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Trends in appliance usage and electricity consumption in households: A case study in Hambantota District, Sri Lanka

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Abstract The study aimed to develop interrelationships among electricity consumption, the plan area of the house, period of construction and appliance availability in Hambantota district in Sri Lanka. For this survey, the data was collected from 385 houses by means of door-to-door visits. Electricity consumption increases with the increase in the number of family members and the plan area of a house, but it is reduced with the age of the house. The availability of air conditioner, refrigerator, electric kettle, electric iron, vacuum cleaner, laptop computer, and incandescent bulbs significantly influences the electricity consumption in a particular housing unit. An increasing trend in energy demand for thermal comfort was observed in the region. Houses built after 2008 use an average of 100 kWh of electricity per month, which is a 30 kWh increase over older houses (built within or before 2008) in the area, resulting in an increase in energy demand in the area. The results of this study are a valuable reference in policymaking related to market availability of appliances, deciding electricity tariffs, and identifying potential ways to improve energy use efficiency in the domestic sector.

Keywords: Appliances, domestic consumption, electricity demand, tropical climate, thermal comfort.

1 Introduction

Sri Lanka has explored almost all the possibilities of producing hydroelectric power, but recent climate changes and the rapid increase in demand for electricity have made it impossible to depend on hydroelectricity alone. According to the Ceylon Electricity Board (CEB, official website), 78% of electricity generated currently is from thermal power plants, which use either coal or oil. From time to time, Sri Lankan consumers experience rolling blackouts due to the inability to generate the demand in drought periods by all means, even with extra generation using higher production costs. Thus,

examining electricity consumption patterns and understanding the trends in appliance usage is an important research focus in Sri Lanka. Therefore, electricity demand modification or reduction through modifications of consumption patterns is a timely requirement.

Residential buildings are responsible for 24% of the global energy consumption in 2010 and appliances' energy usage represented 9% of this energy consumption. This is approximately 180 GWh (Cabeza *et al.* 2018) of energy consumption. Besides the heating and cooling requirements, household electronics and other household electric appliances increase household energy demand (Rao and Ummel 2017, Cabeza *et al.* 2018). While household income is a leading factor in determining the trends in appliance usage, market access, and affordability, some societal trends such as urbanization and electrification also play a role (Gouveia and Seixas 2016, Rao and Ummel 2017). Understanding trends in appliance usage in the domestic sector is extremely important in predicting the energy demand and in policy-making related to market availability and pricing of appliances while ensuring equitable access to decent living conditions (Rao and Ummel 2017, Cabeza *et al.* 2018). In many parts of the world, electricity consumption patterns and appliance usage trends have been studied in detail (Rao and Ummel 2017) and attempts were made to model appliance dispersion targeting demand forecasts, projecting energy-related greenhouse gas emissions and the construction of detailed emissions mitigation scenarios (McNeil and Letschert 2010). Emission reduction of greenhouse gas and minimization of fossil fuel usage have become highly important in facing global warming.

Few studies have focused on electric appliance usage and electricity consumption in the domestic sector in Sri Lanka. They were primarily carried out by the Department of Census and Statistics (e.g. Household Income and Expenditure Survey 2016). Many studies on household energy demand patterns and appliance usage are based on EU countries with diverse types of household units (Huebner *et al*. 2016, and references therein). There are some studies in Southeast Asian countries like China and India, which is the closest to Sri Lanka (Rao and Ummel 2017). In Sri Lanka, most of the household units are single-family dwellings, and electricity demand for activities such as space heating and water heating is uncommon. This case study aimed to have an insight into the relationships among electricity consumption, appliance usage trends and domestic factors such as the plan area of dwellings and the period of house construction (age of the house).

2 Methods

2.1 Study area and data collection

The study was carried out in Tangalle suburban region located in Hambantota district in Sri Lanka, from October 2017 to March 2018. The proportion of electrification of

dwellings in Hambantota district was 5.3% in 1981 and it has increased to 88.3% by 2012. Therefore, this area becomes ideal for analyzing the appliance usage trends, household energy consumption with reference to the period of the house construction and the electrification. For this analysis, the period of construction was divided into four categories, namely, after year 2008, from 1998 to 2008, from 1988 to 1997 and from 1987 to 1978. Houses built before 1978 was not encountered in the region. All these categories are approximately 10-year intervals. In general, older houses have been constructed and inhabited without electrification; hence appliance usage has happened at a later stage once electrification has happened. In contrast, newly built houses were planned with electrification at the beginning. Therefore, this study enables us to study the appliance usage trends into the houses and the behavioral modifications of people related to energy consumption with time, allowing us to recognize future trends.

The information on the housing and energy usage in Hambantota district, according to the Department of Census and Statistics, Census of Population and Housing Sri Lanka – 2012 reveals that 138,246 households out of a total of 156,476 in the district used electric lighting (kerosine 17,712; solar 170 and other types 348 households). For this survey, the data was collected from 385 houses by means of door-to-door visits. The Yamane formula was used to check the sample adequacy (Israel 2003). The information on electric appliances available in a particular house, type of lighting (CFL, LED or incandescent bulbs), number of household members and age of the houses were recorded by talking to householders and the plan area of the house was calculated by taking relevant measurements. The electricity account number was also taken from each household and the details of monthly electricity consumption during April 2017 - March 2018 were obtained from CEB records.

2.1 Statistical analysis

Since the sample population is relatively small, the monthly average electricity consumption, the number of household members and the plan area were subjected to square root transformation before the analysis to ensure homogeneity of variances. One-way ANOVA method was used to compare the electricity consumption between houses built in different periods.

The availability of specific appliances and the use of different types of bulbs were binary coded (availability: 1, non-availability: 0). Period of construction was dummy coded considering houses built after the year 2008 as the reference category. Two Ordinary least squares regression (OLS) analysis models were developed with that data. For the first OLS model, electricity consumption was taken as the dependent variable, whereas the plan area of the house, number of family members, and the age of the house were included as the independent variables. For the second OLS model electricity consumption was the dependent variable, while the availability/non-availability of appliances was considered as the independent variable. Considering the

multi-co-linearity between the variables, separate OLS model was created to investigate the relationships of electricity consumption with appliance availability. Many studies regarding electricity consumption and appliance penetration have encountered multi-co-linearity between parameters and hence have developed several models to explain the relationships between different categories of parameters (Huebner *et al.* 2016).

Latent class analysis was also carried out on the data collected on appliance availability in each household to identify the trends in appliance usage including the year of construction and plan area of the house together as covariates in the analysis. All statistical analyses were performed using R statistical software package.

3 Results and Discussion

3.1 Electricity consumption

Electricity consumption of a domestic unit is influenced by many external factors, such as income, climate, market availability of appliances in the country and societal trends. It is also influenced by internal factors such as type of house, household income and the number of household members (Leahy and Lyons 2010). According to the data of this case study, the monthly average electricity consumption of houses built after 2008 is significantly higher than the older houses (ANOVA, $F(3,381)=36.52$, $P<0.005$), However, the older houses constructed before 2008 did not show any significant difference in energy consumption across those groups. The monthly average electricity consumption across the period of house construction is shown in Figure 1. Houses built after 2008 consumed a monthly average of 103.9 ± 36.8 kWh which was an average of 30 kWh more electricity compared to houses built earlier (74.5 ± 43.3).

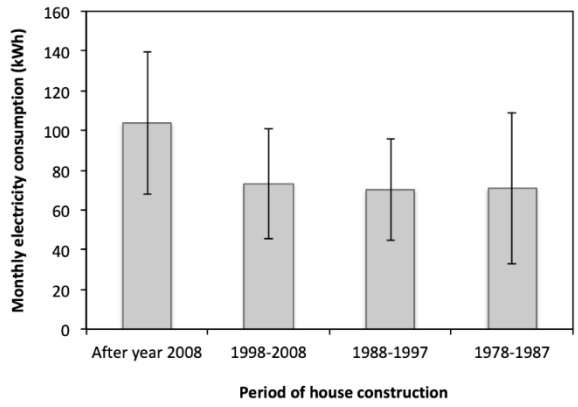

Fig 1. Monthly electricity consumption in households against the time period of house construction (n=385, Tangalle region, Hambantota District, Sri Lanka).

Globally, the monthly average of electricity consumption varies drastically. For instance, in Germany it is 271 kWh, in the UK it is 302 kWh and in Norway it is 1400 kWh (ODYSSEE 2021). This discrepancy is mainly due to the use of different energy sources for space heating; for example, while Germany and UK use gas, Norway uses electricity for space heating. However, these values are not directly comparable with Sri Lanka, because space heating is not used. The most similar case study authors came across in the literature is a case study in Tuy Hoa city, Vietnam (Le and Pitts 2019) where outside air temperature varies from 30ºC to 36ºC, hence space heating is not required. According to that study, the average monthly electricity use in different dwellings ranges from 200 to 350 kWh. Air conditioning has a significant impact on electricity consumption, resulting in 275 - 375 kWh of power consumption per month in homes with air conditioners and 160 - 210 kWh in homes without air conditioners (Le and Pitts 2019). Even though environmental conditions are similar, electricity consumption in our case study is far less compared to Tuy Hoa city in Vietnam. However, other districts in Sri Lanka, particularly Colombo district, have greater average monthly energy use of almost 256 kWh (unpublished data).

The coefficients of OLS model between electricity consumption and period of construction, plan area of the house and the number of family members are shown in Table 1.

Table 1: Results of ordinary least squares regression model among plan area, number of household members and the age of the house.

	Estimated coefficient	Std. Error	t value	Pr(>|t|)
Built between 1998-2008	-0.659	0.213	-3.096	0.002
Built between 1988-1997	-0.801	0.194	-4.127	0.000
Built between 1978-1987	-0.305	0.323	-0.946	0.345
Plan area	0.263	0.033	8.003	0.000
No of household members	1.916	0.245	7.817	0.000
(Intercept)	2.189	0.612	3.579	0.000

Note: The model explains 46% of the variance of the electricity consumption in household level and model significance (ANOVA, $F=65.96$, $p<0.005$)

Plan area of a house and number of family members have a significant positive influence on electricity consumption. Number of household members found to be the most influential factor on electricity consumption than the plan area. This may be because even though plan area is high, when the number of people living in the house is low, frequency and duration of usage of some appliances and lighting requirement is less. Electricity consumption negatively correlated with age of the house and it was observed that older houses have a low possibility of appliance availability compared to the houses built after 2008 (Figure 2).

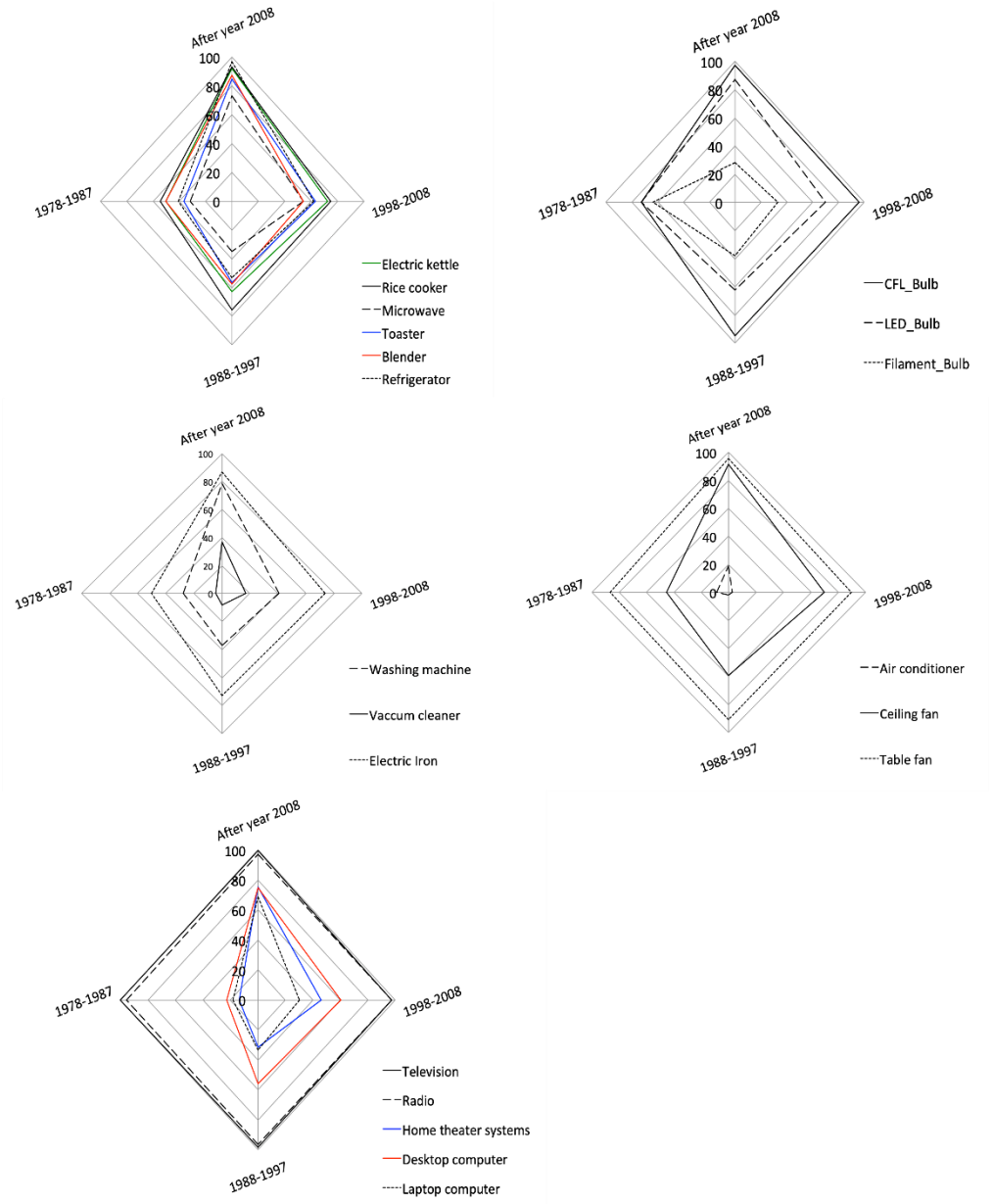

Fig 2. Percentage of houses, which own each type of electrical appliance encountered in the study against the period of house construction (n= 385, Tangalle region, Hambantota district, Sri Lanka).

3.2 Trends in appliance usage

The commonly used domestic electric appliances are aimed at delivering thermal comfort, water heating, refrigerators, water pumps, help in food preparation such as rice cookers, microwaves, toasters and ovens, general helps such as kettles, irons and vacuum cleaners and electronic devices such as computers, radios, televisions, home theater systems and mobile chargers. The appliances such as hotplates and grills were found only in few houses (e.g. hotplates in only 5 houses) thus were not included in the analysis. However, the appliances related to space cooling/ thermal comfort has become a necessity in this area as shown by 10% of the houses installed with air conditioners, while almost all houses having one or more portable fans. Survey has found 39 houses with air conditioners and 33 of these were built after 2008.

Table 2: Latent class analysis- availability of different electric appliances in each latent class.

	Class 1	Class 2	Class 3
Population share	**0.464**	**0.402**	**0.134**
Probability of appliance availability			
Air conditioner	0.201	0.000	0.000
Ceiling fan	0.986	0.706	0.039
Portable Fan	0.979	0.848	0.928
Refrigerator	1.000	0.667	0.000
Electric Kettle	0.963	0.757	0.131
Rice cooker	0.992	0.790	0.340
Microwave	0.858	0.399	0.000
Bread toaster/ Sandwich maker	0.975	0.582	0.073
Mixer/Blender	0.929	0.649	0.051
Washing Machine	0.926	0.289	0.020
Electric Iron	0.894	0.734	0.511
Vacuum cleaners	0.474	0.022	0.000
Radio	0.969	0.978	0.942
Television	0.990	0.985	0.981
Desktop Computers	0.909	0.491	0.110
Laptop computers	0.728	0.346	0.029
Home theater systems	0.901	0.285	0.000
CFL bulbs	0.994	0.929	0.844
LED bulbs	0.947	0.692	0.306
Incandescent bulbs	0.285	0.368	0.430

Performing latent class analysis enabled us to identify three classes of domestic dwellings with different degrees of appliance usage, as given in Table 2. All appliances

except air conditioners and vacuum cleaners were available in more than 90% of class 1 dwellings. In terms of air conditioners and vacuum cleaners, 21% and 47% of houses in class 1 had them respectively. Air conditioners and vacuum cleaners were not available in dwellings in classes 2 and 3. Further, dwellings fallen into class 3 had no refrigerators, microwave ovens and home theater systems. Furthermore, ceiling fans, washing machines, bread toaster/ sandwich makers, mixer/blenders, and laptop computers were present in less than 10% of class 3 dwellings. Televisions, radios and portable fans were available in almost all houses in all 3 classes. Within the sample, 46.4% of the houses were classified as class 1, 40.2% as class 2 and 13.4% as class 3.

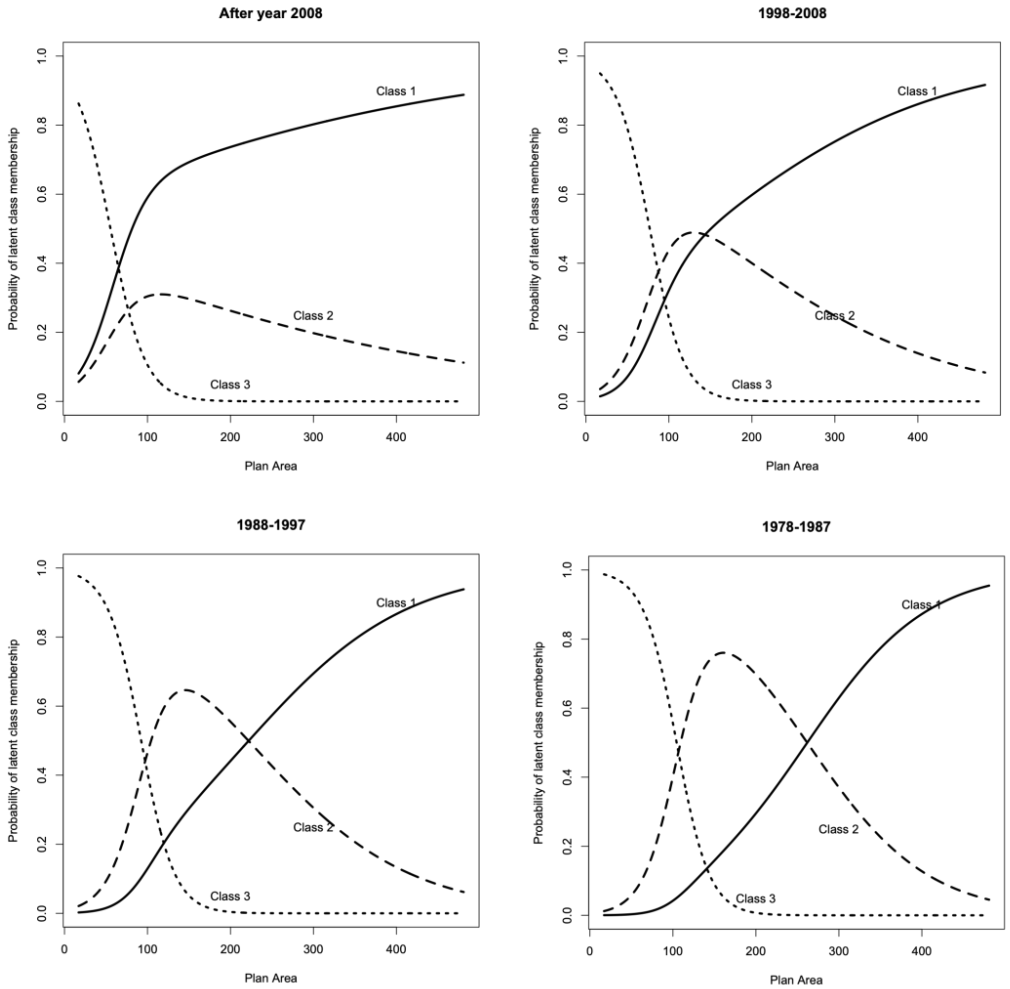

Fig 3. Relationship between plan area of a house, period of construction and latent class

Age of the house was the significant parameter for a house to fall into class 2 compared to class 1, higher the age higher possibility to fall the house into class 2 (Figure 3). In contrast, plan area was the significant covariate in determining the class 2 over class 3. When the plan area of a house exceeds 150 m^2, the probability of the house belonging to class 3 becomes nearly zero, irrespective of the age of the house. However, if the plan area exceeds 150 m^2, the age of construction had a considerable influence in determining which latent class a house falls in. The houses constructed after 2008 had a probability of 75% or more to belong it to latent class 1 if the plan area exceeds 150 m^2. On the contrary, the possibility of a house with a plan area exceeding 150 m^2 falling into latent class 1 has reduced when the age of the house is increased. Such houses had increased the possibility of falling into latent class 2.

Table 3: Ordinary least squares regression model for electricity consumption and appliance availability.

	Estimated coefficient	Std. Error	t value	Pr(>|t|)
Air conditioner	2.500	0.185	13.535	< 2e-16
Ceiling fan	0.275	0.150	1.830	0.068
Portable Fan	0.269	0.183	1.465	0.143
Refrigerator	1.492	0.164	9.095	< 2e-16
Electric Kettle	0.411	0.146	2.812	0.005
Rice Cooker	0.193	0.152	1.269	0.205
Microwave Oven	-0.203	0.127	-1.607	0.109
Bread toaster/ Sandwich maker	0.228	0.144	1.587	0.113
Mixer/Blender	0.164	0.134	1.223	0.222
Washing Machine	0.096	0.140	0.686	0.493
Electric Iron	0.340	0.129	2.631	0.008
Vacuum cleaners	0.404	0.143	2.829	0.005
Radio	0.181	0.285	0.634	0.526
Television	0.608	0.425	1.430	0.153
Desktop Computers	0.170	0.128	1.324	0.186
Laptop computers	0.354	0.114	3.114	0.002
Home theater systems	-0.081	0.142	-0.572	0.567
CFL bulbs	0.105	0.229	0.459	0.646
LED bulbs	0.230	0.131	1.763	0.079
Incandescent bulbs	0.241	0.103	2.339	0.020
(Intercept)	4.858	0.528	9.194	< 2e-16

Equipment availability alone explains 76% of the variance of the electricity consumption at the household level (ANOVA, $F=61.68$, $p<0.005$). The availability of air conditioner, refrigerator, electric kettle, electric iron, vacuum cleaner, laptop computers and incandescent light bulbs significantly influence the electricity

consumption in a particular housing unit (Table 3). In terms of lighting, the survey observed the availability of CFL, LED and incandescent lighting, among them CFL and LED lights use less power, while incandescent lighting use more power to provide same level of illumination. However, at the time of purchase incandescent light costs less than CFL and LED bulbs. Class 3 houses had a higher possibility to have incandescent lighting than houses belonging to other classes.

3.3 Managerial implications of the study

Domestic energy demand comprises a reasonable portion of energy utilization everywhere in the globe, hence, many countries have been studying energy demand in household sector (Cabeza *et al*. 2018). In Sri Lanka, domestic sector utilizes nearly 33% of electricity generated in the country (CEB 2016). In this study, by considering the plan area and the period of construction of the houses we expected to have a simple, yet representative model to describe the electrical appliance usage trends and the electricity consumption in Hambantota district. The plan area of a house and the period of construction play a dominant role in appliance usage. This is similar to the case study by Gouveia and Seixas (2016) in Portugal. Newly build houses have a higher tendency to own most of the electrical appliances available in the market and this possibility increases with the increase in plan area of the house. This may happen because when people move into newly built houses, they may purchase new electric appliances available in the market, while the people who live in old houses received electrification later, so they only buy appliances as per the requirement, from time to time.

A considerable portion of domestic electricity demand is for space and water heating in non-tropical regions of the world as ambient temperature can become very low (Ndiye and Gabriel 2011, Ürge-Vorsatz *et al.* 2015) during winter times. Being a tropical island, heating is not a necessity, in most parts of Sri Lanka, except in central highlands. However, an increasing trend in energy demand for thermal comfort was observed in this case study due to the increased usage of air conditioners in houses. Therefore, introducing passive design techniques in building architecture to minimize the energy consumption of the houses and to improve the thermal comfort of the occupants by changing house construction rules may be a timely requirement.

Furthermore, census data show that the use of electricity for cooking is not a common practice in Sri Lanka, except for using rice cookers. Sri Lankans mostly use gas for cooking purposes. This is not the case in many other countries (Jones *et al.* 2015, Rao and Ummel 2017). Large electric equipment such as electric cookers (except rice cooker), dishwashers, freezers and tumble dryers were not diffused into the Sri Lankan domestic sector, as shown in this case study. However, these trends may change with the market availability of such appliances, increased affordability and with future changes in the cost of gas and electricity. Hence, appliance usage and energy consumption trends need to be considered in policy making with respect to imports

and their price in the market since these have a major influence on estimating the energy demand. The findings of this case study may be applicable to adjacent districts, however, it is recommended to study appliance usage and electricity consumption trends in other districts, before extrapolation, since these trends may vary with time. Continuous monitoring will ensure the validity of available data, which can support policy-making. It is necessary to regulate domestic electricity demand and to take action to increase energy efficiency to reduce carbon dioxide emissions and mitigate global climate change (Jones *et al*. 2015), while, ensuring decent living conditions for people.

4 Conclusions

It can be concluded that newly constructed housing units have a higher tendency to use more electric appliances and the probability increases with the plan area of the house. Electricity demand for thermal comfort is playing a major role in this area, as the lowest appliance available category also has a 90% probability of having portable fans. In addition, the availability of radio and television is almost 100%, hence indicating that the diffusion of these items is saturated in the area. According to the latent class analysis, there are three classes of houses based on electrical appliance usage; where class 1 (46.4% of the population) uses almost all appliances available in the market, class 3 (13.4%) mainly uses electricity for portable fans, radios, television, and lighting, while class 2 lies in between. Newly built houses tend to use 100 kWh per month on average, which is an increase from 30 kWh compared to the older houses available in the area.

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References

Cabeza LF, Ürge-Vorsatz D, Palacios A, Ürge D, Serrano S, Barreneche C. 2018. Trends in penetration and ownership of household appliances. *Renewable and Sustainable Energy Reviews* 82:4044-4059.

CEB. Retrieved from https://ceb.lk/electricity-generated/en (accessed 04-03-2021).

CEB. 2016. CEB statistical report- 2016. Ceylon Electricity Board, Sri Lanka.

Department of Census and Statistics. 2016. Household Income and Expenditure Survey – 2016. Department of Census and Statistics, Sri Lanka.

Department of Census and Statistics. 2012. Census of Population and Housing Sri Lanka – 2012. Department of Census and Statistics, Sri Lanka.

Gouveia JP, Seixas J. 2016. Unraveling electricity consumption profiles in households through clusters: Combining smart meters and door-to-door surveys. *Energy and Buildings* 116:666–676.

Huebner G, Shipworth D, Hamilton I, Chalabi Z, Oreszczyn T. 2016. Understanding electricity consumption: A comparative contribution of building factors, socio-demographics, appliances, behaviours and attitudes. *Applied Energy* 177:692–702.

Israel GD. 2003. Determining Sample Size, Institute for food and agricultural science, University of Florida, USA.

Jones RV, Fuertes A, Lomas RV. 2015. The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings. *Renewable and Sustainable Energy Reviews* 43:901–917.

Le VT, Pitts A. 2019. A survey on electrical appliance use and energy consumption in Vietnamese households: Case study of Tuy Hoa city, *Energy & Buildings* 197:229–241.

Leahy E, Lyons S. 2010. Energy use and appliance ownership in Ireland. *Energy Policy* 38 (8): 4265–4279.

McNeil MA, Letschert VE. 2010. Modeling diffusion of electrical appliances in the residential sector. *Energy and Buildings* 42:783–790.

Ndiaye V, Gabriel K. 2011. Principal component analysis of the electricity consumption in residential dwellings. *Energy and Buildings* 43:446–453.

ODYSSEE-MURE. 2021. ODYSSEE database. Sectoral profile - Households. Retrieved from https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html (accessed 04-03-2021).

Rao ND, Ummel K. 2017. White goods for white people? Drivers of electric appliance growth in emerging economies. *Energy Research & Social Science* 27:106–116.

Ürge-Vorsatz D, Cabeza LF, Serrano S, Barreneche C. 2015. Heating and cooling energy trends and drivers in buildings. *Renewable and Sustainable Energy Reviews* 41:85–98.