Comparative Study on Energy Consumption in the Asian Landlocked Countries

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Abstract. This paper focuses on the present and future of the residential energy consumption in the Asian landlocked countries: Laos (Lao PDR) and Nepal. Although Laos and Nepal are classified as the least developed countries (LDCs) and share many similarities in terms of geographical and socio-economic features, energy use, especially electricity use, is very different. In 2016, the residential electricity consumption (per capita per annum) of Laos and Nepal are 256.8kWh and 79.5kWh, respectively. The regression analysis and the Granger causality test show that there is quantitative and causal relationship between the economic growth and residential electricity consumption. The difference in the electricity consumption is thus able to be illustrated by their economic disparity. And moreover, if the linear relationship between the per capita GDP and residential electricity consumption continues in Nepal for many years to come, Nepal can catch up with Laos in terms of residential electricity use when the level of economic development reaches to that of Laos. However, a detailed consideration draws attention to the fact that Nepal is way behind in the electricity generation capacity per capita as compared with Laos. The limitation of installed capacity may suppress the growth of ownership of home appliances and the residential electricity use in Nepal in the near future despite of the high access to electricity and their abundant water resources.

1. Introduction
There are three landlocked countries in the South and Southeast Asia: Bhutan, Lao PDR (Laos), and Nepal. These are classified as the least developed countries (LDCs). This paper focuses on the past, present, and future of the residential energy consumption of these landlocked LDCs with the exception of the least populous country, Bhutan.

Both Laos and Nepal (Figure 1) have a lot of geographical and socio-economic features in common; large parts of their territories belong to massifs and are rich in water resources; hydroelectric dams are thus the main source of electricity; their societies are multi-ethnic; they are easily influenced by the neighboring superpowers.

However, the residential energy situation is very different in these countries. Table 1 shows the socio-economic snapshots of these countries [1 – 7]. Figure 2 shows the yearly per capita residential energy consumption of Laos and Nepal in 2016, which was estimated by the author based on the latest available data [4, 5].
Figure 1. Locations of Laos and Nepal. Vientiane, the capital city of Laos, features a tropical savanna climate (Köppen Aw) with a wet season (May to Sep.) and a dry season (Oct. to Apr.). Kathmandu, the capital city of Nepal, features a humid subtropical climate (Köppen Cwa).

Table 1. Socio-economic data of Lao PDR and Nepal.

|                     | Laos                     | Nepal                    |
|---------------------|--------------------------|--------------------------|
| Population [persons]| (2017) 6,858,160         | (2017) 29,304,998        |
| Economy             |                          |                          |
| GDP [PPP, const. 2011 int. $] | (2017) 43.87 billion | (2017) 71.59 billion |
| GDP per capita [PPP, const. 2011 int. $] | (2017) 6397.4 | (2017) 2456.3 |
| GDP composition*:  |                          |                          |
| Agriculture [% of total GDP] | (2017) 16.2 | (2017) 27.0 |
| Industry [% of total GDP] | (2017) 30.9 | (2017) 13.5 |
| Services [% of total GDP]  | (2017) 41.5 | (2017) 51.5 |
| Labor force [persons]   | (2017) 3,602,800       | (2017) 17,053,278       |
| Labor force by occupation*: | (2012 est.) 73.1 | (2015 est.) 69 |
| Agriculture [% of Labor force] | (2012 est.) 6.1 | (2015 est.) 12 |
| Industry [% of Labor force] | (2012 est.) 20.6 | (2015 est.) 19 |
| Energy and Electricity|                          |                          |
| Access to electricity of total population [%] | (2016) 87.1 | (2016) 90.7 |
| of rural population [%] | (2016) 80.3 | (2016) 85.2 |
| of urban population [%]  | (2016) 97.4 | (2016) 94.5 |
| Electricity generation installed capacity**** [MW] | (2016) 6373.2 | (2016) 855.9 |
| Yearly per capita residential Energy consumption [MJ / capita / annum] | (2016) 6403.5 | (2016) 14339.6 |
| Electricity consumption [kWh / capita / annum] | (2016) 256.8 | (2016) 79.5 |
| Electricity production from hydroelectric sources*** [% of total electricity] | (2015) 98.2 | (2015) 94.5 |
| Hydropower potential** |                          |                          |
| Theoretical [GW] | (2017) 26.5     | (2017) 84            |
| Technically feasible [GW] | (2017) 18     | (2017) 43         |

Note: The numbers with parenthesis indicate the years of data. * and ** indicate the data from the “CIA World Factbook” [2] and “Country and Region Profiles” [3], respectively. *** indicates the data estimated by the author based on the energy authorities’ reports [4, 5]. **** indicates the data from the electricity authorities [6, 7]. The rest of the data are provided by the “World Development Indicators” [1].
Figure 2 shows that the traditional biofuels (firewood and charcoal) and waste (agricultural residue, etc.) are prime energy sources in the residential sector in these countries. Nepali residential sector depends more on biofuels than Laos. The larger share of biofuels causes a social problem; e.g., Nepali women bear a huge burden of collecting firewood in addition to the other household-related works [8]. Increasing electricity use is one of the solutions to this problem. A Nepali said that “when electricity is introduced into the household, it is definitely women that benefit the most [8].” However, there is the large difference in electricity use in these countries. According to Table 1 and Figure 2, the residential electricity consumption (per capita per annum) of Laos is 256.8kWh (924.3 MJ) while that of Nepal is 79.5kWh (286.3 MJ). Although the access to electricity of both countries are high and almost same (Laos: 87.1% of the total population and Nepal: 90.7%, see Table 1), Nepal is way behind in the in the residential electricity use. To figure out the cause of this difference is the first motivation for this research. This is expressed as the following research question:

(Question 1) What causes the difference in the residential electricity consumption between Laos and Nepal?

To discuss whether this difference can be resolved or not, i.e., whether Nepal will catch up with Laos in the near future in terms of residential electricity use, is the second motivation. Because Nepal upholds the SDG 7 target, i.e., ensures “access to affordable, reliable, sustainable and modern energy for all” and promotes electricity use in the residential sector [9]. This leads to the following research question:

(Question 2) Can Nepal catch up with Laos in terms of residential electricity use?

We try to answer these research questions with the following methodology.

2. Methods
In order to tackle the Question 1, we tentatively assume that the economic growth is the primary factor in the electricity consumption because the increase in the energy consumption is reportedly driven by the economic development [10 - 15]. This assumption is illustrated by a simple model shown in Figure 3 (a). The validity of this model is tested from the viewpoints of quantitative correlation and causal relationship. The quantitative correlation expressed as the following hypothesis:

(Hypothesis 1) Economic disparity between Laos and Nepal relates the difference in the residential electricity consumption.
The author of this paper has proposed an empirical, general, and simple model of the relationship between the real GDP and residential electricity consumption [16]. Most of the southeast Asian countries and southern Chinese provinces follow this model. If a regression analysis shows that the Lao and Nepali data also follow this simple model, the Hypothesis 1 is considered to be correct.

The Hypothesis 1 only states the quantitative correlation between the economy and residential electricity. To answer the Question 1 perfectly, the additional hypothesis relating to the causal relationship should be proved:

(Hypothesis 2) Economic development causes the increase in the residential electricity consumption.

The Granger causality test is applied to the simple model in the case of Laos and Nepal to prove the Hypothesis 2.

If the Hypothesis 1 and 2 are proved, the Question 1 is clearly answered; i.e., the economic growth is thought to be the main cause to increase the residential electricity consumption. If so, the Question 2 is easy to be answered; i.e., Nepal can catch up with Laos in terms of residential electricity use when the level of economic development reaches to that of Laos.

However, we must be careful to present a prospect of energy consumption in the near future. In addition to the discussion of the simple model, in the section 4, we cover a more elaborate model, which may consist of a number of factors such as geographic, cultural, socio-economic, technological ones (as shown in Fig. 3 (b)) and provide insight into the research questions.

3. Correlation and Causality between Economic Growth and Electricity Consumption

3.1. Correlation between economic growth and electricity consumption

The relationship between energy consumption and socio-economic development, i.e., “energy-growth nexus,” draws the interest of energy economists [10 - 15]. However, most of the studies focus on the total (aggregate national) energy consumption and GDP, and use the augmented Cobb-Douglas production functions as the energy use models. A limited number of studies focus on the quantitative relationship between residential electricity consumption and socio-economic indicators such as real GDP, ownership of appliances, access to electricity, etc.

In this section, the author focuses on the quantitative relationship between the residential electricity consumption and real GDP, which has not been studied enough.

(a) Simple model

(b) Expanded model

Figure 3. Simple and Expanded Residential Energy Use Models.
Figure 4 shows the real GDP per capita (PPP, 2011 international constant 2011 international dollars) and the residential electricity consumption of the Asian tropical and subtropical regions. In this figure, “ASEAN+” means the ASEAN countries (excluding Brunei, Vietnam, and Singapore), Southern Chinese provinces (Guangxi, Guangdong, and Yunnan), and Nepal. This figure shows strong and linear correlation between the GDP per capita and electricity consumption. The linear regression result shows that a 1,000 dollar increase in GDP per capita results in a 35 kWh increase in yearly electricity consumption per capita ($p < 0.001$ and the adjusted $r^2 = 0.947$). According to Figure 4 (b) (enlarged figure), the Lao and Nepali data follow this linear relationship. This tells that the Hypothesis 1 is correct.

3.2. Granger causality between economic growth and electricity consumption

The correlation between the economic development and residential electricity consumption is obvious. Subsequently, the Granger causality test is applied to each country or region.

The result of the Granger causality test indicates that the economic development “granger-causes” the residential electricity consumption in Laos and Nepal at the 0.1 level of significance. Therefore, a simple causal model shown in Fig. 3 (a) is acceptable for Laos and Nepal (As a side note, the Granger causality test also indicates that the economic development “granger-causes” the residential electricity consumption in Indonesia, Myanmar, Thailand, and Guangxi ($p < 0.05 – 0.1$)). The result of the Granger causality test tells that the Hypothesis 2 is correct.

Now the Hypothesis 1 and 2 are proved; the Question 1 is thus clearly answered; i.e., the economic growth is considered to be the main cause to increase the residential electricity consumption.

If the linear relationship between the per capita GDP and residential electricity consumption continues in Laos and Nepal for many years to come, the Question 2 is simply answered: Nepal can catch up with Laos in terms of residential electricity use when the level of economic development reaches to that of Laos.

4. Socio-economic Factors Contributing to the Electricity Consumption

4.1. Detailed consideration on the relationship between the economy and electricity consumption

In the previous section, the linear and causal relationship between the per capita GDP and residential electricity consumption in Laos and Nepal is proved on the basis of longitudinal data.

However, we must be careful to conduct a prediction of future energy consumption. We need a detailed consideration on the mechanism of interaction between the economic development and electricity consumption.
In this section, we thus employ the past research achievements of this field, investigate the factors relative to both the economic development and electricity consumption, and provide insight into the research questions.

4.2. Residential energy use models

As to the relationship between the economic growth and residential energy consumption, the energy economists and engineering researchers focus more on the predictability of the residential energy consumption rather than on the causality. So-called “top-down” modeling approaches [17] has been taken to investigate the correlative relationship between the residential energy consumption and the explanatory variables such as the macro-economic indicators (e.g., real GDP and CPI), housing indicators (e.g., construction/demolition rates, floor space, ownership of appliances, family sizes, and access to electricity), climate, etc. The schemes proposed by Eom et al. [18] and van Ruijven et al. [19] can be summarized as an expanded conceptual model shown in Fig 3 (b).

In this model, primary drivers are geographical factors (climate and geological condition), demographic and economic factors (population and GDP), cultural factor, and technological factor. Socio-economic factors such as electrification, urbanization, affordable energy, housing condition, family size are thought to be affected by the primary drivers. For example, the climatic and cultural diversity in Nepal has generated a wide range of housing conditions [20]; the economic performance measured by GDP affects electrification and urbanization; the climatic and geological condition influence the availability of fossil fuels, biomass, hydropower, etc.

It is not easy to define the quantitative relationships among primary drivers and socio-economic factors by using limited available statistic data of the LDCs. We thus select available socio-economic indicators relative to both the economic development and electricity consumption, and try to investigate into the causes of the difference in electricity consumption in these two countries.

4.3. Possession of durable home appliances

Table 2 shows the possession of durable goods in Laos and Nepal [21 – 24], as the indices of housing condition. As to the ownership of the durable home appliances such as TV and refrigerators, Nepal is lower than Laos. The difference in residential electricity consumption in these two countries is thought to be partly caused by the difference in the ownership of the durable home appliances because the electricity consumption depends on the number of the durable home appliances.

Figure 5 (a) shows that TV and refrigerator ownership increase with an increase in the GDP per capita in both countries. Figure 5 (b) only shows the TV ownership with the GDP per capita.

The growth pattern of the Nepali TV ownership seems to trace that of Laos. In this figure, a logistic curve is superimposed as a result of the logistic regression by using both countries’ data. The equation of the curve is as follows:

\[ y = \frac{75.98}{1 + \exp\left(\frac{-2553.73-x}{780.23}\right)} \]  

(1)

where, \( x \) is the GDP per capita and \( y \) is the TV ownership. If the possession of all of the durable home appliances is a function of the GDP per capita as same as Eq.1, the difference in residential electricity consumption in Laos and Nepal is thought to be caused indirectly by the difference in the GDP per capita.

4.4. Construction materials

Table 3 shows the construction materials used in roofs and outer walls of Lao and Nepali houses [21, 23], as the other indices of housing condition. As for the roof materials, the galvanized iron is most used in Lao houses while the tile / slate / concrete are mostly used in Nepali houses in the 2010s. As to the outer wall materials, the brick / concrete and wood / planks are almost evenly used in Lao houses while the brick / concrete are used in Nepali houses in the same period.
Table 2. Ownership of durable goods [% of households]

| Country | Laos | Nepal |
|---------|------|-------|
| Name and year(s) of survey | LECS3 [21] 2002-2003 | LECS4 [21] 2007-2008 | Census [22] 2015 | NFHS [21] 1991 | NDHS [23] 1996 | BCHIMES [23] 2000 | Census [23] 2001 | Census [24] 2011 |
| Car    | 4 7 | 16.2 | NA | NA | NA | NA | NA | 1.6 |
| Motor Bike | 22 | 51 | 80.1 | NA | NA | NA | NA | 9.8 |
| Bicycle | 54 | 39 | 32.6 | NA | NA | NA | NA | 33.0 |
| TV     | 41 | 53 | 77.3 | 3.7 | 6.6 | 13.9 | 22.5 | 37.1 |
| Radio  | NA | 55 | 23.1 | 31.7 | 36.5 | 49.7 | 53.1 | 51.7 |
| Mobile | NA | 42 | 86.2 | NA | NA | NA | NA | 65.8 |
| Refrigerator | 22 | 55 | 59.1 | NA | NA | NA | NA | 7.3 |

(a) TV and refrigerator ownership
(b) TV ownership and a logistic curve

Figure 5. GDP per capita and TV and refrigerator ownership [21 – 24].

Table 3. Percentage of roof and outer wall materials.

| Country | Laos | Nepal |
|---------|------|-------|
| Year of survey | 2005 [22] | 2015 [22] | 2011 [24] |
| Roof materials | | | |
| Tile / slate / concrete* | 13.2 | 42.3 | 49.2 |
| Galvanized iron* | 54.1 | 50.2 | 28.8 |
| Others | 32.7 | 7.6 | 22.0 |
| (Wood / planks) | (3.6) | (-) | (0.8) |
| (Bamboo) | (5.7) | (-) | (-) |
| (Thatch / straw / grass) | (21.7) | (-) | (19.5) |
| (Others) | (1.7) | (-) | (1.7) |
| Total | 100.0 | 100.0 | 100.0 |
| (Total number of households) | (952,386) | (1,183,386) | (5,423,297) |
| Outer wall materials | | | |
| Brick / concrete* | 17.6 | 41.2 | 70.1 |
| Wood / planks | 43.2 | 43.3 | 5.3 |
| Bamboo | 35.7 | 14.2 | 20.2 |
| Others | 3.5 | 1.3 | 4.3 |
| (Unbaked brick) | (-) | (-) | (1.1) |
| (Others) | (-) | (-) | (3.2) |
| Total | 100.0 | 100.0 | 100.0 |
| (Total number of households) | (952,386) | (1,183,386) | (5,423,297) |

* indicates the durable materials
These differences in the selection of construction materials are considered to cause the difference in the thermal performance of the houses and moreover the residential electricity consumption for heating, ventilating, and air-conditioning.

Table 3 also shows the historical change in the use of construction materials in Laos. The share of the durable construction materials has increased in the ten years.

Table 4 shows the percentage of households by types of house in Nepal. Nepali words, Pakki, Ardha-Pakki, Kachchi mean durable/permanent, semi-durable/permanent, and temporal/raw, respectively [23, 24]. Pakki house refers to that with both walls and roof made of durable construction materials like brick, concrete, tile, slate, galvanized iron, etc., which are indicated by “*” in Table 3. Ardha-Pakki house is that either the wall or the roof is made of durable materials and the other is made of temporary materials. Kachchi house refers to that with both walls and roof made of temporary construction materials. The share of Pakki houses has increased in the twenty years.

The increase in the share of the durable houses means acceptance of modernized universal buildings and abandonment of traditional vernacular architecture. The vernacular architecture is climate responsive and reportedly achieves better thermal performance by traditional passive measures [20]. The abandonment of vernacular architecture may cause the increase in the electricity consumption for heating, ventilating, and air-conditioning.

4.5. Affordable energy

Figure 6 shows the GDP per capita and electricity generation capacity (installed capacity of power plants) per capita of Laos and Nepal [6, 7]. The installed capacity is one of the indices of affordable energy. The larger the installed capacity, the larger the available electricity supply.

Figure 6 shows that the Lao installed capacity per capita increases accordingly with the growth of the GDP per capita. Nepal is way behind in the installed capacity per capita as compared with Laos. The limitation of installed capacity has potential for the restriction of residential electricity use.

| Year of survey | 1991 [23] | 2001 [23] | 2011 [24] |
|---------------|-----------|-----------|-----------|
| Pakki (durable) | 23.5      | 36.6      | 58.4      |
| Ardha-Pakki (semi-durable) | 24.8      | 29.2      | 31.0      |
| Kachchi (temporary) | 49.7      | 33.5      | 9.5       |
| Others | 2.0       | 0.7       | 0.1       |
| Not Reported | -         | -         | 1.0       |
| Total | 100.0     | 100.0     | 100.0     |
| (Total number of households) | (3,328,721) | (4,174,374) | (5,423,297) |

Figure 6. GDP per capita and installed capacity of electric power plants per capita in Laos and Nepal [6, 7].
5. Results and Discussion

As described in the section 1, Nepali households use only limited amounts of electricity as compared with Lao households. The results of the regression analysis and the Granger causality analysis in the section 3 tell that the difference in the residential electricity consumption between Laos and Nepal is caused by their economic disparity. And moreover, Nepali residential electricity consumption will increase with the GDP capita growth if the linear relationship between the economy and electricity consumption continues.

In the section 4, the expanded residential energy use model is employed to examine causes and correlates of the residential electricity consumption. The examination of the selected socio-economic factors suggests the following possibilities: the GDP per capita affects the residential electricity consumption through the possession of the durable home appliances; the selection of construction materials makes an impact on the residential electricity consumption through the thermal performance of houses. The examination also indicated that the electricity generation capacity per capita of Nepal is lower than that of Laos. The lack of the installed capacity results in the electricity supply restriction and instability. In Nepal, the widespread power shortages and frequent interruptions were reported [9]. The limited installed capacity may suppress the growth of ownership of home appliances and the residential electricity use despite of the high access to electricity. In Nepal, the power development using its abundant water resources is crucial to achieve the SDG 7 target.

6. Conclusions

Longitudinal residential energy consumption in the two landlocked and least developed countries, Laos and Nepal, were comparatively investigated. The energy use, especially electricity consumption, is very different in these countries. Although the access to electricity are high and almost same in these countries, there are profound differences in residential electricity consumption. The regression analysis and the Granger causality test shows that there is linear and causal relationship between the economic growth and residential electricity consumption. The difference in the electricity consumption is thus able to be illustrated by their economic disparity. And moreover, Nepal can catch up with Laos in terms of residential electricity use when the level of economic development reaches to that of Laos if the linear relationship between the economy and electricity continues. However, a detailed consideration on the indicators linking the economic development and electricity consumption draws attention to the fact that Nepal is way behind in the installed electricity generation capacity per capita as compared with Laos. The limitation of generation capacity may suppress the growth of the residential electricity use in Nepal in the near future despite of the high access to electricity and their abundant water resources.

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