Performance Evaluation of Energy Technologies in Residential Sector

Anita Prajapati, Amrit Man Nakarmi

Department of Mechanical Engineering, Central Campus,Pulchowk, Institute of Engineering, Tribhuvan University, Nepal

Corresponding Email: anita.praj@gmail.com

Abstract: Energy situation of Nepal at present is very critical. Continuous energy crisis holds back economic advancement of the nation. With time, advance technologies are available and there is shift in consumption pattern as well. Assessment of preferences of technologies in residential sector was done. After reviewing of relevant scholarly literature and discussion with experts, an appropriate decision model was formulated consisting of goal, criteria, sub-criteria and alternatives. Existing technologies that utilizes Electricity, LPG, Fuelwood, Kerosene and Solar are the alternatives in all end use services. Economical, technical, social and environmental criteria are considered. Analytical Hierarchy Process (AHP) model was developed to highlight the preference of technologies in major end use services of residential sector. The output of the model shows electric technology as the preferred options in almost all the end use services of residential sector. Besides prioritization of technologies, the results from AHP can also be used in future energy planning. With the availability of electricity throughout the nation, preferences shifts from traditional to modern technologies.

Keywords: Energy; AHP; criteria; sub-criteria; residential; technologies

1. Introduction

Energy is the vital element for sustainable development of country. Energy resources are regarded as the key strategic natural resources having the potential to be the catalyst for all round development and economic growth of the country. Unless the energy sector is geared up for efficient and indigenous sustainable resources along with their sustainable harnessing, economy cannot move forward on a higher growth path. Every advanced economy requires secure access to modern sources of energy to fortify its development and growing prosperity. While many developed countries may be focused on domestic energy security or decarbonising energy fuel mix, many other developing countries like Nepal are still seeking to secure enough energy to meet basic human needs (IEA, 2011). According to Human Development Index, Nepal rank 157th[1] position with 0.458. Access to reliable and affordable energy services is fundamental to reducing poverty and improving health, increasing productivity, enhancing competitiveness and promoting economic growth.

The economy of Nepal is based mainly on agriculture with more than 76% of people engaged in it. According to the economic survey and statistics on Nepal by Asian Development Bank, the contribution of the agricultural sector has declined to 35% and that of the non-agricultural sector increased to 65% showing a positive sign of improving economic status of country (MoF, Economic Survey FY 2011-2012, 2012).

Energy is an indicator of development. High per capita energy consumption signifies high living standard of people. Developed countries have significantly higher per capita energy consumption. For example, the United States has a per capita energy consumption of 314 GJ/year, Japan has 163 GJ/year, and United Kingdom has 142 GJ/year. According to world energy statistics of 2010, the per capita total primary energy supply (TPES) of Nepal is just 15 GJ/year, which is far less than world's average per capita TPES of 77 GJ/year. Energy consumption per capita of Nepal is lowest among south Asian countries and electricity consumption per capita is 104 kWh (UNESCAP, Statistical Yearbook for Asia and the Pacific 2012, 2012). The EDI (Energy development Index)[2] ranks Nepal at 74th position with EDI of 0.08. One of the main reasons for this fact is that about 37% of households do not have access to electricity that can boost economic indicator (SERN, REEEP Policy Database, 2011). The total primary energy consumption in the year 2008/09 was estimated to be about 401 PJ (WECS, 2011). Energy statistics of Nepal exhibit large dominance of traditional and non-commercial forms of energy such as fuel-wood, agricultural residue and animal waste. Energy carriers like petroleum fuels, coals and electricity contributes only 9%, 3% and 2% (WECS, 2010) respectively in total energy consumption.

Residential sector consume substantial amount of energy. Energy consumption characteristics of the

[1] http://hdrstats.undp.org/en/countries/profiles/NPL.html

[2] EDI is devised by IEA, as an indicator that tracks progress in a country's or region's transition to the use of modern fuels. (http://www.iea.org/publications/worldenergyoutlook/resources/energydevelopment/theenergydevelopmentindex/)

residential sector are complex and inter-related, comprehensive models are needed to assess the techno economic impacts of adopting energy technologies (Lukas & Ugural, 2009). Residential energy consumption in Nepal for the year 2008/09 accounts for the major share of energy consumption (89%). This sector consumed about 357 PJ of energy. Biomass resources are the major fuels source in this sector that accounts to 99% of the total fuel wood consumed only in the residential sector. Similarly 91% of the agricultural residue is consumed and animal dung is being used in biogas generation which increased by about 15% in annual basis (WECS, 2010).

WECS (2006) has assessed that 48 PJ energy is consumed in the urban residential, which is equivalent to about 15% of the total residential energy consumption. In context of urban sector energy consumption, cooking purpose consumes large share of energy i.e. 52% followed by electric appliances (14%) and lighting (13%) heating and cooling (10%). LPG contributes about 25% of the total consumption followed by kerosene (9%), animal residue and dung (3% each) and biogas (2%). Fuel wood share in rural residential is about 71%.

The energy synopsis report of WECS shows that there is distinct change (both in amount and type of fuel) in energy consumption over time. The total energy consumption of Nepal in the year 1994/95 was about 285 million GJ. About 92% of this energy consumption was met by traditional energy sources and the rest by commercial energy sources. In 2010, total energy consumption increases to 401 PJ and about 87% of this is met by traditional energy sources.

The total energy consumption data in the country shows an annual increase of about 2.4%. Significant rise of annual electricity consumption by around 10% implies growing demand for electricity as household income is rising. However, 25% annual surge of imported LPG fuel consumption seems perilous to national economy. As of WECS data 2008/09, fuel wood consumption share is 87% of total energy consumption and almost 99% of which is consumed in residential sector.

Nepal has huge potential for hydropower development with an estimated potential of 83 GW and feasibility of 42 GW[3]. However to our dismay, only 2% of it has been harnessed. Further, eelectricity contributes only 2% of the total energy demands (SERN, REEEP Policy Database, 2011). At present, Nepal has a total installed capacity of 762 MW. Of the total installed capacity of the hydropower, 478 MW is contributed by NEA hydro, 5 MW by NEA thermal, 0.10 MW by solar and 230 MW-all Run-off-the River (ROR) by IPP hydro (NEA, 2009) (NEA, A Year In Review Fiscal Year 2012/13, 2013).

Nepal is totally dependent on imported petroleum fuels. Soaring international oil market price is making countriy's economy vulnerable. The nation spent approximately 126% of its commodity exports in 2010/11 on import of petroleum products which stood at 27% of the exports earnings in 2000/01 (MoF, 2001) (MoF, 2012). If Nepal can overcome the barriers of indigenous electricity production, it can avoid the cost of importing petroleum products. Without proper vision, strategies, and action plans for the sustainable development of energy sector, Nepal's economy could be in jeopardy in the coming years

2. Methodology

Existing technologies in residential sector for cooking, lighting, space heating and water heating were identified based on relevant literatures. Details of technologies were analyzed based on its performance and availability. Regional questionnaire survey conducted for the study of water and energy vision data were collected. The survey was conducted among 163 participants from five development regions among various strata of people from government bodies to energy experts. An AHP model is used for the selection and prioritization of energy technologies. Relative weights of criteria with respect to goal are calculated. Alternatives are incorporated in the final level of hierarchy for evaluation. Capital cost, investment cost, efficiency, emission level, durability

2.1 Analytical Hierarchy Process (AHP)

AHP is a widely used Multi Criteria Decision Analysis (MCDA) method and considered a very effective and powerful technique (Athanasios & Pilavachi, Technological,economic and sustainability evaluation of power plants using the Analytic Hierarchy Process, 2009) (Belton & Gear, On a shortcoming of Saaty's Method of Analytical Hierarchy, 1983). It is used in numbers of studies related to energy. AHP is comprehensive multiple criteria decision-making tool that has been used in almost all the applications related with decision-making (Vaidya & Kumar, 2006). Further, energy resource allocation can also be done using a multi-criteria decision with the criteria being quantitative and/or qualitative. Solving such a problem requires an integrated approach (Ramanathan & Ganesh, 1995).

AHP method employs a consistency test to screen out inconsistent judgments by any expert and this is also

[3]Estimation was done by Dr. Hari Man Shrestha some 44 years ago in his Ph.D. research dissertation(Shrestha, H.M., 1966)

considered as an advantage of using AHP. It is important that the decision-makers should be consistent in their preference ratings expressed by pair wise comparisons. It has been recommended that consistency ratio (CR) should be less than 0.10 and mentioned that CR greater than 0.10 indicates serious inconsistencies and in that case AHP may not provide meaningful results (Saaty, The Analytic Hierarchy Process, 1980).

2.2 AHP Model

AHP model was developed using Expert's Choice. Technologies in residential sector were evaluated using numbers of criteria and sub-criteria. There are numbers of end use services considered in residential sectors namely cooking, lighting, space heating, space cooling and water heating. Different end use technologies based on survey output were considered as alternatives for each end use services in AHP. Each of the criteria and sub criteria were weighted based on literature and survey. In each criteria and sub-criteria, alternatives were rated and then normalized to prioritize the technologies.

3. Results and Discussions

3.1 Cooking

The analysis of data shows that at present most of people use LPG for cooking in residential sector but they preferred to cook in electricity in near future. People want to shift from traditional and imported cooking technologies to modern indigenous and efficient technologies. These data were incorporated in AHP along with other criteria. The preferences are as shown in table 1

Table 1: Preferences of Technologies in Cooking

Technologies	Current	Expected
TR	31.9%	6.4%
ICS	12.3%	7.8%
Gasifier	3.1%	4.0%
LPG	30.7%	9.5%
Kerosone	4.7%	0.6%
Electricity	10.2%	36.6%
Biogas	5.6%	14.5%
Solar stove	1.4%	20.5%

The efficiency, investment cost, O&M cost, and emission are given below in table 2.

Table 2: Factors affecting selection of technologies

Technologies	Efficiency	Investment Cost (Million Rs/TJ)	O&M Cost (Million Rs/TJ)	Life (Years)	Emission factor GHG tonnes/TJ
Kerosene	23%	0.274	0.007	5	72.328
LPG	54%	0.967	0.024	10	63.254
Electric	65%	0.503	0.013	5	0
Fuel Wood	7%	0.000	0.000	1	120.692
Bio Gas	57%	0.398	0.010	10	54.754

Different criteria and sub criteria along with the alternatives were selected based on the literature and survey which are as shown in table 3.

Table 3 Criteria, sub-criteria and alternatives in cooking

Criteria	Sub-criteria	Alternatives
Economic	Investment cost	Fuelwood Kerosene LPG Electricity Biogas
	O&M cost	
Technical	Design	
	Maintainability	
	Efficiency	
	Availability	
Social	Peoples Acceptibility	
	Quality of life	
Environmental	Emission	

The assessment model indicates economic criteria as most important with relative weight of 50%. In addition, investment cost affects the technology selection as it weighs 75% compare to 25% for O&M cost. Based on this approach, ICS is the best technology to be adopted as investment cost is very low compare to other technologies in this end use

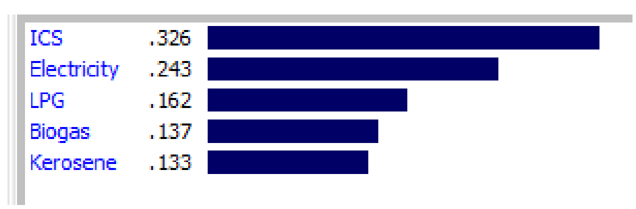

Figure 1: Screenshot of synthesis result of Cooking technologies

The performance evaluation of cooking technologies shows that ICS is the best technology to be adopted for cooking in residential sector. The priority weight is

0.3207 for ICS followed by electricity with 0.24. AHP thus shows that economic criteria plays crucial role in determining technologies. However when all four criteria are given equal weights in another scenario, AHP ranks electric cooking as the best. The overall inconsistency of 0.02 depicts the acceptability of output from AHP. Biomass also receives higher ranking depicting its low investment, O&M cost and simple design. Investment cost and operating cost is high for LPG. Kerosene stove is socially and environmentally outdated in modern technologies. Biogas and kerosene is least preferred technology in overall aspect. Biogas is mainly due to high installation cost and O&M cost and less acceptability of people due to requirement of daily man hour.

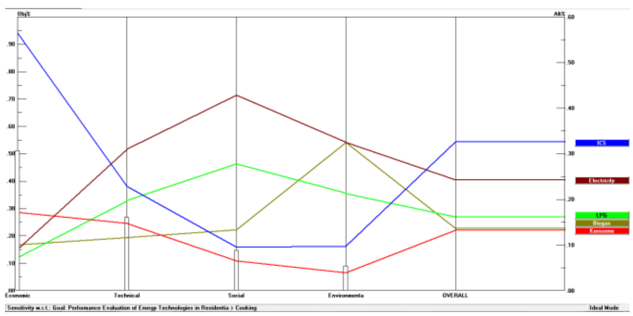

Figure 2 Sensitivity analysis of Cooking technologies

3.2 Lighting

In lighting, as per the survey data, most of the people are using CFL lamp at present followed by tube light and incandescent lamp. But in near future they preferred to use LED and CFL as major lighting technologies. Considering their preferences the AHP analysis was done under different criteria. The result shows that LED and solar are the most preferred technologies for lighting

Table 4: Technologies in lighting

Technologies	current	expected
Kerosene	9%	1%
Incandescent	19%	4%
Tube light	21%	14%
CFL	33%	24%
LED	15%	49%
Biogas	4%	4%
SHS	9%	26%

The criteria and alternatives for this end use service are as in table 5

Table 5: Criteria and alternatives in lighting

Criteria	Alternatives
Capital Cost	Incandescent
O&M Cost	Fluorescent
Reliability	CFL
Comfort	LPG
Efficiency	Solar

The sensitivity analysis for this service is as in figure 3. It imparts that LED and solar are the best options to be adopted for lighting in residential sector of Nepal. High efficiency, high comfort, reliability are the deciding factors. Reliability comfort and efficiency factor each weighs 25%.

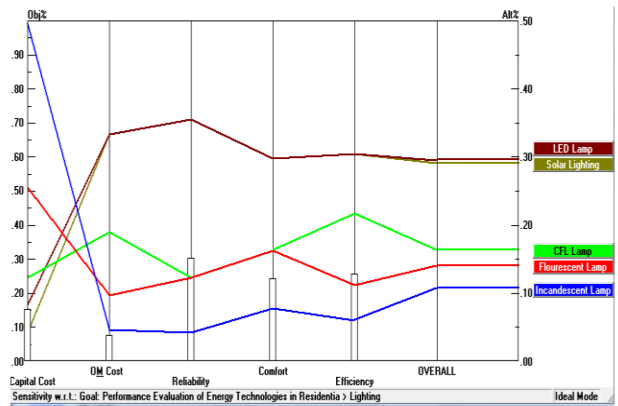

Figure 3: Sensitivity analysis of lighting technologies

The priority weight of both are 0.29 each. Capital cost is high as both are imported technology. Solar lighting is highly reliable and efficient. On the other hand electric LED lights are more efficient and durable. The prioritization of technologies is as shown with an overall inconsistency of 0.03. The sensitivity graph also shows the effect of criteria and their weight in prioritising the technology.

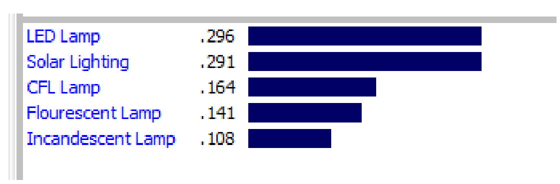

Figure 4 Ranking of lighting technologies

3.3 Space Heating and Water Heating

Currently, traditional biomass, LPG and electricity are used for space heating while the figure shows shift in future energy technology for the same. Criteria in space heating include reliability, comfort, efficiency, capital, operation and maintenance cost, time of repair, layout flexibility and emission. The overall weight of criteria shows that reliability and comforts have relative weight of 28% each, capital and O&M cost weighs 17% and 12% each.

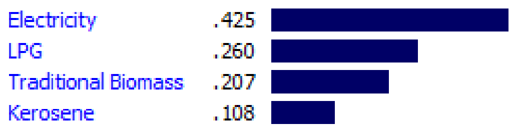

Figure 5: Synthesis result of space heating technologies

The model thus gave ranking of technologies based on the weights of criteria. It ranks electricity as the best option with priority weight of 0.42 followed by LPG with 0.24. Electricity is less reliable in our country because of low electricity supply than demand, however, comfort from electricity is higher than other technologies and consequently it scores highest in all other criteria providing the highest overall weight to electricity. The overall inconsistency of result is 0.05.

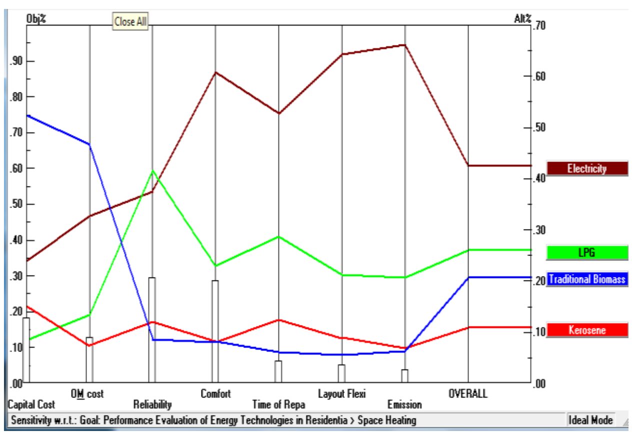

Figure 6: Sensitivity in space heating

Water heating is another residential energy technology consuming energy. Criteria in water heating include reliability, efficiency, capital, operation and maintenance cost, emission, energy saving, acceptability and maintainability. Reliability weights 24% of total weight, efficiency and energy saving weights relative 16% each. Thus reliability of technology affects the prioritization. Highly reliable water heating technologies surpass other technologies.

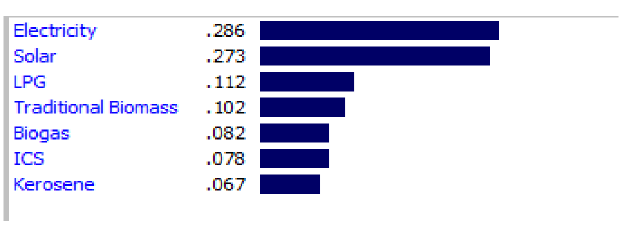

Figure 7: Synthesis result of Water Heating technologies

At present LPG and traditional fuelwood is use for water heating purpose however there are prospective approach to shift to modern energy technology.

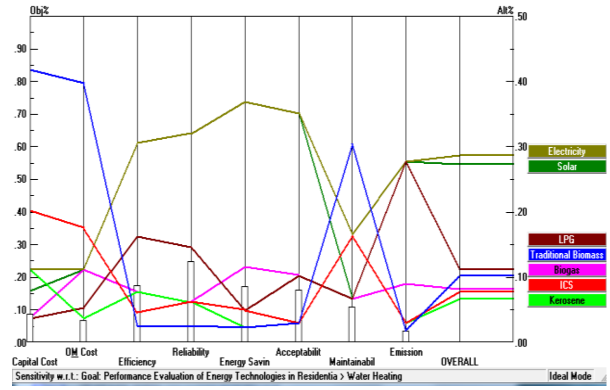

Figure 8: Sensitivity in water heating

Sensitivity analysis of water heating is as shown in figure 8. It indicates that electricity is the best technology for water heating followed by solar, LPG, traditional biomass and kerosene. Sensitivity result shows preference of technologies in each criterion. Electricity is less reliable in our country because supply is lesser than demand. However, it weighs higher than other technologies in remaining criteria. The overall inconsistency of result is 0.05. Solar and electricity are best option to be adopted in residential water heating

4. Findings

Performance evaluation of energy technologies shows that modern electric technology is the best technology to be adopted in future. The consumption pattern at present is mostly biomass, imported petroleum which by far is not the preference of people as shown by survey data analysis. Choice of technology depends on different criteria and sub-criteria. Economic criteria determine the technology prioritization in cooking, while reliability, acceptability, efficiency and design complexity determines the choice of technology in other end use services. To shift the energy consuming pattern in future, criteria and sub-criteria that play major role should be addressed. In cooking, electricity should be made available with low cost and technology cost should also be reduced. ICS should be made available in rural area where there is no grid connection. LPG is imported technology but is adopted due to reliability, efficiency, and social and environment point of view. In lighting, electric LED and solar are highly efficient, comfortable and reliable technologies. These are also energy saving technologies. Solar water heating and electric space heating are best technologies in residential sector. To meet demand of people to use best technology so as to improve living standard, supply of electricity needs to be sufficient. Huge potential of hydropower needs to be harnessed for domestic purpose.

5. Conclusions

Energy scenario of Nepal is poor and technology availability in the country is even poorer. The comparative study of energy consumption and preferred technology shows disparity in availability and desired technology.

The major findings of the survey is that electric technology is the most desired technology for cooking, lighting, water heating, space heating. In cooking, ICS is preferred best, however technically, socially and environmentally electric technology is best preferred LED light is preferred best for lighting in residential sector due mainly to its reliability, efficiency and comfort. In water heating, electricity and solar are best preferred technology as they are highly efficient, technically feasible, socially acceptable and durable followed by LPG water heater while least preferred are kerosene and biomass. In space heating, electricity and LPG are desired technology because of its comfort, layout feasibility, reliability and low emission while least preferred one is biomass and kerosene. Thus it can be concluded from above results considering each of criteria and sub-criteria that electric technology is the most desirable and suitable technology in residential sector of Nepal.

6. Recommendations

- Combined use of scenario building and participatory multi-criteria analysis (PMCA) can be done which has been done separately in this study. Scenario analysis involves high degree of complexity inherent in the system while MCA assess options on the basis of multi-dimensional criteria and calculates ranking of options. Assessing scenario with PMCA involves intensive resource. 'Metacriteria' combination of scenario and primary criteria can be generated to address complex decision context.
- Further study can be done for other end-use sectors like commercial, transportation, industry, etc
- Comparative analysis of energy technology can be done using other decision making tools.

7. Limitations of the study

The study was solely based on the questionnaire developed for participants in regional workshop conducted for the study of water and energy vision conducted by Water and Energy Commission Secretariat in 2012 with total participants of 163 from different sectors. Required input data were generated from the analysis of survey data. Criteria and sub-criteria selected are basically the outcome of literature. Data base was developed based on available secondary database for 2010.

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