery Data_Attock.xls Attok Refinery Response 17-9-2010.pdf	09.11.02 10.09.17	Mr Latif (EW) Mr Latif (EW)
	Bosicor Refinery		PIEM Refinery Data_Bosicor.pdf	09.11.02	Mr Latif (EW)
	National Refinery		PIEM Refinery Data_National.xls NRL Response 9-9-2010.pdf	09.11.12 10.09.09	Mr Latif (EW) Mr Latif (EW)
	Pakistan Refinery		PRL_Refinery_Data.pdf	10.09.20	Mr Latif (EW)
	PARCO Refinery		CP-Reminder_letter_for_Refineries_ (PARCO).doc	10.05.24	Nauman Bhutta
Electricity Generation	KESC	Comprehensive dataset on KESC generation and distribution	PIEM KESC data.pdf		Mr Latif (EW)
	KESC	Hourly demand data for KESC system	Hourly_Demand_KESC.xls	10.03.24	Nauman Bhutta
	KESC	Load curve graphs (based on above	Load Curve _030310_KESC.doc	10.03.24	Nauman Bhutta

Sector	Data Provider	Data	File Name	Date provided	Sent to IRG by
		file)			
	KESC	Additional data from KESC	KESC data sheet.doc	10.03.24	Nauman Bhutta
	KESC	KESC information on options for reducing losses and T&D investment costs	KESC's Response 23-9-10.pdf	10.10.08	Mr Latif (EW)
	PEPCO		PEPCO_Consumption_Patterns.xls		MEC provided XLS data (based on information provided by PEPCO)
	PEPCO		PEPCO 24 hour and seasonal load profile data_v03.xls		MEC provided XLS data (based on information provided by PEPCO)
	PEPCO	Information on load shedding on PEPCO system and captive generation plus generation	Power Sector Load Shedding & Captive Power Data.pdf (+ XLS copies)	09.08.19	Mr Latif (EW)
	PEPCO	IPP generation data	Data of Existing IPPs.pdf (+ XLS copy)		Mr Latif (EW)
	PEPCO	PEPCO information on plant retrofit, hydro potential, plant retirement, planned and recent new build and grid improvement	Response to Remaining Power Sector Issues 3-2-10.pdf	10.02.03	Mr Latif (EW)
	PEPCO	PEPCO thermal generation data	PEPCO Thermal Power Station.pdf (+ XLS copy)		Mr Latif (EW)
	PEPCO	Additional information regarding PEPCO thermal generation data	Planning Commission 20-03-09.xls		Mr Latif (EW)
	PEPCO	Data on transmission losses and	PEPCO Response 17-9-2010.pdf	10.09.17	Mr Latif (EW)

Sector	Data Provider	Data	File Name	Date provided	Sent to IRG by
		costs of transmission lines (in km)			
	PEPCO	Alternative load profile data from PEPCO	Hourly Load Data 2002-03.xls Hourly Load Data 2003-04.xls Hourly Load Data 2005-06.xls	September 2010	Mr Latif (EW)
Agriculture	Independent expert	Provision of data to validate tractor stock and fuel consumption estimates	Independent Expert TRACTORS 30-03-09.pdf	09.03.30	Provided by MEC
	Independent expert	Data on stock of combines provided at Task Force meeting	Agricultural & Transport_subgroup_Summary_v03.doc	04.08.09	
	NARC	Estimates of tractor and biomass stove costs	NARC Correspondance_Tractor&StoveCosts.doc	29.01.10	Dr Munir (NARC)
Industry – I&S	Pak Steel	Fuel consumption and production statistics	Pak Steel Data 12-2-2010.pdf	10.02.12	Mr Latif (EW)
	Pak Steel	Additional responses to queries	PakSteel Qry Responses _032010.rar	10.03.24	Nauman Bhutta
	PSRMA	Response to request for information from EW	Pakistan Steel re-Rolling Mills Association.pdf		Mr Latif (EW)
	Magna Steel	Steel sector presentation	Steel Sector Presentation Final on 10-8-09.ppt		MEC
Industry - General	ENERCON	ENERCON MIS database			MEC
Economic Indicators	Planning Commission	GDP forecasts	GDP Projections of Pl Commission.pdf	09.11.10	Mr Latif (EW)
Emissions	GCISC	Emission factors for GAINS (by technology-fuel) for CO2, NOx, SO2	Emission Factors (CO2,SO2,NOx)_GAINS.xls	10.01.27	GCISC (Kaleem Anwar)

Sector	Data Provider	Data	File Name	Date provided	Sent to IRG by
	GCISC	Emission factors for GAINS in 2005 for CO2, NOx, SO2	Emissions by Source Category GAINS 2005.xls	10.02.17	GCISC (Kaleem Anwar)

Appendix 4. Selected Examples of Energy Planning Applications Using MARKAL/TIMES

Developing/Transition Countries	Developed Countries
"Energy Policy and Systems Analysis Project," eight-country (3.5 year) capability building undertaking sponsored by AusAID under Phase III of the ASEAN-Australia Economic Cooperation Programme, http://www.epsapforum.com/. [See Exhibit C-3.]	Second National Communication of Italy for the United Nations Framework Convention on Climate Change, G.C. Tosato, M. Contaldi, and D. Gaudioso, prepared by ENEA for the Ministry of the Environment, 1999. Available from the Italian Ministry of the Environment, SIAR, Via Cristoforo Colombo 44, I-00100 Roma; also www.unfccc.de.
USAID is supporting the Athens Forum process for Southeast Europe by promoting capacity building in eight countries of the region to look at the potential for and implications of increased access to natural gas, energy efficiency, and accelerated economic growth.	Options for a Low Carbon – Phase 2, prepared by AEA Technology Plc. for the UK Department of Trade and Industry, 2002, http://www.dti.gov.uk/energy/whitepaper/phase2.pdf.
Modeling China's energy future: A China national MARKAL model including a large number of renewable energy, energy efficiency, and advanced clean energy technologies was used to determine the impact of advanced technologies to meet China's future energy demand, improve urban air quality, limit oil and gas imports, and reduce GHG emissions. Energy for Sustainable Development l Volume VII No. 4 l December 2003.	Final Report on DTI-DEFRA Scenarios and Sensitivities using the UK MARKAL and MARKAL-Macro Energy System Models, 2007, http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM.aspx.
Examining energy issues in South Africa including: • South Africa's first integrated energy plan. http://www.dme.gov.za/pdfs/energy/planning/integrated_energy_plan_dec03.pdf, and • Clean Energy and Development for South Africa, http://www.erc.uct.ac.za/publications/Report%201-%20Haw-Hughes.pdf • An Energy Model for a Low Income Rural African Village, Stanford University PESD, June 2003, http://iis-db.stanford.edu/viewpub.lhtml?pid=20219&cntr=cesp	EC New Energy Externalities Development for Sustainability (NEEDS) pan-European model integrated with life-cycle analysis, www.needs-project.org.
Models to Assess the Implications of the Kyoto Protocol on the Energy System and Economy of Colombia, Cadena Angela, HEC, School of Economy and Social Sciences, University of Geneva, Switzerland, 2000.	*The Third National Communication of the Republic of Latvia Under the UNFCCC*, Ministry of Environment Protection and Regional Development, 2001, http://www.varam.gov.lv/vide/publik/Epub.htm.
Including New and Renewable Technologies in Economy-level Energy Models, Asia-Pacific Economic Cooperation, September 2002, APEC#202-RE-01.011, ISBN: 0-9726293-0-0.	*System for the Analysis of Global Energy* markets (SAGE), Model Documentation, US Energy Information Administration, 2003 - Volume 1, http://www.eia.doe.gov/bookshelf/docs.html.
The Future of Natural Gas vs. Coal Consumption in Beijing, Guangdong and Shanghai: An	IEA Energy Technology Perspectives–Scenarios and Strategies to 2050, 2006 and

Developing/Transition Countries	Developed Countries
assessment utilizing MARKAL, BinBin Jiang, Program Coordinator, http://pesd.stanford.edu/news/chinagasreport/, September 2007.	bi-annually, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1693.
Enhanced Economic Modeling Capacity for Kazakhstan http://www.sofreco.com/projets/c886/Reports.htm, Task 6.	Northeast States for Coordinated Air Use Management, New England MARKAL Model, ongoing, http://www.nescaum.org/projects/ne-markal/index.html.

Of the undertakings mentioned above, the AusAID EPSAP is worth elaborating on a bit more owing to their proximity to Pakistan, and in many ways similar energy system challenges. To this end, the Table B-3 provides further evidence of the merits of MARKAL/TIMES for both capacity building and meaningful policy analysis for Pakistan.

Table B-3: AusAID EPSAP Undertaking Using MARKAL/TIMES

"Country"	Participating Institution	Study Description/Status
ASEAN	ASEAN Centre for Energy	• The Trans-ASEAN Energy Network - Analysis of gas pipelines and electricity interconnections • ASEAN Energy Market Integration
Cambodia	Ministry of Industry, Mines and Energy	• National Energy Policy - Analysis of Options
Indonesia	Badan Pengkajian Dan PenerapanTeknoiogi	• Gas Utilization: National Gas Pipelines, Alternative Fuel Mix for Power Plant and Demand Sectors • The Future Demand for Natural Gas in Indonesian Regions with Particular Reference to the Use of CNG in Transport • Future Technologies for Power Plants in Indonesian Regions with Particular Reference to the Use of Renewable Energy and Small Scale Coal Steam Plant
Laos	Ministry of Industry and Handicrafts, Electricity	• Energy Security and Diversity.
Myanmar	Ministry of Energy	• Energy Self-Sufficiency - Options and Strategies
Malaysia	PTM Malaysia Energy Centre	• Fuel Diversification - Economic and Environmental Impact of Alternative Fuel Mix • Cost and Environmental Impact of Renewable Energy Technologies • GHG Mitigation Options with Emphasis on Energy Efficiency and Renewable Energy Strategies
Philippines	Department of Energy	• Impact of Natural Gas Expansion • Promoting Renewable Energy in a Restructured Electricity Market • Increasing Renewable Energy Utilization by Full Cost Accounting of Electricity Supply
Thailand	National Energy Policy Office	• Removing the Subsidy on LPG and Implementing a Policy to Increase the Use of CNG in Transport • Fuel Options for Power Generation • Renewable Energy

Vietnam	Ministry of Industry	• The Strategy Orientation for Electricity Supply • Analysis of Power Development Strategies in Compliance with Environmental and Energy Security Issues • Energy Pricing and its Implication for Energy Efficiency and Environment

For other references to the application of MARKAL/TIMES in support of policy see the links posted on the ETSAP website (http://www.estap.org)for the various partner activities.

Appendix 5. Job description for role of Lead Energy Modeler and Analyst

Requirements:

Education:	Masters of Science Degree or Bachelors Degree with Computer Modeling Experience
Prior Work Experience:	Minimum of 5-10 years of relevant experience preferably in energy sector evaluation, computer model development, data collection and evaluation. Familiarity with optimization models a plus.
Software Experience:	MicroSoft Office (particularly Excel), Microsoft Outlook, computer software and programming language skills is beneficial.
Travel:	Domestic travel to Karachi and Lahore likely

Job Summary:

This position provides lead analytical and data management expertise to the Chief of the Energy Wing in conjunction with the Pakistan Integrated Energy Model (PIEM). Responsibilities include ongoing stewardship and application of the PIEM on behalf of the Planning Commission of the Government of Pakistan (GOP). The incumbent will manage Energy Wing staff working on the PIEM, coordinate with the PIEM Support Institution teams, provide data and interact directly with the data source institutions (PEPCO, NTRC, WAPDA, ENERCON, etc.). The candidate will be working with an international team of experts, providing data management and coordination assistance to a multi-national team of experts. General project support skills and a willingness to travel to a variety of GOP and key energy sector entities are required. Candidate must be capable of working independently or with minimal supervision on technical and energy modeling related tasks. Data collection, data management, and energy modeling are all integral to this position.

Duties and Responsibilities:

Project Management and Support Tasks:

- Support/ensure timely delivery of technical outputs (i.e. contract deliverables and data).
- Participate in energy modeling and capacity building exercises within the Energy Wing.
- Develop in-depth MARKAL/TIMES energy modeling expertise.
- Support data collection and model development.
- Serve as a central point of contact for a multi-national team of energy modeling experts on technical issues. Assisting with project management tasks as assigned.
- Provide guidance to project personnel, consolidate and manage large databases, support data collection, and serve as the lead energy modeling expert for the Energy Wing.
- Oversee the activities of the Energy Wing PIEM staff, and coordinate activities with the various PIEM Support Institutions (PAEC, UETT, PIAS, etc.)
- Assist in coordinating energy modeling workshops, capacity building exercises, and other managerial tasks as assigned.

Technical Requirements:

- Must have a science or engineering background.
- Level of comfort working with databases and computer models. Knowledge of Operations Research a major plus.
- Provide technical input, data management, and analysis.
- Demonstrated ability to manage and coordinate support staff and other institutions in a collaborative manner.
- Ability to communicate effectively by preparing briefing material and reports relating to the PIEM analyses being undertaken.