Energy Consumption and Scenario Analysis of Residential Sector Using Optimization Model – A Case of Kathmandu Valley

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Abstract: Urbanization is a common characteristic of a developing country. Whilst urbanization is an indicator of development, it demands high utilization of resources. The urbanization rate of Nepal is one of the highest in South Asia and among developing countries as well. Kathmandu Valley is the chief center of the urban transition in Nepal. This study is conducted to understand the current energy consumption pattern of residential sector of Kathmandu valley. A primary survey was conducted though household questionnaire survey within the three districts of valley, with division of valley into two regions viz. urban and peri-urban area. Residential energy system has been developed using MAED and MARKAL. A set of residential alternatives have been assumed considering both conventional and renewable resources. The energy model has been evaluated using least cost optimization method using ANSWER MARKAL for various scenarios. Various indicators have been derived to evaluate each scenario. According to evaluation results, the current pattern of energy demand would put huge pressure not only in energy requirement but also national economy. An effective policy is the imperative requirement in current situation. The policy should be driven by strategies for utilization of indigenous renewable resources instead of importing petroleum products. The effective outcome of a properly planned strategy would be reduction in energy demand, emissions as well as national economy along with opportunity of utmost utilization of energy resource potential and employment opportunities.

Keywords: Residential energy system; Kathmandu; Survey; Optimization; Scenario

1. Introduction

Urbanization is a global phenomenon which occurs in both economically advanced and developing countries. With global population reaching over 7 billion, the population residing in urban area has already reached over 50 % (UNDESA, 2012) . While annual urban growth rates now average over 1.97 percent, the urban population growth for the least developed countries rate is 3.69 percent (UNDESA, 2013). However, urbanization is not simply relates to an increase in population density. One of major effect of urbanization is the loss of rural habits and traditional behavior patterns, and the acquisition of new domains of information and infrastructure (Barnes et al., 2004). Urbanization is characterized by high level of availability and utilization of resources, interaction among urbanized and non-urbanized centers and avenues for economic prosperity (Reddy, 1998). Thus, urbanization results in increased resource utilization that includes energy resources as well. It increases per capita energy and also causes shift in consumption pattern to more commercial types of energy due to increasing economic level and access to the resources. It plays a key role in what has become known as the "energy transition" from traditional sources to modern forms of fuels (Leach, 1993), with major influencing drivers - income, energy access, and energy prices (Pachauri & Jiang, 2008). The consumption of modern fuels will also be growing as urban areas expand, due to economies of scale in infrastructure development and fuel distribution which makes bottled LPG distribution and the expansion of electricity grids more economical (Leach, 1993).

1.1 Kathmandu valley

The urban population of Nepal accounts for 17% of total and the rate of urbanization is 3.62% (CIA, 2014). Meanwhile, Kathmandu Valley alone accounts for 9% of total population with the population growth rate of 4.35% and is one of the fastest growing urban agglomerations in South Asia (CBS, 2012; Muzzini & Aparicio, 2013).

Kathmandu valley is the largest and most populous urban agglomerate of Nepal. The valley constitutes major portions of three districts viz. – Kathmandu, Lalitpur and Bhaktapur constituting 85%, 50% and 100% land area of each districts (Pant & Dongol, 2009). However, major portion of the population is concentrated in the urban centers within the valley. Kathmandu district is the most densely populated district of Nepal with population density of 4,416 people per square kilometer and nearly 60% of the district's population resides in Kathmandu metropolitan city – the capital of the nation (CBS, 2012).

According to energy synopsis report, 2010, only 14.5% of total residential energy is consumed by urban household. However, by energy resource type, the consumption was dominated by commercial resources like electricity and petroleum products. The report also indicates that 52% of urban energy was used for cooking purpose, followed by electric appliance (14%), Lighting (13%),heating and cooling (10%), animal feeding (8%) and agricultural processing (3%) (WECS, 2010). Wherein, Nepal living standards survey reported that 59% of urban households used LPG for cooking (CBS, 2011). The recent annual household survey by Central Bureau of Statistics shows that the share of urban households cooking in LPG has increased to 70% (CBS, 2014). WECS (2010) also indicated that the demand for LPG in urban area increased at rate of 23% whereas demand for electricity increased at the rate of 10%.

There has been quiet a few studies regarding energy consumption and energy system of Kathmandu valley. Shrestha & Malla (1996) have examined sectoral energy-use patterns to estimate the associated emissions of local pollutants in the Valley in 1993 till 2013. But the study did not use a comprehensive energy system model to estimate the future energy consumption and structure of energy use in the Valley. Later in 2009, Shrestha & Rajbhandari (2010) has analyzed the sectoral energy consumption pattern and emissions for five different economic sectors, viz. – agriculture, residential, commercial, industrial and transport – using MARKAL framework. The study concludes that with decreasing urban population growth and increasing non-residential activities, the percentage share of residential energy would go decreasing in total energy consumptions, but would increase by around two folds in quantitatively. Malla (2013) has examined the household energy consumption patterns and its environmental implications of whole Nepal, along with Kathmandu valley as one of the 13 analytical sectors in his study for three end uses. He has developed 4 different scenarios in LEAP framework and concluded on the environmental implications. Adhikari (2012) has conducted a thesis study on Electricity Demand Side Management of Residential Sector in Kathmandu Valley with focus on future electricity consumption scenario and demand side management options in urban Kathmandu households under different separate income growth scenario for each economic stratum.

Central bureau of statistics, Nepal has conducted various studies, one of them which enumerate number of household that uses particular type of energy carrier for cooking and lighting and presence of household facilities (CBS, 2012). However, it fails to give a picture of energy usage pattern i.e. it does not clarify how often the consumer uses certain type of energy, what capacity of energy consuming appliances they have and what are the energy consumption levels of energy consuming appliances and activities. Although it gives an idea of technology penetration, to forecast true consumption pattern, a better details on energy consumption is required, not just by mere estimation and comparison, but by quantitative analysis via investigation at consumer level.

2. Methodology

2.1 Primary data survey

Kathmandu valley covers three districts which comprise 5 core urban areas[1] surrounded by 97 VDCs referred to as rural or peri-urban area.

The valley was divided into 2 sectors – urban and peri urban. The sectors were further subdivided into 5 and 15 strata respectively for distributive collection of data over the valley.

Total of 200 energy related data were gathered through questionnaire survey.

The sample size was calculated using the following equation (Krejcie & Morgan, 1970) :

$$S = \frac{\chi^2 NP(1-P)}{d^2(N-1) + \chi^2 P(1-P)} \qquad \text{……. (1)}$$

Where,

S = required sample size

χ^2= table value of chi-square for 1 degree of freedom at the desired confidence level

N = population size

P = population proportion

d = the degree of accuracy expressed as a proportion.

With confidence level of 95% and degree of accuracy 10%, the sample size would be 96 households for each sector summing to 192 samples. However, according to household survey conducted by Nepal Rastra bank, the results based on market centers would provide unbiased estimates of urban domain, but upward biased estimates of other domain. It was concluded in the report that including more number of peri-urban sector biasness of this domain could be reduced (NRB, 2008). Thus for better accuracy and to reduce biasness, the total 200 samples were taken, with higher proportion of data for peri-urban area.

[1] Kathmandu Metropolitan city; Lalitpur Sub-metropolitan city; Bhaktapur Municipality; Madhyapur Thimi Municipality; Kirtipur Municipality

2.2 Energy Model

Model for Analysis of Energy Demand (MAED)

MAED-2 is an energy modelling tool developed by IAEA. It evaluates future energy demand based on medium- to long-term scenarios of socio-economic, technological and demographic developments using bottom up approach.. Energy demand is disaggregated into a large number of end-use categories corresponding to different goods and services. The influences of social, economic and technological driving factors are estimated and combined in each different category to present an overall picture of future energy demand growth under the assumptions of that scenario. (IAEA, 2006; Hainoun et al., 2006; UN-energy, 2006; UN-energy, 2007)

Although there are several sector in MAED-2, the energy demand in household can be calculated separately due to the fact that the scenario parameters and related equations which characterize their energy consumption are not the same to other sectors: in the Household sector the determining factors are of demographic nature (population, number of dwellings etc.) whereas in the other sectors they are related to the economic level of activity of this sector. (IAEA, 2006).

MARKet ALlocation (MARKAL)

MARKAL is a generic model tailored by the input data to represent the evolution over a period of usually 40 to 50 years of a specific energy system at the national, regional, state or province, or community level. MARKAL is a data-driven, energy systems economic-optimization model. The objective is a target-oriented integrated energy analysis and planning through a least cost approach. The energy demands are exogenously supplied in this model and the supply options are analyzed. Both linear as well as dynamic (non-linear) programming mathematical approaches can be utilized by this model. MARKAL solves a model run by minimizing the objective function. It uses LP methods to optimize the system. The present value of the total energy system costs throughout the planning horizon is the objective function, which is subject to specific constraints. The discount rate of 10% is used. MARKAL assumes perfect foresight in making the decisions, i.e. decisions are made with full knowledge of future events.

MARKAL is currently being in used in more than 60 countries and 200 institutions worldwide. It is a comprehensive model that well facilitates the scope in representing detail technologies and its characteristics. Throughout the system it takes into account the conversion processes, their efficiencies and losses as well as costs such as extraction costs, transportation and distribution costs, etc. Energy supply mix with optimum cost is given by the model. It can undertake number of user-defined constraints such as resource availability, cost, environmental emission threshold, etc. (Loulou et al., 2006)

The general categories of data required for a MARKAL model are:

- System-wide global parameters
- Energy service demands
- Energy carriers
- Resource technologies
- Process and demand technology profiles
- Environmental emission factors

The more elaborated description of data requirement is stated in conference paper by Rajbhandari, Prajapati and Nakarmi (2013).

3. Methodological Framework

Figure 1 represents the methodological approach applied for the study. The framework shown is used to analyze the energy scenarios from base year 2013 to next 20 years in future. The base year data was developed form the primary survey data. The energy intensity and other parameters, which are required for MAED-2, were calculated as well from the primary data. The demographic parameters were calculated from report and literature (CBS, 2012) (Muzzini & Aparicio, 2013), meanwhile energy intensity and other parameters were assumed to be constant for future years. Using these data, MEAD model was developed comprising 2 sub-sectors – urban and peri-urban and 6 enduse in each subsector (See Fig. 1). Then the useful energy demand scenario was developed for next 20 years.

A long term energy system model for residential sector of Kathmandu valley was developed using MARKAL framework. The residential sector was subcategorized into two sub-sectors viz. urban and peri-urban. Each sub-sector comprised 6 enduse services as in MAED model and a total of 46 enduse technologies based on fuel types.

All conventional, efficient and renewable technologies have been considered in the model. The technological data have been obtained from technology database of LEAP, other relevant sources and market study. The fuel price in this study is based on IEA (2010).

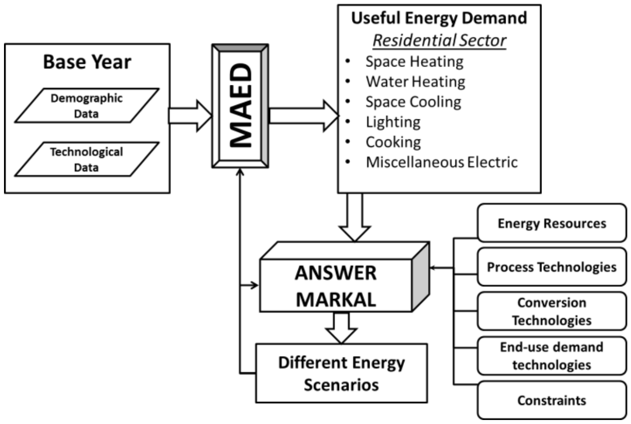

Figure 1: Methodological Framework

4. Scenario Description

4.1. Business-as-usual Scenario (BAU)

Business As usual Scenario is the baseline scenario, also termed as reference scenario. Here the historic trend of exogenous variables is assumed to be continued in future at the absence of intervention. Thus, the share of each demand technology in the energy supply in future years will be the same as in the base year i.e. similar consumption trends will continue in future as well.

4.2. All Electrification Scenario (AEL)

All Electrification Scenario total access to uninterrupted electricity supply policy. This scenario follows the principle objectives of sustainable energy for all (SE4ALL) whose one of the target is to electrify the urban areas. The policy targets full utilization of hydropower potential. However the rate of electrification of gradual until all other fuel types are replaced by renewable electricity from hydro and grid connected solar PV. The enduse technologies are gradually replaced by more efficient electrical appliances and for lighting efficient devices such as CFL and LED are penetrated, replacing incandescent bulbs and fluorescent tube lights. The population growth will be as same as BAU scenario.

4.3 Modern Fuel Access Scenario (MFA)

Modern Fuel Access scenario also follows the principle objectives of sustainable energy for all (SE4ALL) that promoted modern energy usage and sustainable development. However, in this scenario, the dirty fuels like coal, kerosene and other petroleum are gradually replaced. The energy optimization model is set to choose least cost energy mix for fulfilling the energy demand. The population growth will be as same as BAU scenario. The mainstream of this scenario is access to modern form of electricity at least cost.

4.4 GHG cap Scenario (GCP)

GHG cap scenario is based on limiting the total GHG emission in future to lower than that of base year. The energy model is optimized for least cost energy system under the given constraint fulfilling the energy demand. In calculation of GHG, biomass is taken as carbon neutral energy source, i.e. biogenic CO_2 emission is not considered while calculation GHG equivalent. The population growth will be as same as BAU scenario.

4.5 CO_2 cap Scenario (CCP)

Under GCP, the assumption is made that GHG emission should not go beyond base year level. However, the GHG equivalent considers biomass as carbon neutral as explained above. This scenario however takes an account of CO_2 emission from all sources and constraint is applied that the future emission will not exceed the base year level. The model is then optimized for least cost energy system. The population growth will be as same as BAU scenario.

5. Results and discussions

5.1. Energy Demand pattern in 2013

The final energy demand of residential sector of residential sector of Kathmandu valley was found to be about 7,500 TJ. Figure 2 shows the share of final energy demand by fuel type. It seen that the total energy share was dominated by petroleum products (48%). Modern renewables like electricity, solar accounts for about 33% of total share while traditional renewables also has noticeable share. It was observed that 97% of LPG was used for cooking purpose. Biomass was primarily used or cooking and heating purpose meanwhile electricity was chiefly used for electrical appliances, cooking and lighting.

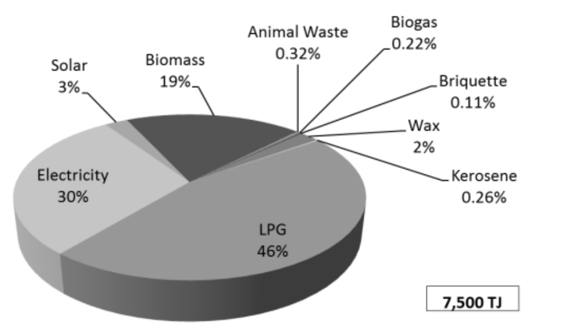

Figure 2: Final energy demand share by fuel type in 2013

Figure 3 shows the final energy demand by enduse types. It is seen that cooking was the dominant enduse which accounts for 69% of total energy demand. It is followed by electrical energy consumption by electrical appliances (17%), lighting (6%), water heating (4%) and room heating (4%). About 64% energy for cooking was fulfilled by LPG followed by biomass (25%). Over 50% of energy demand for space heating was fulfilled by biomass followed by electricity and LPG (25% and 16%). Very small amount of bio briquette is used for this purpose.

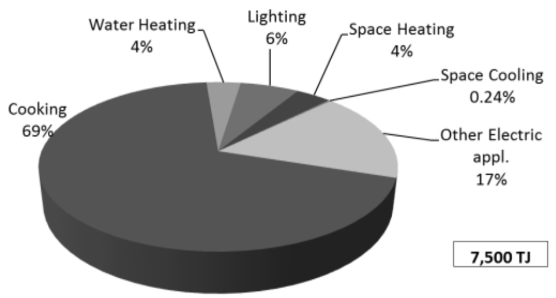

Figure 3: Final energy demand share by enduse in 2013

The sub-sectoral energy demand analysis shows that the energy urban area accounts for 60% of total final energy demand. The per capita final energy for urban and peri-urban subsectors is 2.8 and 2.7 GJ respectively. The per capita energy intensity does look nearly equal. However, point to be noted is that efficient technologies are prominent in urban area than in the peri-urban area. This shows the urban Kathmandu is not only densely populated, but also more energy intensive.

Figure 4 depicts the sub-sectoral energy demand by fuel type. It evidently shows that urban area consume more modern energy forms such as electricity and LPG while peri-urban area is in a transitional phase form traditional source to modern energy sources This is in conformity with the theories of energy transition (Leach, 1993) (Barnes, Krutilla, & Hyde, 2004) (Pachauri & Jiang, 2008).

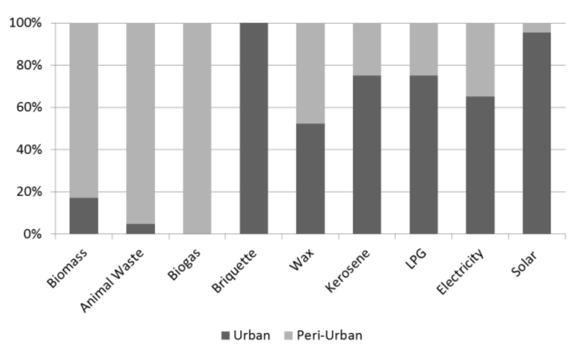

Figure 4: Sub-sectoral final energy demand by fuel in 2013

5.2. *Scenario Results*

5.2.1. Final Energy

The final energy demand in BAU will increase at the rate of 4% per annum from base year value of 7,500 TJ to 16,500 TJ in year 2033 as shown in Figure 5. The shares of energy mix will be same as that of base year and thus the per capita final energy demand will remain constant at 2.74 GJ. However, in AEL scenario, the rate of increment in demand is limited to 1.4% per annum only with total final energy demand reaching 10,000 TJ by 2033 with decrease in per capita final energy to 1.6 GJ due to intervention of efficient electric technologies. The MFA and CCP scenarios have similar growth rate of 1.5% per annum, a little higher than AEL because of low efficient non-electric technologies than later. The per capita final energy demand will be slightly higher than that of AEL. Meanwhile, the energy demand in GCP scenario would grow up at the rate of 3% per annum to 13,500 TJ in year 2033. The per capita final energy demand will decrease only to 2.1 GJ. The peculiar features about the three later scenarios are that there is a sudden drop in the final energy demand in first interval. It is due to abrupt switching from non-electric resources such as biomass and petroleum to electricity. The optimization approach taken in the system recommends that switching to electric technologies is the most cost effective energy system.

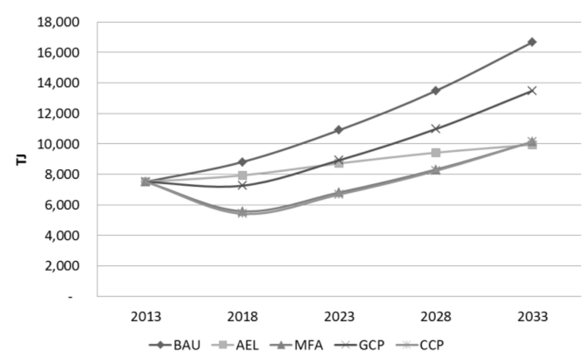

Figure 5: Final Energy Scenario

Figure 6 shows the energy mix for the various scenarios. The share of energy resources in BAU scenario is as same as in base year. In ALE scenario, the total final energy share is primarily dominated by electricity (98%) and a small contribution of solar energy. In MFA there is abrupt switching to electric energy, meanwhile other petroleum sources resources reduces significantly, later having very low increments. Thus, in final year 2033, the energy share is dominated by electricity 89% followed by LPG (5%). GCP scenario also follows similar pattern with final energy share in year 2033 dominated by electricity (67%) and biomass (33%). In CCP scenario, kerosene and wax are phase out in very early interval and in year 2033, the share is as same as for MFA scenario. From these results, it can be seen that electricity is the most prioritized energy resource in terms of cost saving.

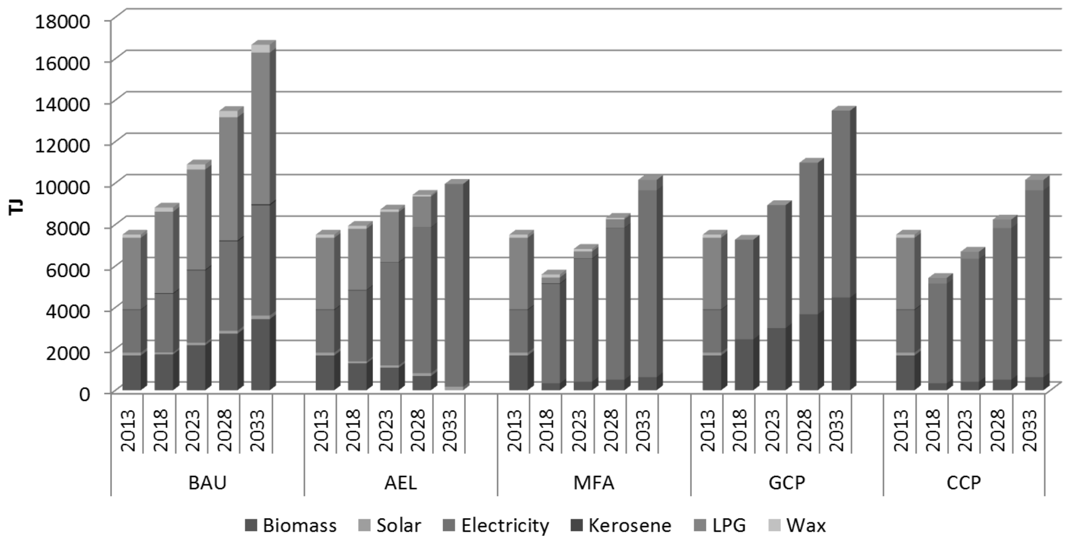

Figure 6: Energy Mix

5.2.2. Emission

Figure 7 shows the total GHG emissions in respective years for each scenario. At base year, the GHG emissions form residential sector of Kathmandu valley is about 235 kilotons, accounting for 86 kg GHG emission per capita. The most effective reduction in GHG emissions can be seen in AEL and GCP scenario. In AEL scenario, the reduction is gradual, while in GCP, there is abrupt reduction. The reduction in MFA and CCP scenarios also follows the same trend as for GCP, but the emission will reduce to 33 kilotons in year 2033, i.e. 5 kg per capita, which is a reduction by almost 95% than base year.

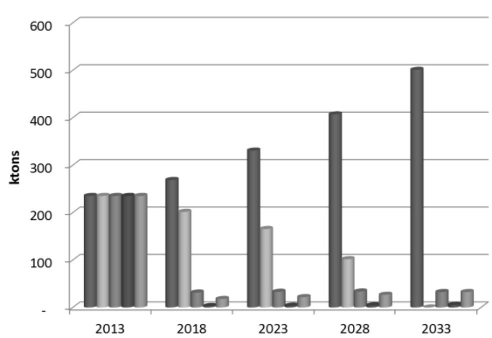

Figure 7: GHG emissions

5.2.3. Power plant requirement

The electricity is assumed to be generated majorly by hydropower plants, supported by grid connected solar PV plants. The peak power plant requirement in base year was about 250 MW. The requirement will gradually increase to 600 MW in BAU scenario. The fastest rate of power plant requirement is for AEL scenario which will gradually increase to 1400 MW in year 2033. Meanwhile in MFA, GCP and CCP scenario, the power plant requirement at end of first interval will be about 680 MW and will gradually increase to about 1,300 MW in year 2033.

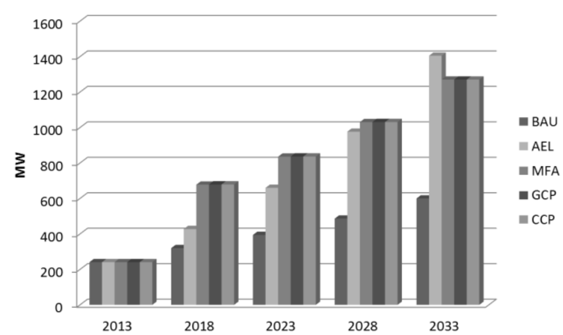

Figure 8: Powerplant requirement

5.2.4. Fuel import cost saving

It is well known fact that residential sector has also been in regular distress of petroleum import disruptions. However, with proper policy implementation and technology intervention, this can be reduced as seen in previous sections. Another most promising benefit of such intervention is saving in fuel import cost. Figure 9 shows the fuel import cost saving for each scenario. It can be seen that each scenario is favorable for fuel import cost saving. The saving will increase gradually in AEL scenario with saving of about 22 billion NRs (2005 constant price) in year 2033. For other scenario also the saving in last year is similar. However, due to sudden fuel switching, the overall fuel import cost saving is higher in later three scenarios. This save in cost can be invested in power plant development to fulfill the demand from nationally available resources.

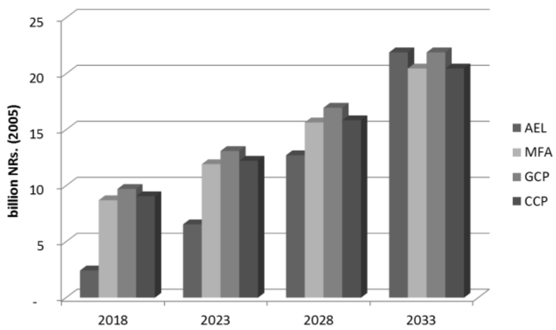

Figure 9: Fuel import cost saving

5.2.5. Marginal abatement cost

Marginal abatement cost (MAC) depicts investment required to reduce the emission from that of reference level, and is generally expressed in cost per kg of CO_2 equivalent. Figure 10 shows the (MAC) for GHG reduction. In AEL scenario, the MAC is about NRs. 50 per kg of GHG abated. This is due to high investment in hydropower plant and lower but gradual reduction in GHG emission. MAC for AEL reduces gradually to about NRs. 10 in year 2033 when electric technologies will be takeover other non-electric technologies. However, in rest of the scenarios, the MAC in very beginning is a negative number which indicates net economic benefit. This is due to huge reduction in emission. However, there have been many arguments regarding negative-cost abatement opportunities as stated by Ackerman and Bueno (2011) in their working paper. If a net economic benefit can be achieved with energy saving, why hasn't it been implemented? The possible reasons for efficiency gap as put upon by Brown (2001) are discouragement in investment due to market failures and barriers. DeCanio (1998) terms it as "efficiency paradox" and argues consumer behavior and organizational factors could be cause for such deviations.

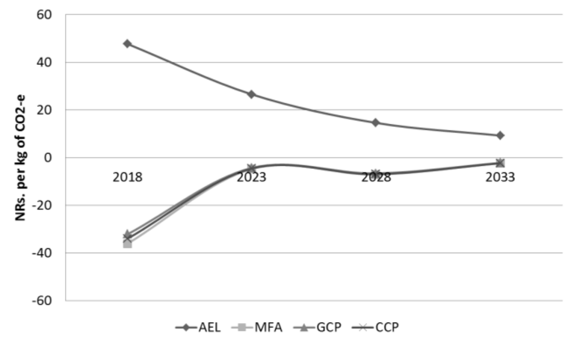

Figure 10: Marginal abatement cost

6. Conclusion

Kathmandu valley is one of the fastest growing agglomerate which is in transition from early urbanization stage to modern stage. The urbanization has brought about energy transition long with increase in energy demand. With growing energy demand, especially for commercial source of energy, which is currently fulfilled by imported fuels like kerosene, LPG, and even electricity itself, it's a major concern to maintain the future energy supply for uninterrupted development meanwhile decreasing the consumption of conventional energy sources and imported supplies.

The survey data clearly shows the phase of energy transition in case of urban and peri-urban sectors of Kathmandu valley. The growing population in the valley will increase energy demand. However, the more important message is that growing urbanization would require more commercial resources.

The scenario analysis shows that under current circumstances, the final energy demand would be more than double in next 20 years. However, with proper policy implementation and technology intervention, the final energy demand can be reduced significantly. With availability and accessibility to cleaner energy sources, which are abundantly obtainable, the emissions can be reduced to an insignificant level as well. The development of hydropower plant and solar PV plants will not only be appropriate use of indigenous resources, but also will prove to be help n reduction of emissions as well as significant saving in fuel expenditure. The development works in other hand would increase national revenue and provide employment opportunities as well.

References

Ackerman, F., & Bueno, R. (2011). Use of McKinsey abatement cost curves for climate economics modeling. MA, USA: Stockholm Environment Institute - US.

Adhikari, S. (2012). *Electricity Demand Side Management of Residential Sector in Kathmandu Valley.* Kathmandu: Pulchowk Campus, Institue of engineering, Tribhuvan University.

Barnes, D. F., Krutilla, K., & Hyde, W. (2004). *The Urban Household Energy Transition.* Washington D.C.: Resources for the future.

Brown, M. A. (2011). Market failures and barriers as a basis for clean energy policies. *Energy Policy* .

CBS. (2012). Kathnamdu: Central Bureau of Statistics.

CBS. (2014). *Annual Household Survey 2012/13.* Kathmandu: Central Bureau of Statictics, National Planning Commission Secretariat, Government of Nepal.

CBS. (2012). *National Population and Housing Census 2011.* Kathmandu: Central Bureau of Statistic, National Planning Commission Secretariat, Government of Nepal.

CBS. (2011). *Nepal Living Standards Survey 2010/11.* Kathmandu: Central Bureau of Statistics, National Planning Commission Secretariat, Government of Nepal.

CIA. (2014). *The World Factbook*. Retrieved 2014, from Central Intelligence Agency: https://www.cia.gov/library/publications/the-world-factbook/geos/np.html

DeCanio, S. J. (1998). The efficiency paradox: Bureaucratic and organizational barriers to profitable energy-saving investments. *Energy Policy* .

Hainoun, A., Seif-Eldin, M. K., & Almoustafa, S. (2006). Analysis of the Syrian long-term energy and electricity demand projection using the end-use methodology. *Energy Policy* , 1958-1970.

IAEA. (2006). *Model for analysis of energy demand (MAED-2), Computer manual series no.18.* Vienna,Austria: International Atomic Energy Agency.

IEA. (2010). *World Energy Outlook 2010.* International Energy Agancy.

Krejcie, R. V., & Morgan, D. W. (1970). Determining Sample Size for Research. *Educational and Psychological Measurement* , 607-610.

Leach, G. (1993). The energy transition. *Energy Policy* , 761–764.

Loulou, R., Goldstein, G., & Noble, K. (2006). *Documentation for the MARKAL Family of Models, Energy Technology Systems Analysis Programme.*

Malla, S. (2013). Household energy consumption patterns and its environmental implications: Assessment of energy access and poverty in Nepal. *Energy Policy* , 990-1002.

Muzzini, E., & Aparicio, G. (2013). *Urban Growth and Spatial Transition in Nepal: An Initial Assessment.* World Bank Publications.

NRB. (2008). *Household Budget Survey.* Kathmandu: Nepal Rastra Bank.

Pachauri, S., & Jiang, L. (2008). The household energy transition in India and China. *Energy Policy* , 4022– 4035.

Pant, P. R., & Dongol, D. (2009). Kathmandu Valley Profile: Briefing Paper. Kathmandu, Nepal.

Rajbhandari, U. S., Prajapati, A., & Nakarmi, A. M. (2013). Future Energy Scenario and Implications for Technological Interventions for Nepal. *Proceedings of IOE Graduate Conference.* Kathmandu, Nepal: Institue of Engineering, Tribhuvan University.

Reddy, B. S. (1998). *Urban Energy System.* New Delhi, India: Concept Publishing company.

Shrestha, R. M., & Malla, S. (1996). Air pollution from energy use in a developing country city: the case of Kathmandu Valley, Nepal. *Energy* , 785-794.

Shrestha, R. M., & Rajbhandari, S. (2010). Energy and environmental implications of carbon emission reduction targets: Case of Kathmandu Valley, Nepal. *Energy Policy* , 4818–4827.

UNDESA. (2012). *World Urbanization Prospects: The 2011 Revision.* United Nations Department of Economic and Social Affairs Population Division.

UNDESA. (2013). *World Urbanization Prospects: The 2011 Revision*. Retrieved 2013, from United Nations Department of Economic and Social Affairs, Population Divison,: http://esa.un.org/unup/index.html

UN-energy. (2006). *Assessing policy options for increasing the use of renewable energy for sustainable development: modelling energy scenarios for Ghana.* New York: UN Headquarters.

UN-energy. (2007). *Assessing policy options for increasing the use of renewable energy for sustainable development: modelling energy scenarios for Sichuan, China.* New York: UN Headquarters.

WECS. (2010). *Energy Sector Synopsis Report Nepal.* Kathmandu: Secretariat, Water and Energy Commission, Ministry of Energy, Government of Nepal.