Urban Energy Scenario: the Case of Kathmandu Valley

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Abstract. Rapid urbanization has made Kathmandu Valley one of the fastest growing metropolitan cities in South Asia, resulting in the need of additional facilities and infrastructure. The local energy crisis is one of the issues to be addressed. High dependence on imported fossil fuels and the sluggish development of hydropower for electricity generation despite abundant water resources are the major causes to be blamed for the energy crisis in Nepal. This study investigated possible strategies to be implemented in Kathmandu Valley to deal with the discrepancy between energy demand and supply. Several scenarios have been developed and analyzed, both quantitatively and qualitatively. The Comprehensive Scenario, which borrowed from all other developed scenarios, seems superior to the others. It reduces the energy demand by 32.36%, the GHG emission by 44.12%, and the social cost by 33.79%. This scenario implies that the Kathmandu Valley authority will support the installation of photovoltaic solar panels, the use of electric vehicles and electric cookers, and convert solid waste into energy. However, the EV Scenario (electric vehicles) is the one to be given priority in the implementation for its better performance than the other individual scenarios.

Keywords: *electric cookers; electric vehicles; energy supply demand; GHG emissions; photovoltaic solar panels; social cost; waste to energy.*

1 Introduction

Over 60% of global energy demand is consumed in urban areas [1]. This fact leaves its mark on energy expenditure in all such areas and causes environmental pressure. Therefore, the topics of energy saving and conservation now dominate the discussion in the context of sustainable development [2]. The same thing happens in Nepal. The prolonged energy crisis in Nepal has a great impact on local economic activities and social development. It has been reported that about 99% of the firms in Nepal suffer due to load shedding [3].

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Being a country with a promising source of energy, i.e. hydropower, Nepal has not been able to utilize it at its best, mainly due to inadequate financial sources, lack of technical expertise and the unstable political situation. Nepal is currently using a maximum of only 1% of its ability to produce 83,000 MW of hydropower.

Urbanization and population growth have been two major reasons behind the continuous increase of energy demand in Kathmandu Valley. The population has increased from 1,645,091 in 2001 to 2,510,788 in 2011 with an average rate of 4.3% per year. This accounts for approximately one third of Nepal's total urban population, which has been growing at a rate of 7% per year. The rapid urbanization of Kathmandu has made the city one of the fastest growing metropolitan cities in South Asia [3].

The energy crisis reached its climax after the promulgation of the new constitution of Nepal in 20 September 2015. General strikes along the Nepalese-Indian border have caused severe disturbances in the supply of various commodities from India, including petroleum products. Being highly dependent on fuel imports from India, Nepal experienced a serious fuel crisis for more than five months, with Kathmandu Valley being hit the hardest.

Based on the reviews of background and current problems in Kathmandu Valley, the following objectives have been set: 1) to identify variables that may influence energy consumption behavior, 2) to determine energy consumption patterns, 3) to develop scenarios based on the current situation and available resources, 4) to investigate and analyze how the energy system may evolve over time and to propose the best energy scenario for Kathmandu Valley.

1.1 Literature Review

The issue of energy is always an interesting topic in the sustainable development debate. Study of the relationship between energy and lifestyle started during 1970s in the United States. Sanquist, *et al.* have statistically examined the relationship between energy consumption and lifestyle factors and found that lifestyle accounts for 40% variation in energy consumption [4]. The inclusion of human behavior was expected to enhance the establishment of energy policies. Age has been studied as a factor that plays an important role in determining energy consumption patterns in households. Toth, *et al.* have found that young children and teenagers have significantly different energy consumption patterns [5]. The application of scenario analysis in the field of energy planning and management is one of the emerging fields in response to energy crises and security. Scenarios can be built and then compared to assess their energy requirements, social costs and benefits, and environmental impacts

[6]. The result of an energy scenario analysis may not give an exact picture of the future. The process does not really depend on historical data and does not presuppose that previous observations will be still valid in the future. Dhakal predicted the trend of energy demand and environmental pollution for passenger transportation in Kathmandu Valley, with a scenario that deals with traffic improvement measures, promotion of public transportation and electric vehicles [7]. Shin took into account the technological aspects in the environmental and economic assessment of landfill gas electricity generation in Korea [8]. Analysis of the possibility for Cleveland, Ohio to become a self-reliant city from a technological point of view was done, including several alternative sources of energy [9].

The analysis of sectoral energy demand patterns and CO_2 emissions in Kathmandu Valley done by Shrestha and Rajbhandari considered the scenario with different CO_2 emission reduction targets. The paper indicates that there is a need of switching energy consumption from oil and gas to electricity [10]. With regard to CO_2 emission measures, Feng and Zhang have studied urban energy saving and carbon abatement policies in Beijing. The study shows that the building and transportation sectors have been found to be promising sectors to reduce CO_2 emission [11].

Energy policies are now moving towards future energy security, emphasizing more on alternative sources of energy. Rigorous research on building energy policy in China has shown that many barriers exist in the implementation of such policy, such as legal, administrative, social and financial issues [12]. The Slovenian government has established various policies on energy efficiency and set up a target named *Plan 20-20-20*, which means reaching a 20% increase in efficiency by the year 2020. In Nepal, the following policies and plans were supposed to be strategic ones, yet the implementation is not as expected. *Water Resources Strategy 2002 and National Water Plan 2005* targets 2100 MW by 2017 and 4000 by 2027 to meet domestic requirement and export of the excess. *Ten Years Hydropower Development Plan 2009* mentions the plan to develop 10,000 MW in 10 years. These policies are just a few among others that have been developed by the Government of Nepal.

Energy modeling is one of the crucial fields in the discussion of energy problems. The bottom-up approach lies the foundation for technical measures, such us efficiency improvement, changes in technology, utilization rate and inter-fuel substitution. It uses the engineering and economic calculation of energy saving, emissions and cost of different technologies [13]. The top-down approach is based on the economic paradigm. It places its groundwork on historical data, which are referred to as an aggregate of human behavior in the previous period [14]. It usually uses an econometric model and multiple regression methods to explain the relationship between dependent and independent variables [15]. LEAP (Long-term Energy Alternative Plan) is not a model, but rather a tool that can be used to develop a model. It supports the two major approaches (bottom-up and top-down) in energy modeling. Furthermore, several research questions have been raised to encounter the existing problems: What are the factors that influence energy consumption? How are the energy consumption patterns and behaviors? How should the scenarios be developed? How does the energy system evolve over time? How should policies be initiated?

2 Research Methodology

2.1 Data Collection and Sampling Method

This research involved a series of surveys concerning different aspects of energy consumption in urban areas and alternative energy sources. The primary data were obtained through interviews and questionnaires with respondents covering different groups of house occupants, businessmen, investors, policy makers and government officers residing in Kathmandu Valley. The questionnaire was used as a tool to investigate energy consumption in the residential sector, because this is the sector that dominates energy usage in Kathmandu Valley. The questionnaires incorporated the following major components: energy consumption, energy consumption behavior that accommodates possible variables that may affect energy consumption, and responses to promotion of energy alternatives.

As the research method is a mix of quantitative and qualitative, the questionnaires were designed with both closed-ended and open-ended questions. The samples were taken using proportional stratified random sampling. The sampling frame consisted of the five major municipalities in Kathmandu Valley, where each of them was considered as a stratum. The number of samples was then proportionally determined, based on the number of households in each municipality. Finally, households were randomly selected for each municipality. The sample size was calculated using the following Eq. (1):

$$n = \frac{N}{1+Ne^2} \tag{1}$$

where n is sample size, N is population size, and e is sampling margin error. With a margin error of 5%, 384 samples were required for analysis.

The secondary data were population, population growth, population density, total electricity consumption, electricity transmission and distribution related data, total number of vehicles in Kathmandu Valley, and other related data required for analysis. They were obtained from various sources such as books, data compilation, journals, magazines, dailies, published researches and articles and published material from authorized institutions in Nepal. This study also used published interviews with businessmen, energy experts, policy makers and government officers.

2.2 Scenario Development

Using the base year of 2015, the following scenarios were employed, focusing only on the urban area of Kathmandu Valley:

1. **Business As Usual (BAU)**: The scenario assuming that there will be no change in existing policies.
2. **Solar Radiation (SR)**: This is a scenario involving the use of solar energy. It is expected that 25% of the total energy demand share will be solar energy. The final energy intensity for solar is 274 MJ per year per household.
3. **Solid Waste (SW)**: This scenario involves the conversion of solid waste into energy. The share of energy resulted from this conversion is expected to be 10% in 2035 with a final energy intensity of 1095 MJ per household per year.
4. **Electric Cooker (EC)**: This scenario incorporates the use of electric cookers, given the prerequisite that there is an adequate supply of electricity. It is estimated that the share of LPG in cooking will drop from 95% to 75% and the energy intensity will drop from 10,096 MJ to 2524 MJ per year, while the share of electricity for cooking increases to 75% with a final energy intensity of 7572 MJ per household per year.
5. **Electric Vehicle (EV)**: This is the scenario that falls under the transportation sector. It is expected that the share of electric cars in Kathmandu will reach 50% in 2035, while electric motorbikes will reach only 30% due to tough competition with petrol motorbikes in energy consumption. The final energy intensity is 1230 KWh per vehicle per year for cars and 244 KWh per vehicle per year.
6. **Comprehensive (COMP)**: Comprehensive scenario borrowing all properties of the other scenarios other than BAU.

2.3 Data Analysis

The quantitative analysis in this study covers two major parts:

1. Correlation analysis to find the relation between energy consumption and six variables (age of building, size of household, number of persons over 60 in the family, number of children below 5 in the family, income and

education). The analysis was performed using the Excel software application.

2. Scenario analysis to determine the best energy scenario suitable for Kathmandu Valley. The analysis was performed using the LEAP software application incorporating an activity analysis, environmental analysis and cost benefit analysis as described in the following paragraphs.

The activity analysis was aimed at estimating the energy consumption for all demand branches in the LEAP structure. Total energy consumption was calculated by the general equation in Eq.(2):

$$\text{Energy Consumption} = \text{Activity level x Energy intensity} \quad (2)$$

For the final energy demand analysis, energy demand was calculated for the current account year and for each future year in each scenario. Thus, it is expressed in the following equation:

$$D_{b,s,t} = TA_{b,s,t} \text{ x } EI_{b,s,t} \quad (3)$$

where *D* is demand, *TA* is total activity, *EI* is energy intensity, *b* is branch, *s* is scenario, and *t* is year. The total activity of a technology is calculated using Eq. (4):

$$TA_{b,s,t} = A_{b',s,t} \text{ x } A_{b'',s,t} \text{ x } A_{b''',s,t} \text{ x } \ldots \quad (4)$$

where A_b is the activity level in a particular branch *b*, *b'* is the parent of branch b, *b''* is the grandparent, etc.

All the devices used in the demand analysis are potential sources of environmental loading. In this analysis, environmental loading is specified by using the TED (Technology and Environmental Database) feature in LEAP. Emission is expressed as the amount of CO_2 equivalent, which is calculated using Eq. (5):

$$CO2 = (\text{Activity Level x Final Energy Intensity}) \text{ x } (\text{Fuel Carbon Content}/100) \text{ x } (1-(\text{Carbon Stored}/100)) \text{ x } (44/12) \quad (5)$$

The cost benefit analysis in LEAP focuses on social cost (opportunity cost) and it is not intended for analyzing the financial feasibility. Instead, it centers on what degree a scenario is socially acceptable. The cost per activity is calculated in the following way in Eq. (6):

$$Cost_{s,t} = \text{Cost per Activity}_{s,t} \text{ x Activity Level}_{s,t} \quad (6)$$

For the industrial sector, the cost analysis is expressed as cost of saved energy (as per the availability of data). The calculation for CSE (cost of saved energy) was calculated using Eq. (7):

$$Cost_{s,t} = CSE_{s,t} * Activity\ Level_{s,t} * (Energy\ Intensity_{BL,t} - Energy\ Intensity_{s,t}) \quad (7)$$

where s is scenario, t is year, and BL is baseline year.

The output of the LEAP software was then combined with qualitative data to produce more practical findings and recommendations.

3 Result and Discussion

The result from the correlation analysis differs from some previous studies on energy behavior. The outcome of this study shows that there is a moderately positive relationship between education level and income and energy consumption. The relationship between age of building, household size, number of elderly people in the household and number of small children in the household with energy consumption is weak(See Table 1). This result is similar to that reported by Wilson, *et al.*, who found that there is no strong correlation between income, education and household composition with energy behavior [15].

Table 1 Coefficient correlation of factors that influence household energy expenses in Kathmandu.

Factors	Correlation coefficient	Remarks
House's age	-0.1355	Weak negative relationship
Household's size	0.0746	Weak positive relationship
No. of people above 60	0.1730	Weak positive relationship
No. of children below 5	-0.1216	Weak negative relationship
Income	0.3064	Moderate positive relationship
Education	0.4226	Moderate positive relationship

3.1 Energy Consumption Patterns and Energy Mix

As the LEAP output indicates, in the present situation, transportation is the sector with the largest consumption of energy (48%), followed by the household sector, which occupies 33.2% of total energy consumption in the urban area of Kathmandu Valley. With no change in the current policy, the transportation sector will still lead for the next 20 years in energy consumption, with a significant increase in its share from 48% to 80.9% by the end of 2035 (Figure 1).

This is in accordance with the fact that the number of vehicles registered in Kathmandu Valley has been increasing significantly in the last ten years and is expected to continue to grow in the future. Meanwhile, the energy mix in Kathmandu Valley has been as follows: gasoline (petrol) has the highest proportion in the energy consumed (35.1%), followed by LPG (29.1%). This shows how high the dependency of Nepal is on other countries as both fuels are required to be imported from India. Figure 2 depicts the energy mix in Kathmandu Valley. This trend is expected to continue until 2035, when gasoline will occupy the highest percentage in the energy mix, much higher than its proportion in the current year (increasing from 35.1% in 2015 to 73.2% in 2035), followed by LPG with a smaller proportion in 2035 compared with that of 2015. The two figures below give an indication of alternative policies being necessary to reduce the dependency on imported fossil fuels.

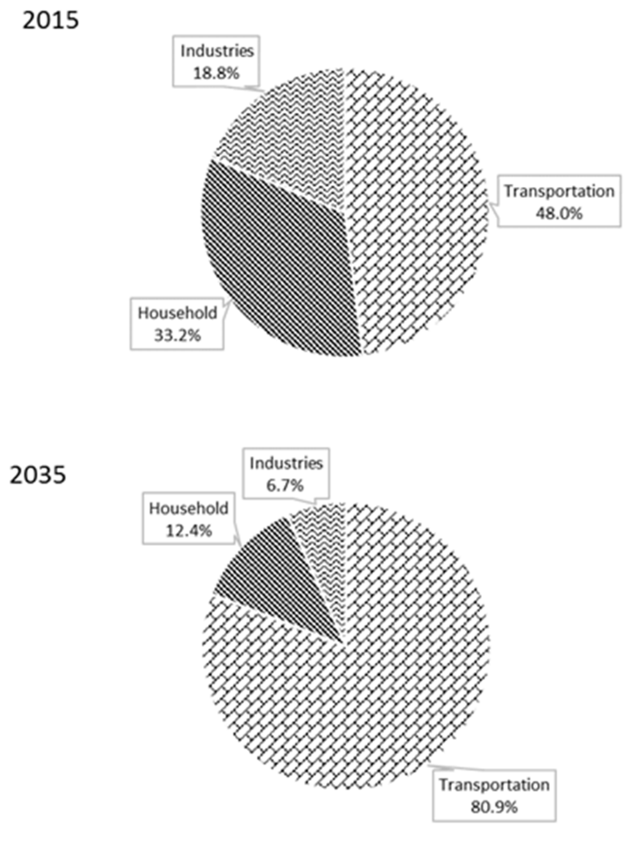

Figure 1 Comparison of sectoral energy consumption in Kathmandu Valley in 2015 and 2035.

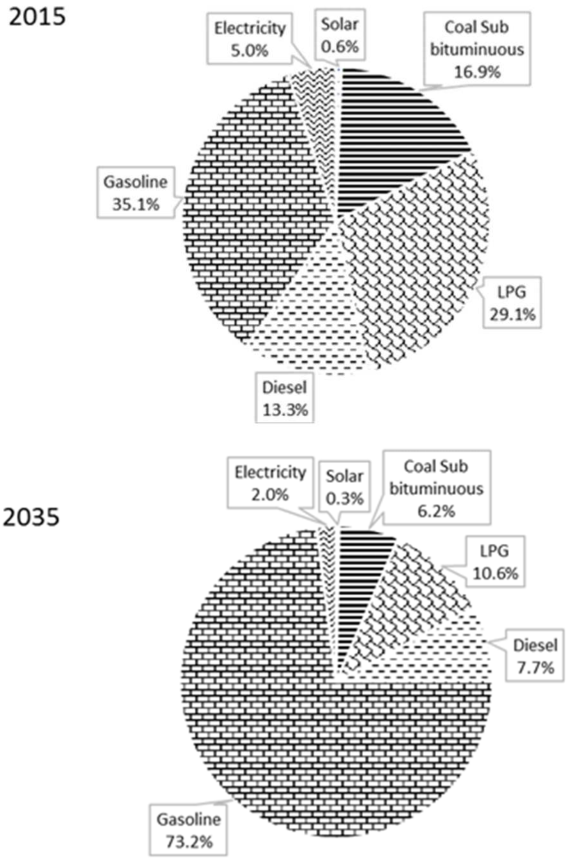

Figure 2 Comparison of energy mix in Kathmandu Valley in 2015 and 2035.

3.2 Scenario Analysis

Determining the best scenario is the most important part of the scenario analysis. There are three major factors that were used as criteria to determine the best scenario using LEAP. They are: 1) final energy demand, 2) GHG emission, and 3) social cost. The following sections describe the output of the LEAP concerning these three factors, which were the major consideration to determine the best scenario in this study.

3.3 Final Energy Demand

Based on the survey and socio-demographic information of Kathmandu Valley, five scenarios have been developed to predict the energy demand in Kathmandu

Valley in the future. Comparing all of them, all scenarios show a tendency of increasing in energy demand but with a different growth rate. BAU is expected to have the highest growth with an energy demand of 146.8 million GJ in 2035 and the Comprehensive Scenario has the lowest expected growth and energy demand of 99.3 million GJ in 2035 (Figure 3 and Table 2).

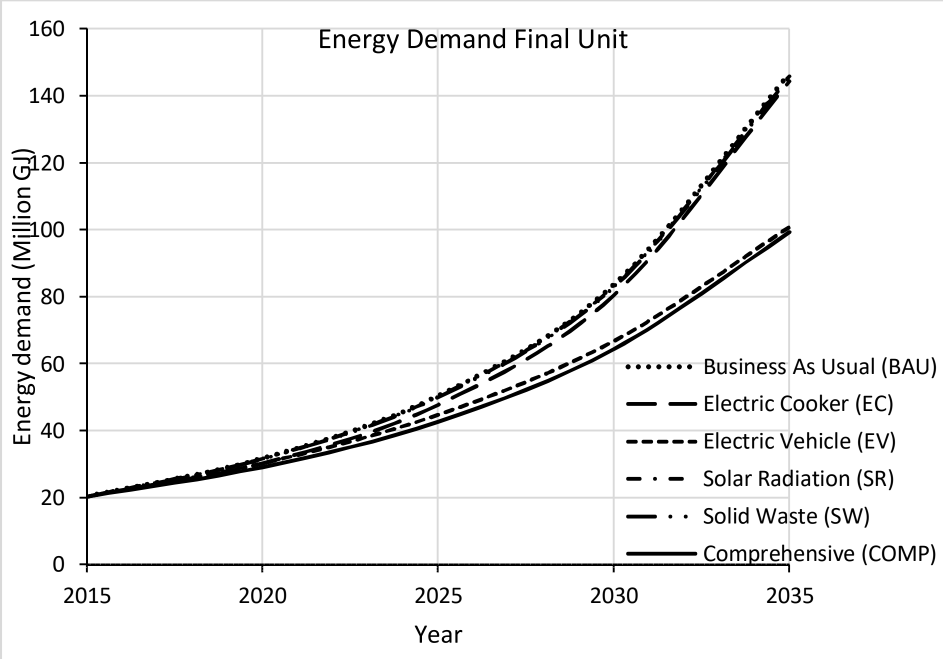

Figure 3 Projection of energy demand final units for various scenarios.

Table 2 Prediction of energy demand final units.

Scenarios	Energy Demand (Million Giga Joules)				
	2015	**2020**	**2025**	**2030**	**2035**
Business As Usual (BAU)	20.4	31.8	50.5	83.7	146.8
Electric Cooker (EC)	20.4	30.3	47.8	80.5	144.4
Electric Vehicle (EV)	20.4	30.3	44.8	66.8	100.9
Solar Radiation (SR)	20.4	31.7	50.2	83.2	145.9
Solid Waste (SW)	20.4	31.6	50.0	82.9	145.5
Comprehensive (COMP)	20.4	29.2	42.7	64.4	99.3

3.4 Environmental Impact

The total GHG emission prediction of the six scenarios is presented in Table 3. BAU is predicted to have the highest level of carbon emissions with 10.2

million tons of CO2 equivalent in 2035. The Comprehensive Scenario has the lowest level with 5.7 million tons of CO2 equivalent. None of the scenarios is seen to have the capability to reduce CO2 emission in the future.

Table 3 GHG emissions of various scenarios.

Scenarios	GHG emissions (million tons of CO2 eq)				
	2015	**2020**	**2025**	**2030**	**2035**
Business As Usual (BAU)	1.4	2.2	3.5	5.8	10.2
Comprehensive (COMP)	1.4	2.0	2.8	4.0	5.7
Electric Cooker (EC)	1.4	2.1	3.2	5.3	9.4
Electric Vehicle (EV)	1.4	2.1	3.1	4.4	6.5
Solar Radiation (SR)	1.4	2.2	3.5	5.8	10.2
Solid Waste (SW)	1.4	2.2	3.5	5.8	10.1

3.5 Cost Benefit Analysis

A cost benefit analysis was done in LEAP from a social perspective by comparing the social cost of different scenarios. The analysis was not intended to analyze the financial feasibility. Instead, it centered on to what degree a scenario is socially acceptable. Table 4 shows the social costs prediction of all scenarios. By 2035, BAU is predicted to have the highest social cost (NRs 375.6 billion). The Comprehensive Scenario is at the lowest position until 2024, and EV is seen to replace it subsequently, reaching a value of NRs 236.4 billion.

Table 4 Social cost prediction for various scenarios.

Scenarios	2015	2035
Business As Usual	39.2	375.6
Comprehensive	39.2	248.7
Electric Cooker	39.2	376.3
Electric Vehicle	39.2	236.4
Solar Radiation	39.2	369.7
Solid Waste	39.2	375.5

*) Cost in billion NRs

3.6 Policy Implication

Various scenarios were analyzed in this study. The Comprehensive Scenario is considered to be superior, except for its performance in social cost, which is led by the EV Scenario. However, if only the individual scenarios (excluding the Comprehensive Scenario) are compared, the performance of the EV Scenario is at the highest position in all categories of comparison. Therefore, it could be better if the government gives higher priority to the implementation of an electric vehicle policy for both private and public use.

As mentioned before, the success of the EV Scenario will depend on the government's policy on custom duties and road tax, and the availability of infrastructure, i.e. charging stations. Another possible barrier in the implementation of the EV Scenario is the lack of information on the long-term benefits of using the technology. In fact, the implementation of this scenario will affect to two major changes: reducing dependency on petroleum products (gasoline and diesel) and reducing GHG emission.

The survey showed that more than 90% of respondents have shifted their cooking mode from LPG to electricity during the fuel crisis. The implementation of the use of electrical appliances in the household sector (especially for cooking activities) should not be a problem from a financial point of view, given the adequate supply of electricity. However, people still favor LPG when it is available. Some respondents pointed out this trend as a habit and a psychological factor. It was stated by some respondents that food cooked on a stove tastes better than food cooked using an induction cooker.

Solar energy has already been promoted before the crisis. It was long seen as too high-priced, but recently that perception is changing as the price of solar energy has decreased globally with about 70% over the past five years [17]. In the context of Nepal, the government has given full support in making use of solar energy for generating heat as well as electricity. It provides a capital subsidy of Rs 15,000 for installation of solar PVs generating a minimum of 500 Wp and 75% of the bank loan subsidy with a maximum interest of 9% without collateral. The government has recently come up with a more attractive scheme, in which the capital subsidy has been increased from Rs 15,000 to Rs 20,000 and the minimum electricity generated has been decreased from 500 Wp to 100 Wp for domestic purposes and to 1500 Wp for the industrial sector. The government has teamed up with some banks that are ready to offer a concessional interest rate of 2.25% for domestic purposes and 4.5% for commercial purposes.

The last scenario, which is the conversion of solid waste into energy, is the most unpopular despite its potential to solve two major problems in the valley: energy supply and solid waste management. Based on the survey conducted in this study, unawareness and technical difficulties are the main reasons for people not paying interest to this matter. The only concrete and noticeable step taken by the government so far is the initiative to convert solid waste in the Teku dumping site with a target to produce 14 kilowatts of electricity from the waste collected in Kathmandu Valley. If successful, similar projects will be implemented in other urban areas in Nepal. In addition, as stated by Pasek, *et al.,* the technology used in solid waste conversion into energy must be economically sustainable and use a relatively small area over a long period of time [18].

4 Conclusion and Recommendations

Following a rigorous literature review, surveys and data analysis, the following conclusions were obtained:

1. The study shows that there is a moderately positive relationship between education level and income with energy consumption. The relationship is weak between age of building, household size, number of elderly people in the household and number of small children in the household with energy consumption. The study also indicates that people are willing to shift from LPG to electricity as cooking fuel.
2. The transportation sector is the sector with the highest energy demand, followed by the household and finally the industrial sector.
3. All the proposed scenarios showed an increasing tendency in energy demand but with a different increase rate. The Comprehensive Scenario is the scenario with the lowest increase rate and therefore is considered to be the most plausible scenario.
4. The Comprehensive Scenario, which inherits the properties of all scenarios (except BAU), is considered to be the best among the other individual strategies. However, implementation of the EV strategy should be given priority because of its superior performance compared with the other scenarios in all categories of comparison. The EV scenario will have two major benefits if implemented. First is lowering the dependency on petroleum, and second significant reduction of GHG emission.

People have shown the intention to change their cooking method from LPG to electric cookers. With full support from the concerned authority and rapid development in hydroelectric projects, the output from LEAP seems to be practical for use as groundwork for developing energy policy in Kathmandu Valley. Converting solid waste into electricity seems possible only at a large scale, because the technology cost is quite high. Nevertheless, people should be urged at the household level to manage solid waste to be converted into energy or more useful products (biogas or fertilizer).

Upon the completion of this research, the following actions are recommended. Policy on the implementation of the Electric Vehicles Scenario should be reinforced along with providing the necessary infrastructure (i.e. charging stations) and deduction of custom duties on the import of electric vehicles (half of the current custom duties), batteries and other spare parts. The National

Transport Policy 2001/2002 states that the number of electric vehicles and solar chargers will be increased throughout the country. The government needs to be more serious about the implementation of this policy. Government should also encourage people to change their cooking method from LPG (or any other petroleum product) to electricity-based appliances by installing adequate capacity of transformers and providing a regular supply of electricity. The financial scheme on the installation of solar panels should be continued and made more favorable for the public, commercial enterprises and industries. The low level of technology penetration can be alleviated by reducing the price of solar panels and other devices or spare parts required for the installation of solar power. Grid-connected solar photovoltaic systems would be another incentive for people to use solar energy, one where they can sell any excess of electricity produced from their home. Government should soon turn this plan into reality.

It is also essential to consider the actual demand of energy in the demand prediction. Suppressed demand needs to be taken into account in future research on energy, so that the desired consumption of energy can be predicted more accurately. A future survey may also categorize the area into urban and peri-urban to get a better picture of energy consumption and energy saving behavior of people.

Research on the feasibility of the implementation of electric vehicles needs to be carried out as this scenario is very promising in terms of reducing the dependency on imported petroleum products and reduction of GHG emission. The study may focus on how to bring down the cost of purchasing, operation and maintenance of electric vehicles, and how to enforce the infrastructure development by the government, which is required to make the scenario successful.

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