Modeling and Analysis of Long Term Energy Demands in Residential Sector of Pakistan

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Abstract-Residential sector is the core among the energy demand sectors in Pakistan. Currently, various techniques are being used worldwide to assess future energy demands including integrated system modeling (ISM). Therefore, the current study is focused on implementation of ISM approach for future energy demand analysis of Pakistan's residential sector in terms of increase in population, rapid urbanization, household size and type, and increase/decrease in GDP. A detailed business-as-usual (BAU) model is formulated in TIMES energy modeling framework using different factors like growth in future energy services, end-use technology characterization, and restricted fuel supplies. Additionally, the developed model is capable to compare the projected energy demand under different scenarios e.g. strong economy, weak economy and energy efficiency. The implementation of ISM proved a viable approach to predict the future energy demands of Pakistan's residential sector. Furthermore, the analysis shows that the energy consumption in the residential sector would be 46.5Mtoe (Million Ton of Oil Equivalent) in 2040 compared to 23 Mtoe of the base year (2007) along with 600% increase in electricity demands. The study further maps the potential residential energy policies to congregate the future demands.

Keywords-Energy Modeling, TIMES Model, Residential Sector, Pakistan

I. INTRODUCTION

At the current age, economic growth depends on the availability and affordability of sustained energy supplies and vice versa [i]. Energy demand is increasing globally due to population growth, improved living standards, access and availability of energy resources to the poor especially in developing countries [ii]. Several future outlooks show that by 2040, the world population is likely to increase from 7 billion to around 9 billion, with 35% more energy demand than of current level [iii-iv]. The world energy consumption has also been grown at a rate of 5.4% per annum in residential buildings since 1992 [v]. In Pakistan, the energy demand is also increasing exponentially due to a rapidly growing population and the number of households. Pakistan stands at six among the most populous countries in the world, having a population over 180 million in 2013, and the future estimates show over 350 million citizens in 2035 [vi]. At present, Pakistan is facing the severe energy crisis and energy shortage has declined the economic growth [vii]. This energy crisis has also ruined the social welfare and created unrest in the form of unemployment and mental anxiety. Based on the data of 2013-14, all major sectors (residential, industrial, commercial, agriculture, and transport) consumed nearly 60 Mtoe of final energy. The electricity balance has been severely disturbed due to 7000-9000 MW shortage in energy supplies in 2013 [viii].

In the developed countries, residential sector mostly consumes about only 20-25% of final energy and stands at a 3rd or 4th place among the other demand sectors [ix]. However, the residential sector in Pakistan consumes much higher of nearly 46% of total produced electricity[x]. Therefore, nowadays the residential sector has become the largest end-user of energy supplies both the commercial and non-commercial energy resources. This consumption has exceeded the industrial sector, which is an alarming situation to the future economic development, energy security, and sustainability. The higher level of energy consumption in the residential sector is due to non-functioning of the industrial sector - owing to also many other factors like terrorism, worse law and order situation, and energy crisis. In the recent past, the residential sector has also been enormously affected by the technology and behavioral changes due to increase in living standards since 1990. The cities having better facilities also appeal people from rural areas, and it has congested poorly planned old cities with limited resources. Estimates show that the population living in urban households is nearly 38% [xi]. Urban households consume about threefold energy than rural households. The urbanization is increasing at an average rate of 3% per year since 1995 [xii]. As the residential sector is heavily subsidized by government, both for electricity and natural gas commodities, it is a challenge to fulfill the future needs without properly planned infrastructure and deployment of proven energy management strategies.

The purpose of the study is to assess the future energy demands in residential dwellings in a long-term perspective i.e. 2040. This assessment is of great importance for future energy policies, such as the development of the nation-wide energy network and the planning of capacity expansion [xiii]. Furthermore, the precise forecast of energy demand is also vital for effective policymaking on capital-intensive projects. The study portrays the existing consumption of energy commodities in households and projects the future energy demands by modeling the household sector up to2040, for three different policy cases, slow economic growth, strong economic growth, and household sector energy efficiency at 10% to the existing base case. Section 2 of the paper offers an overview of historical trends of energy consumption by various sectors relative to the residential sector in the country. Section 3 illustrates the business-as-usual case development in TIMES energy modeling paradigm and its structuring with key assumptions. Section 4 contains the future energy demand projections resulted from the energy model and examines the outcomes of scenario cases in detail. Section 5 finally concludes and summarizes the future energy demands and limitation of study.

II. DATA AND METHODS

A. A Review of Sectoral Energy Consumption in Pakistan

In developing economies like Pakistan, the residential sector dominates for overall energy demands among all other sectors because of the low scale of economic activities in the industrial, commercial, or agriculture sector [xiv]. The dwelling units consumed more than 9.5 Mtoe of commercial energy in 2012 [viii]. Moreover, shrinking the economic growth in industrial and agriculture sectors has been observed due to intense energy outages of natural gas and electricity. For 2012, total primary energy supplies were about 65.0 Mtoe including all energy resources, imported fuel, hydropower, natural gas, oil, and biomass, etc. Being agrarian society, biomass energy resources share over one third of the total primary energy supplies. Natural gas as an indigenous resource commodity provides nearly 32% share in the overall primary energy mix, while the last year oil commodities imports were over 22.0 Mtoe. Total electricity production was over 6.2 Mtoe in 2013 and the electricity consumption in the residential sector was 3.0 Mtoe [x]. Existing sectoral energy consumption and historical fuel supplies to the residential sector from 1985 to 2012 are shown in Fig. 1 and Fig. 2.

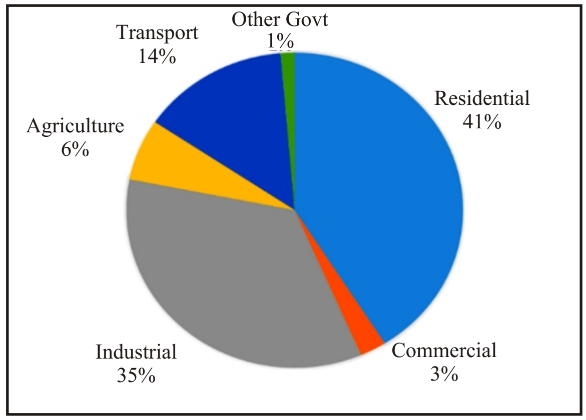

Fig. 1. Sectoral energy consumption profile among demand-side sectors

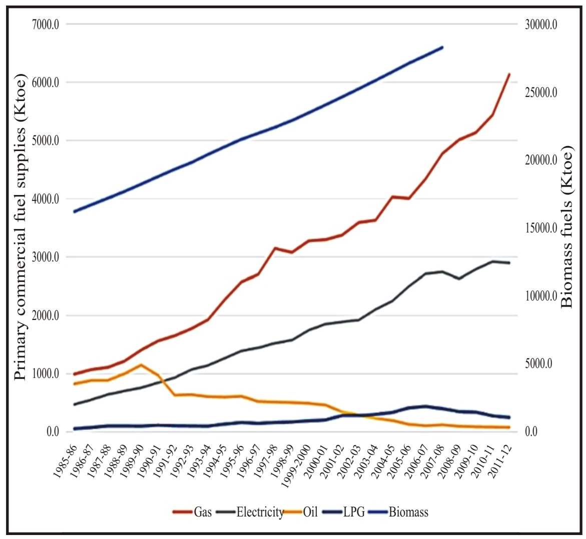

Fig. 2. Primary energy supplies, including commercial and non-commercial fuels

B. Main Drivers of Energy Consumption

Many factors are involved in residential energy consumption like rapid population growth, increasing urbanization and improved lifestyle [xv-xviii]. According to government statistics, electricity consumption in residential sector was 20 TWh in 2000. In 2013, the residential sector's consumption reached to 35 TWh [xviii-xx]. This rise is mainly due to higher urbanization and rapid growth in population [xxi]. The income level is another most vital factor inenergy use, as the division of resources, in poor economies and under developed countries, is dependent on the family's wealth. Accessibility and availability of energy commodities depend upon the affordability [xxii]. Estimates show that about 40% population live below the poverty line based on mostly in the suburbs and rural areas in Pakistan [xii]. This segment of society, in common, relies on minimal commercial energy resources. These households consume relatively dirty fuels particularly for cooking purposes because of limited financial resources.

In developed countries, many studies have been carried out related to energy management in dwellings as there is a large potential in energy savings by virtue of efficient end-use devices and building equipment like insulated and glazed windows, walls, roofs [xxiii-xxvi]. Deploying energy conservation and efficiency improvement schemes in different income groups may also reduce energy use [xxvii]. In the developing world, household income is strongly related to energy expenditures intended for various energy services. The other correlated factor with household's income is the use of inferior quality and more energy consuming appliances. But the technology characterization is not only the sufficient criterion to elucidate the requirement of final energy as dwellings also exhibit varying socio-economic characteristics, even in similar geography. Some studies examined the energy requirement in households and also attempted to establish the relation between energy requirements and socio-economic factors such as income and lifestyle [xxviii].

III. TIMES-PAK METHODOLOGY

The study deploys TIMES (The Integrated MARKAL-EFOM System) energy model to reveal the required energy and technological resources, particularly in the residential sector. The approach presented in this study may provide the consistent modeling framework to evaluate the energy needs in urban and rural dwellings. Besides, this methodology has two additional advantages. Firstly, the model based on mainly bottom-up approach may capture the energy intensity of an individual social group such as urban and rural instead of assuming the sector as a whole. Secondly, it has the ability to assess the potential of energy savings by substituting different set of technologies for each end-use energy service. This type of technological characterization allows constructing detailed energy scenarios. In Pakistan, long-term integrated energy planning could not be functional in the past and hence, this study would contribute to consolidate efforts in this subject [xxix]. The starting point was the quantification of energy demand for different end-uses at household level, and we gathered data regarding fuel shares and main energy services from different published and unpublished sources.

TIMES energy modeling platform is widely used to evaluate the long term energy demands from municipal level to global level [xxx-xxxiii]. In energy modeling, exogenous variables are required like the end-use energy statistics at sector/sub sector level, existing technology characterization, competing technology datasets, and sub-models predicting population and economic growth in the future. After, the model generator solves the whole energy system on the basis of least-cost [xxxiv-xxxvi]. By setting the residential base year (2007) data, e.g. available energy resources and energy service demands subjected to many physical and economic constraints, we developed a BAU (business-as-usual) case to predict the future energy demands.

A. *Utilized Data and Structuring*

The residential sector in this study was modeled as a single geographic region to simplify the modeling insights in the long term planning horizon. Two approaches were used to characterize this sector; top-down decomposition and bottom-up aggregation [xxxvii]. Top-down approach was necessary due to non-availability of data such as the fuel resources used by existing stock of household end-use devices. For this activity, fuel-shares were decomposed to be used in each end-use. These shares were further cross checked by expert judgment and surveys. Two important reference documents were used to validate the fuel characterization on an average basis in dwelling units such as Energy Yearbook (2007), Economic Survey of Pakistan and Energy Sector Management Assistance Program (ESMAP) [xx]. Besides this, other necessary data was collected through many empirical research resources, technical reports, including Planning Commission, National Electric Power Regulatory Authority (NEPRA), and other government and non-government agencies.

Contrary to it and also to validate the proper formulation of input dataset, bottom-up aggregation was also used. Energy consumption patterns on daily basis were surveyed for different income group householders, and then were normalized on an average household level. These average expenditures on fuel and lighting were then aggregated to verify the results from'top-down outcomes'. The primary dataset employed in this model is the Residential Energy Survey by (UETT) University of Engineering & Technology Taxilain 2009-10 [xxxviii] and 2012-13. This study explored the dynamics of energy consumption of dwellings in different geographic divisions of Pakistan by general social behaviors.

B. *Research Process*

The following research process was adopted for proper characterization of this sector:

- Determination of the number of households in an urban/semi-urban and rural division in whole horizon 2007-2040;
- Estimation of specific fuel usage of households in both categories;
- Extraction of average energy purchases for each fuel by energy service type for households in each category;
- Characterization of households' appliances regarding their penetration rate, upfront cost, maintenance cost, efficiency and lifetime;

Figuring the key assumptions and time-of-use demand curve development for energy commodities;

Converting the energy use data to estimate the shares in urban and rural households;

Future energy demand projections and analysis of results.

A detailed process to model the residential sector is shown in Fig. 3.

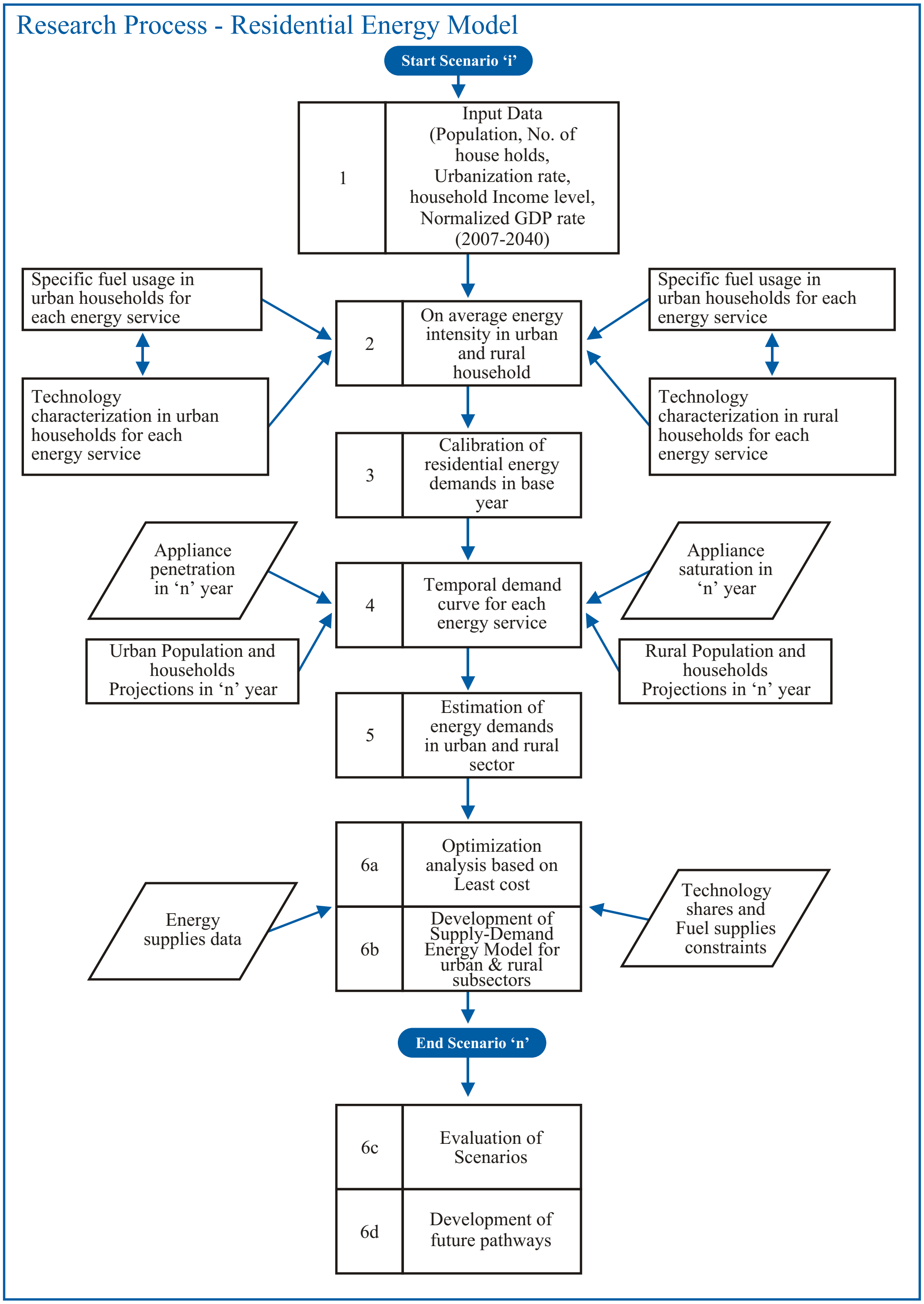

Fig. 3. Residential energy modeling flow diagram.

In the first phase of the above stated process, we determined the number of households from the statistics of PBS (Pakistan Bureau of Statistics) for urban and rural categories. Then data was further categorized to estimate electrified, non-electrified, and households connected to gas pipelines in each domain. Next, we looked for the percentage of urban/rural households using the specific fuel to fulfill their daily energy related non-transport requirements. Using the data from UETT survey [xxxix] and Pakistan Household Expenditure Survey, the energy carriers were disaggregated into residential fuels like electricity, natural gas, kerosene, coal, biomass etc., [xx] as given in the Table I. Biomass resources were further decomposed such as wood available to households at no cost and purchased-wood, (reference to Table A-II in Appendix A). Similarly, free animal dung besides the purchased dung fuel by households, particularly in rural areas was estimated. Although the differences were small, but different cost profiles have been used to distinguish the biofuels.

TABLE I
(A) END USE FUEL SHARES (DECIMALS) BY ENERGY SERVICE AND TOTAL FUEL CONSUMPTION (PJ) FOR EACH SERVICE IN AN URBAN RESIDENTIAL SECTOR IN BASE YEAR 2007

Urban Households	Total (PJ)	Kerosene	LPG	Coal	Natural Gas	Electricity	Wood fuel	Dung	Agr. Residues
Space Heating	34.8		0.01		0.91		0.08		
Water Heating	37.5		0.01		0.76		0.23		
Space Cooling (Fans)	28.9					1.00			
Space Cooling (AC & Coolers)	16.7					1.00			
Lighting	16.6	0.03				0.97			
Cooking	194.8		0.03		0.63		0.24	0.06	0.03
Refrigeration	12.9					1.00			
Miscellaneous Electric	21.7					1.00			
Total	**363.9**								

TABLE I
(B) END USE FUEL SHARES (DECIMALS) BY ENERGY SERVICE AND TOTAL FUEL CONSUMPTION (PJ) FOR EACH SERVICE IN THE RURAL RESIDENTIAL SECTOR IN BASE YEAR 2007

Urban Households	Total (PJ)	Kerosene	LPG	Coal	Natural Gas	Electricity	Wood fuel	Dung	Agr. Residues
Space Heating	33.7		0.01		0.05		0.95		
Water Heating	49.5		0.01		0.03		0.74	0.23	
Space Cooling (Fans)	9.7					1.00			
Space Cooling (AC & Coolers)	0.9					1.00			
Lighting	15.8	0.25				0.75			
Cooking	514.5		0.03		0.01		0.67	0.16	0.13
Refrigeration	1.6					1.00			
Miscellaneous Electric	3.9					1.00			
Total	629.6								

Table I shows the fuel share estimates consumed for each energy service demand in the residential sector for base year 2007. For example, common urban households on average meets its space heating needs by 91% natural gas and 8% from wood fuel. The other important data shown is total energy consumption (PJ) in each energy service of urban and rural residential sector. As for instance, urban households, on average, consumed 34.8 PJ for space heating purposes in base year. For the energy services required in a typical housing unit, these were categorized such as space cooling, cooking, lighting, refrigeration, water-heating, space heating, and miscellaneous. Space cooling was further divided into cooling by fans and air-conditioning. For the fourth action, existing appliances were grouped as standard, improved, and advanced (reference to Table A-I in Appendix A). New technology dataset has also been developed by predicting the efficiencies and costs.

Many exogenous assumptions were taken like the growth rate of population, households, GDP linked to individual income level, fuel price data and remaining available energy resources [xl]. Table II presents the key projections of many exogenous variables used for predicting the future energy use in the residential energy model. Furthermore, the information of demand timing is required for each of the energy services to distinguish the load pattern for under consideration commodity like electricity. This data was put into the model as time-of-use of the commodity. The next step was the further split of demand timing that determined the amount of each energy service that should be met based on seasonal and time-of-day requirements. For this purpose, representation of these patterns was derived for each residential fuel. Thus the demand for each energy service has been tracked at a seasonal level, reflecting that cooling by air-conditioners is mostly required during hottest periods and space heating during the winter. The supply of these commodities should be able to meet the temporal patterns of each energy service.

In this case, decomposed utility load curves, in particular, on the sectoral and sub-sector basis could be ideal. These load curves provide information to counter the effects of varying climate on energy demands, daily or seasonal. However, due to limited information available on these fronts, the estimation of energy service demands was done mainly on surveys and empirical studies. The temporal dataset of demand profile using the hourly load available in aggregated form was calibrated from electricity providers PEPCO (Pakistan Electric Power Company) &K-Electric formerly KESC Karachi Electric Supply Company Ltd) and gas utility companies SNGPL (Sui Northern Gas Pipelines Limited) & SSGC (Sui Southern Gas Company).

TABLE II

A LIST OF KEY ASSUMPTIONS (BASE YEAR - 2007) AND PROJECTIONS FOR WHOLE TIME-HORIZON

Key Assumptions	**2007**	**2012**	**2015**	**2021**	**2027**	**2030**	**2036**	**2039**	**2045**
Population									
Total Population **(Million)**	158.2	173.8	183.9	205.8	230.1	243.1	271.4	286.7	320.1
Annual growth rate (%)	1.90	1.90	1.90	1.88	1.86	1.85	1.85	1.85	1.85
Urban Population **(Million)**	53.8	67.5	75.9	93.3	111.5	121.8	143.3	154.3	179.0
Annual growth rate (%)	4.82	4.00	3.50	3.00	3.00	3.00	2.50	2.50	2.50
Rural Population **(Million)**	104.3	106.3	107.9	112.4	118.6	121.3	128.1	132.4	141.1
Rural % of Total	66.0	61.2	58.7	54.6	51.6	49.9	47.2	46.2	44.1
Households									
Total Households **(Million)**	23.40	26.99	28.87	33.01	37.69	40.28	45.96	49.10	56.06
Urban Sector									
Avg. No. of occupants/HH	6.50	6.20	6.14	6.01	5.88	5.82	5.69	5.63	5.50
Total Urban Households **(Million)**	8.28	10.89	12.38	15.53	18.95	20.93	25.19	27.43	32.54
Rural Sector									
Avg. No. of occupants/HH	6.90	6.60	6.55	6.44	6.33	6.27	6.16	6.11	6.00
Total Rural Households **(Million)**	15.12	16.10	16.49	17.47	18.74	19.34	20.78	21.67	23.52
GDP growth rates									
Strong economy case (%)	5.0	4.9	6.6	6.3	6.0	5.9	6.2	6.4	5.6
Base case (%)	5.0	4.0	5.5	5.8	5.0	5.0	5.0	5.0	5.0
Weak economy case (%)	5.0	3.5	4.0	4.8	4.0	4.0	4.0	4.0	4.2

Scenario analysis method was used to explore future energy demands and potential technology pathways of the energy system.

TABLE III
DESCRIPTION OF SCENARIOS USED IN RESIDENTIAL SECTOR MODELING

Scenario	Description
Base Case (BAU)	Base case (BAU) scenario reflects the continuation of on-going and near-term trends, technologies, practices and policies, current regime of planning and effects occurring in the future. Furthermore, the overall level of demands in energy commodities and energy services will rise in association of economic growth at 5% GDP level over the time horizon. In this case, the smartly use of energy is also out weighted due to the non-acceptance of any such scheme in the society.
Weak Economy (WE)	This scenario explores the changes in energy demands, if the slow economic growth persists at 4.2% GDP level. The energy intensity level of many energy demands will fall, mainly due to energy poverty.
Strong Economy (SE)	A high energy demand scenario with an assumption of high sustained economic growth. As households get rich due to increase in disposable income, the lifestyles will be improved. Thus the existing inefficient technologies to increase the comfort level will penetrate rapidly in the society. The assumed GDP growth level is set 5.6% throughout the time horizon.
Energy Efficiency (EE)	A scenario of accelerated energy conservation and efficiency measures having the constant economic growth level as was set in BAU case. This scenario investigates how the residential sector behaves to achieve the average 10% reduction of energy demands in 2040. A technology led energy demand reduction via currently known efficient technologies.

IV. Results and Discussion

The minimum efficiency level in energy consumption of residential sector was set to 10% in energy efficiency (EE) scenario. To encompass the complexity of the evolution over a 30-year period, a number of scenarios had to be developed. The main focus of this paper is on integrated energy analysis of future final energy demand and energy savings. Two TIMES scenarios, BAU and increased EE are presented in this study. Table III shows the underlying scenarios and their economic variants. The other two economic variants of BAU are the weaker economic growth and strong economic growth.

The residential final energy consumption of 22 Mtoe in the base year 2007 increases to double in all the cases by 2040. Table IV presents the residential sector's final energy demand projections in all scenarios. This rise in energy demand is because of increase in population, and high urbanization rate. Moreover, base case scenario shows the share of electricity use of a residential sector increase from 46% (2007) to 54% in 2040, which could be even more than 59% in the weak economic (WE) growth case. Fig. 4 presents the sectoral share of electricity consumption in 2040 in all scenarios.

TABLE IV
RESIDENTIAL SECTOR'S FINAL ENERGY DEMAND PROJECTIONS IN DEVELOPED SCENARIOS (MTOE)

Years	Base Case	Weak Economy	Strong Economy	Energy Efficiency
2007	22.52	22.52	22.52	22.52
2015	24.65	23.91	25.54	24.02
2020	25.91	25.10	29.17	25.14
2025	34.09	33.02	34.25	32.61
2030	37.65	36.03	39.62	34.94
2035	41.65	38.98	44.34	37.37
2040	46.46	43.40	50.66	41.09

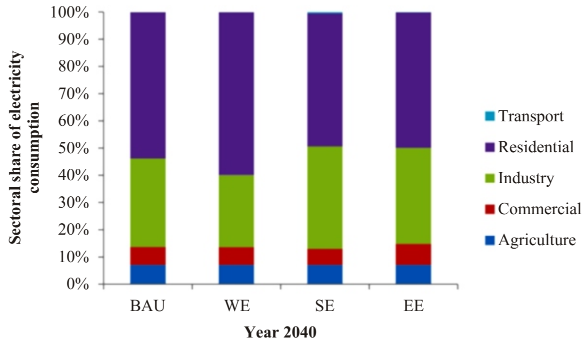

Fig. 4. Sectoral electricity consumption among demand-side sectors in 2040 in all underlying scenarios

Major energy-consumptions in the residential sector comprise of services such as cooking, space-cooling, refrigeration, and lighting. These energy-uses are calculated based on normalizing the actual fuel demands in households of different socio-economic groups. To account the energy use, energy intensity for each energy service is calculated. This includes natural gas, biomass, and electricity use within the total residential RES (reference energy system). The share of energy consumption in 2040 is decreased to 31% as compared to 40% in the year 2007, Table IV, while energy demand in the industrial sector is increased due to the stabilized economic growth of the industrial sector in BAU case.

Fig. 5 depicts the urban and rural residential end-use applications and the final energy demand by fuel type in BAU scenario over the entire time horizon.

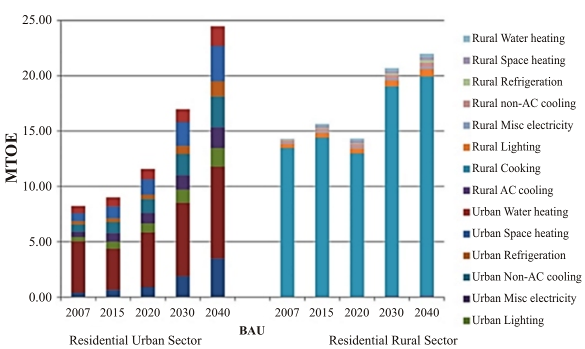

Fig. 5. *(A)* Energy service demand projections in urban and rural residential sectors.

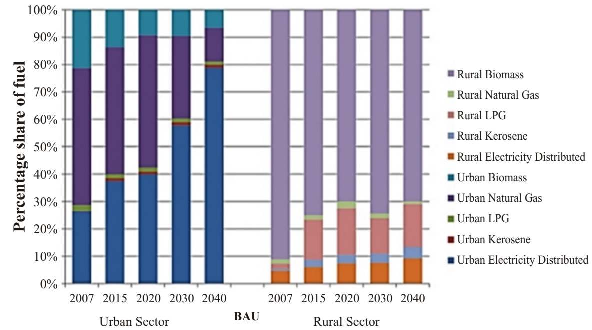

Fig. 5. *(B)* Percentage share of fuels in urban and rural residential sectors in 2040

The residential final energy demand growth is due to urbanization and access to commercial energy resources by electrification in rural areas. The uptake of appliance stock (e.g. space coolers/air-conditioners, refrigerators, and entertainment devices, etc.), and lifestyle improvements are the main drivers of future energy demands. For instance, energy use for space cooling increases as the income level of the community will increase. On the other hand, in EE scenario, the final energy demand in 2040 is 11% lower than the BAU case, and this low level in energy demand is by virtue of energy conservation and efficient measures - uptake of efficient households' appliances. The energy saving actions become cost-effective significantly, also due to projected future fuel prices.

There is significant change in the final energy between the base case and strong economic growth scenarios (see Table IV). The system-wide total energy requirements also increase as the whole energy system responds to the growing population and economic expansion. The additional energy use in the strong economy case is met by increasing energy supplies,while energy imports increase 530% in 2040 by 2007 level. In weaker economic growth, the final energy declines in 2040 by 19.5% from the reference case. This is due to the non-availability and restricted energy supplies to the masses. In this case, energy import declines by 32% in 2040 as compared to the strong economic growth case.

In each scenario, the natural gas supply is gradually decreasing due to depletion of current identified gas wells. The total energy mix shows the great vulnerability in coming years. The other dangerous trend can be seen in the restricted availability of comparatively cheaper energy resource of biomass, especially for rural households. The residential sector is mainly dependent on these two energy resources for cooking needs. In turn, the model is switched to electric applications as these two sources vanish. If an energy efficiency (EE) case does not fully work, then the final energy demand in 2040 increases more than double to base level in stronger economy scenario. These sensitivities show the importance of energy efficiency in a national energy system.

In terms of residential energy services, the share of the cooling demand increases from 5.6% in 2007 to 14.7% in 2040. The higher cooling energy demand attributes to use of more climate control technologies and a significant shift from traditional fans to an air-conditioning system that increases demand for electricity. The other category is the refrigeration that tends to increase due to high saturation of refrigerator stock in dwellings. The electricity demand further increase as these electronic gadgets become more common in the society.

A. Implications to an Existing Energy System

Fig.6 (a) and Fig.6 (b) show the overall growth in final energy-use in all main sectors, together with the required energy supplies in years 2015 and 2040 for all scenario cases.

The analysis shows that overall energy use would be tripled the current demand, while Industrial energy use increases 2.5 times in 2030. Over 570% increase in electricity consumption entail drastic modifications in an existing energy system, resource and infrastructure usage, and investment in new technologies. Fig. 7 displays an overall tremendous growth in the electricity generating capacity dominated by coal plants, together with modest expansion in non-hydro renewable technologies in base case scenario. Nuclear plants, together with some big hydro plants dominate the electricity generation in 2040. The other additions in electric capacity are imported oil and gas operated plants. This needs the huge capacity investments to fulfill the future electricity requirements. This is another negative impact on the national economy as energy imports grow to over 40% of total supply by 2030 as natural gas imports come on-line. In terms of the energy system cost in the residential sector, the incremental cost of energy efficiency scenario increases in the mid-term and is about 17.4% higher than reference case.

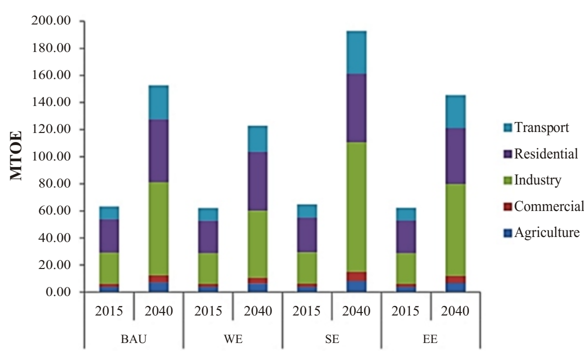

Fig. 6. *(A)* The final energy demand in demand-side sectors

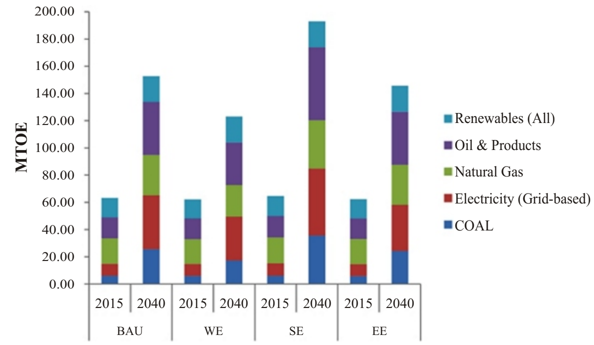

Fig. 6. *(B)* Energy supply shares of the future energy system**.**

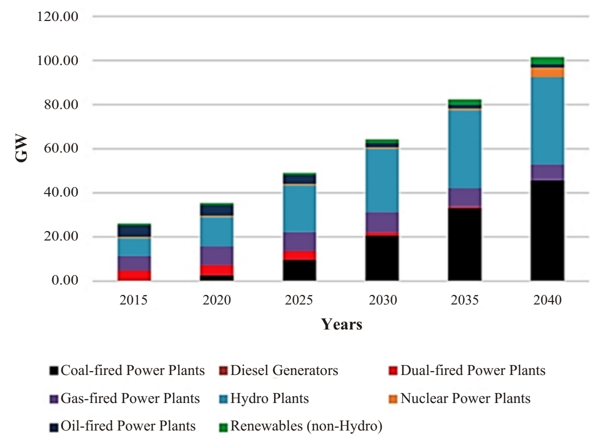

Fig. 7. A profile of electricity generating capacity by different types of power plants in BAU scenario

Fig. 8 presents the cost profile of the residential sector by projecting the investment, together with fixed and operating costs in Energy Efficiency (EE) case. The increase is due to the replacement of an existing inefficient stock of household appliances. Fig. 9 shows the total system cost in undiscounted terms among all scenarios

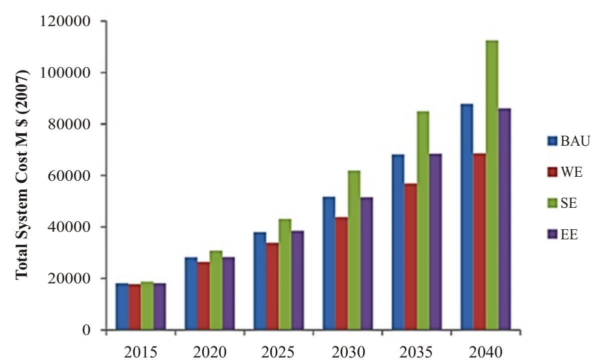

Fig. 8. The projected difference in cost profile of the residential sector

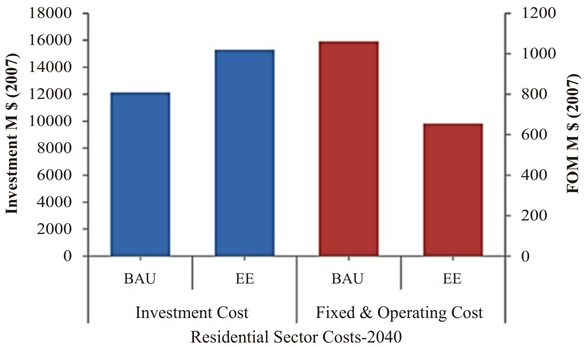

Fig. 9. Total undiscounted cost increase among all scenarios

The results from these scenarios are not only intended as future predictions, these also represent development paths for the energy sector that reflects the future energy requirements aligned with the government's projections for GDP growth. It might serve as the comparison point for GDP variant analyses. The reference case (BAU) scenario for residential domain without any newly developed national policy intervention, exhibits the insights of future energy demands and likelihood of technological evolution in the energy system. Increase in the cooling energy service by air-conditioners is significant and indicates the need of thermal insulation of buildings by deployment of building energy codes in true spirit [xli]. Cooking and water-heating are showing the upward tendency of energy-increase which account for more than half of the energy demand in the future. This projected energy demand is due to the growth in urban population along with the urbanization factor. The household energy demand is projected based on average energy intensity per household which is assumed to grow over the period due to rise in the comfort level, lifestyle of citizens and behavioral change towards the adoption of more appliances. These scenarios depend on many factors, such as prices assumed for fuel sources, demand projections in populations, GDP, urbanization rate, price and performance of technology outlook, evolution of the future energy system at supply side, and end-use technology adoption of demand side sectors.

The technology and fuel-share constraints are crucial to control the system's evolution rate. Limitations applied to reference case are comparatively tight, as it is unlikely to change the scenario radically without detailed policy interventions. Significant changes such as behavioral change of stakeholders and acceptance of cost-effective efficiency measures cannot be revolutionized in society without awareness, the proper execution of strategies, and implementation control. The policy analysis based on this base case would help to explore possible pathways for Pakistan that could be shaped by choices, circumstances, and policy alternatives.

B. Energy Efficiency

The base case (BAU) also contains restrictions which are intended to prevent overly rapid change in the energy system. These include the upper bounds on the appliance penetration rate and the degree of fuel switching in the residential sector. The penetration limits on energy efficient technologies for each energy service are considered as 10% of the whole stock by 2030. In EE scenario, more rapid uptake of energy efficient appliances in households allows for increased levels of energy efficiency. It permits many technologies such as lighting up to 50% of new technology purchases in 2030, rather than 10% imposed limit in the reference scenario. Implementing efficient practices reduces gas consumption in the residential sector due to enhanced and efficient stoves, together with electricity savings by new and modern devices. The energy efficiency measures, which also support the reduction of overall electricity consumption, concedes some large power projects such as coal and nuclear plants.

C. The Way Forward

The first attempt must be made to restructure the energy system according to some established workable plan from national to municipality level. Deployment of local energy plans' aggregation at national level would provide the pathways for future development. To reduce energy consumption particularly in the residential sector augments the better technology characterization at low costs and implementation of performance energy standards to household appliances [xlii-xliii]. Some prioritization may be set to the changeover of appliance's stock with energy efficient devices in phases. In early phase, the inefficient lighting system replacement and retrofitting by some efficient solutions is relatively easy which then follows the space cooling technologies up-gradation. Energy performance measurement for newly constructed buildings should be mandatory in an obligation of standardized practice of building energy codes in other countries. Appliance standardization and labeling should also be a prime focus to lessen the future energy requirements [xliv].

V. CONCLUSIONS

A residential energy load model for long term energy planning has been presented. The model uses hybrid approach; a bottom-up method in which the individual appliances are assessed by their power rating and availability factor to compose a household load, and the top-down approach in which energy profile of a household is made through decomposition of fuel-shares and energy services. The input dataset was mainly prepared and collected through the survey and other studies conducted by governmental and non-governmental organizations. Additionally, the dataset used in the model was calibrated, tested and validated against federal statistical report, energy yearbook, and PEPCO mid-term energy demand forecasting respectively. The model covers the whole residential non-transport energy demands. Three scenario cases of energy demand and a special case of energy efficiency were established to develop the insights for residential urban and rural sectors.

Base case scenario shows the share of electricity use of a residential sector increase from 46% (2007) to 54% in 2040, which could be even more than 59% in the weak economic (WE) growth case. On the other hand, in EE scenario, the final energy demand in 2040 is 11% lower than the BAU case. If an energy efficiency (EE) case does not fully work, then the final energy demand in 2040 increases more than double to base level in stronger economy scenario. These sensitivities show the importance of energy efficiency in a national energy system.

This paper explores the consistent method to create possible pathways for adoption of new technologies and switching to fuels for different household energy services under different economic variants. This model also captures many trade-offs in the reduction of energy consumption. The model mainly resides and takes decisions on the basis of technology parameters and fuel costs. However, this optimization modeling framework does not consider the choices made on the basis of other social attributes such as color, design and brand of the appliance. Though it is challenging in standard TIMES generator, but this type of consumer behavior is separately controlled through logistic function sub-models for appliance penetration in the residential sector. In addition, due to the first study of its kind, preparation of large dataset may involve some associated uncertainties. The residential sector is also modelled as the division of urban and rural households, rather at full resolution of the other socio-economic basis, i.e., income groups. This weighted averaging method to conceive the energy-use profile is coarse one and should be refined further in the succeeding modeling efforts.

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APPENDIX-A

TABLE A-I
A SCHEME OF TECHNOLOGY CHARACTERIZATION IN URBAN AND RURAL SUBSECTORS.

		URBAN			**RURAL**		
Energy Service	**Technology**	**% stock**	**% house-holds**	**% households with appliance**	**% stock**	**% house-holds**	**% households with appliance**
Cooling (AC)	Air cooler Standard - Metal Body	0.7	0.32	0.22	0.7	0.17	0.12
	Air cooler Improved - Plastic Body	0.3	0.32	0.10	0.3	0.17	0.05
	AC standard	1.00	0.17	0.17	1.00	0.015	0.02
	1 Ton	*0.65*	*0.17*	*0.11*	*0.65*	*0.015*	*0.00975*
	1.5 Ton	*0.3*	*0.17*	*0.05*	*0.3*	*0.015*	*0.0045*
	2 Ton	*0.05*	*0.17*	*0.01*	*0.05*	*0.015*	*0.00075*
	AC improved						
Cooling (Fans)	Ceiling fan Standard	0.85	0.92	0.78	0.85	0.81	0.69
	Ceiling fan Improved	0.15	0.92	0.14	0.15	0.81	0.12
Refrigeration	Refrigerator Standard	1.00	0.56	0.56	1.00	0.26	0.26
	Refrigerator Improved						
Lighting				No. of lights (Mln)			No. of lights (Mln)
	Incandescent bulbs	0.36		#REF!	0.36		#REF!
	CFLs	0.42		#REF!	0.42		#REF!
	Fluorescent tube lights (FTL)	0.22		#REF!	0.22		#REF!
	Fluorescent tube lights (FTL) - Upgraded						
Water Pumping	Traditional	0.95	0.5	0.48	0.95	0.3	0.29
	Improved	0.05	0.5	0.03	0.05	0.3	0.02
Washing Machine	Standard	0.6	0.71	0.43	0.6	0.25	0.15
	Improved	0.4	0.71	0.28	0.4	0.25	0.10
Television	Standard	0.88	0.82	0.72	0.88	0.44	0.39
	Improved	0.12	0.82	0.10	0.12	0.44	0.05
Others	Monitor/CPU/Stereo	0.99	0.19	0.19	0.99	0.03	0.03
	Laptop	0.01	0.19	0.00	0.01	0.03	0.00
	Dry Iron-1000	0.85	0.98	0.83	0.85	0.83	0.71
	Dry Iron-2000	0.14	0.98	0.14	0.14	0.83	0.12
	Steam Iron	0.01	0.98	0.01	0.01	0.83	0.01
	17 Liter	0.95	0.12	0.11	0.95	0.005	0.00
	39 Liter	0.05	0.12	0.01	0.05	0.005	0.00
	Blender	0.9	0.58	0.52	0.9	0.07	0.06
	Food Processor	0.1	0.58	0.06	0.1	0.07	0.01
P & B (Fans)	Pedestal	1	0.11	0.11	1	0.19	0.19
	Bracket	1	0.09	0.09	1	0.04	0.04
Exhaust (Fans)	Traditional	0.66	0.75	0.50	0.66	0.29	0.19
	Plastic Body	0.34	0.75	0.26	0.34	0.29	0.10

TABLE A-II
BIOMASS ENERGY USE IN PAKISTAN RURAL / URBAN HOUSEHOLDS (TOES), 2006/07

	Wood	**Dung**	**Agr. Residues**	**Total**
Urban				
Cooking	1041	271	136	1448
Space Heating	68	0	0	68
Water Heating	204	0	0	204
Other	23	23	0	45
Total Urban	1335	294	136	1765
Rural	0	0	0	0
Cooking	7692	2036	1561	11290
Space Heating	724	0	0	724
Water Heating	837	0	0	837
Other	68	136	0	181
Total Rural	9299	2149	1561	13009
Total	10633	2443	1697	14774