FORECASTING RESIDENTIAL ELECTRICITY CONSUMPTION BASED ON URBANIZATION AND INCOME PROJECTIONS

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KEYWORDS

residential electricity consumption, income deciles, rural-urban life, urbanization, scenarios

ABSTRACT

This study presents an alternative method for predicting residential electricity consumption. Based on electricity expenditures data from Hungary, we calculated consumption patterns for people living in different types of settlements by income deciles. We developed 12 scenarios of expected urbanization and income effects for the period 2020 to 2050. Our forecast outputs are consistent with scenarios in the literature proving that in the absence of long-term panel data, future electricity consumption can still be adequately estimated based on the evolution of electricity expenses.

INTRODUCTION

The economic growth of the developed economies, the population growth and the urbanization are likely to cause a robust increase in electricity consumption of the households (Ramírez-Mendiola et al. 2017; Taale and Kyeremeh 2016). Thus, the residential sector has immense potential regarding the improvement of energy-saving and efficiency (Sun et al., 2018). As the sustainable energy management is a top priority in the EU as well (Bianco et al. 2019), the efforts to identify the crucial factors of households electricity consumption have become prominent (Bianco et al. 2019; Wiedenhofer et al. 2013; Curtis and Pentecost 2015; Rosas et al. 2010). The energy consumption simulations and the forecasts are vital in shaping the proper energy policies and in making the right decisions to maintain sustainable development. Earlier papers prefer time-series models to forecast annual electricity consumption (Daut et al. 2017; Wei et al. 2019). Although the traditional models do not require a lot of historical data (Wei et al. 2019; Deb et al. 2017), In the case of Hungary even the needed minimum is not available for modelling (Jebli and Youssef 2015).

This paper develops a new model for estimating the residential electricity consumption based on historical income and urbanization data while the detailed regional distribution of income remains unknown. This forecast seeks to answer the question of whether urbanization helps the achievement of the sustainability goals and whether the increasing rate of the rural and urban population will contribute to the reduction of the long-term residential electricity consumption. We used Hungary as an example in our model because electricity consumption decreased in the past decades, while the rate of urbanization grew (KSH 2018).

SOCIO-ECONOMIC AND SPATIAL FACTORS

We may divide the factors affecting electricity into two groups depending on how those influence electricity consumption directly or indirectly. The direct factors are the characteristics of the households, like the age of the members, their qualifications, the efficiency of the appliances they use or the dwelling characteristics. The indirect factors are income and urban form (Wiedenhofer et al. 2013; Yang et al. 2019; Taale and Kyeremeh 2019). This paper builds on the effects of the latter group.

Income proved to be a significant factor in several studies to affect electricity consumption. (Wiedenhofer et al. 2013; Santamouris et al. 2007; Hussain and Asad 2012). However, the direction and the extent of its impact on electricity consumption varies widely (Table 1). A 1% growth in the income can increase electricity consumption even by 11% (Brounen et al. 2012), though, the same change may also cause a significant decline (Borozan et al. 2017). Not only the consumption of the poorest and most rich differ, but there are also significant differences across all the income deciles (Rosas et al. 2010; Szép 2013). Researchers agree that the change of the electricity price does not affect the consumption significantly (Atalla and Hunt 2016; Yang et al. 2019; Wang et al. 2019) but the income remaining after electricity expenditures (Gomez et al. 2013) and the ratio of the expenses per income affect electricity consumption (Rosas et al. 2010).

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Table 1: The effects of income on electricity consumption

Effect	Extent	Source
Increase	+0.13%	Ye et al. (2017)
	+0.40%	Wiedenhofer et al. (2013)
	+0.57%	Yang et al. (2019)
	+11.00%	Brounen et al. (2012)
Decrease	-0.50%	Borozan et al. (2017)
	-0.44%	Contreras et al. (2009)
	-0.47%	Gomez et al. (2013)

Santamouris et al. (2007) examined the relationship between the annual electricity expenditures and the income and found that wealthy households used nearly 38% more electricity than poor ones. Gomez et al. (2013) identified spatial differences (Table 2).

Table 2: The effects on electricity expenditures

Factor	Effect	Extent	Source
Income	increase	0.27%	Gomez et al. (2013)
		0.13%	Rosas et al. (2010)
		0.38%	Santamouris et al. (2007)
		0.15%	Hussain and Asad (2012)
	decrease	-0.20%	Curtis Pentecost (2015)
Price	-	-	Atalla and Hunt (2016) Yang et al. (2019

Population determines the electricity use since each 1% growth of it boosts the latter by nearly 1.5% (Yang et al. 2019; Sun et al. 2014). However, population growth differs across urban forms (Liddle and Lung 2014; Larson and Yezer 2015).

The spread of cities is often regarded as the leading cause of increased energy use (Poumayong and Kaneko 2010; Yang et al. 2019; Lariviére and Lafrance 1999) and the emission of harmful substances (Yang et al. 2019; Taale and Kyeremeh 2016; Jonas et al. 2015;). However, it has also been proven that urbanization has its advantages coming from the economies of scale (Shammin et al. 2010; Poumayong and Kaneko 2010; Yang et al. 2019).

Table 4: The effects of urbanization on electricity consumption

Effect	Direction	Extent	source
rate of urban residents	decrease	-0.10%	Shammin et al. (2010)
	increase	+0.19% +0.23%	Yang et al. (2014)
urban areas	increase	+1.06%	Yang et al. (2019)
country-side	increase	+2.55%	Yang et al. (2019)
depending on the income	decrease increase	-0.13% +0.14%	Poumayong (2010) Yang et al. (2019)
	decreasing increasing	-0.03% +0.50%	Yang et al. (2019)
	increasing	+0.90% +0.07%	Poumayong (2010)

The rural electricity consumption is up to 10% higher than the use of the urban population (Yang et al. 2019; Poumayong and Kaneko 2010, Lenzen et al. 2004; Shammin et al. 2010). Thus, the urbanization rate might have a favourable effect on electricity consumption (Chen et al. 2008) (Table 4). According to Poumayong and Kaneko (2010), urbanization has an increasing impact only in electricity consumption of the poorest people. In the case of the medium and high-income households, urbanization reduces electricity consumption.

INCOME INEQUALITIES

Electricity consumption is a widely used index of economic development. The amount of consumed electricity reflects the population's income conditions quite well (Liddle and Lung 2014). According to Szép's (2013) discriminant analysis, electricity consumption of the lowest and the highest income deciles show a significant gap in Hungary. Figure 1 shows that the highest growth in electricity consumption can be seen in the case of the wealthiest households. The lowest five deciles spent 5 to 10 percent of their income on electricity, while the higher deciles spent only 2% in 2010. By 2018, these percentages had decreased in the case of both groups (KSH 2018). (Figure 1). For the top deciles, most of the savings on energy expenditures were lost due to a large number of electronic equipment in rich households.

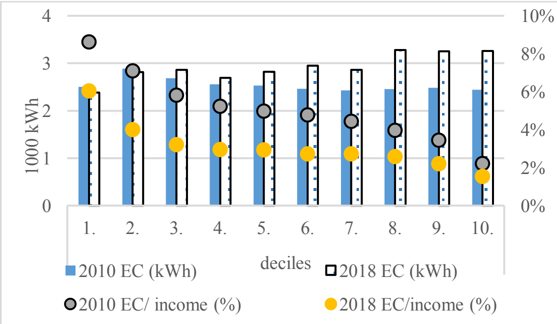


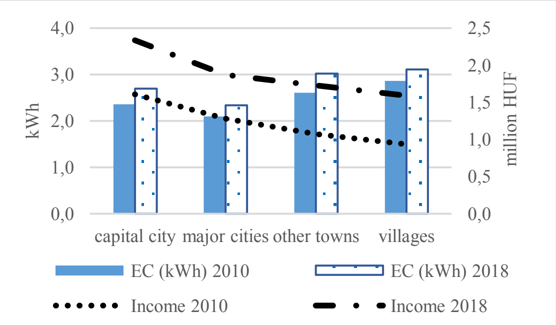
Figure 1: The annual electricity consumption (EC) of the households (1,000 kWh) and the electricity/income ratio (EC; %) by deciles in 2010 and 2018

The poorer households are not so abundant in modern appliances, their financial conditions are well below the average, so they cannot afford energy-saving renovations or investments (Bíró-Szigeti 2011). Thus, there is no significant energy saving in their case, either. Finding a way to reduce the electricity consumption of poor households is an often-raised issue in the literature (Rosas et al. 2010).

The per capita electricity consumption is also affected by the number of people living in a household. In 2018, the average number of people in the least wealthy household was 2.8, while this figure was 1.8 in the wealthiest households (KSH 2018). The per household electricity consumption peaked in the richer households in 2010, while it was there that the per capita consumption was the lowest By 2018, per household consumption topped in the upper three deciles (KSH 2018).

SPATIAL INEQUALITY

In 2000, there were more than 200 towns registered in Hungary, while in 2014 almost 350 settlements enjoyed town status, with 70% of the country's population. (Gerse and Szilágyi 2015). If we move downward in the hierarchy of the settlements, the income per household continuously decreases. The people living in rural areas earn only 89.5% of the national average (KSH 2018). However, the per household electricity consumption is the highest there (3,110 kWh) (Figure 2).



*1 euro=335 HUF, March 1, 2020

Figure 2: The annual consumption of households (1,000 kWh) and the annual gross income (HUF) according to settlement type in 2010 and 2018

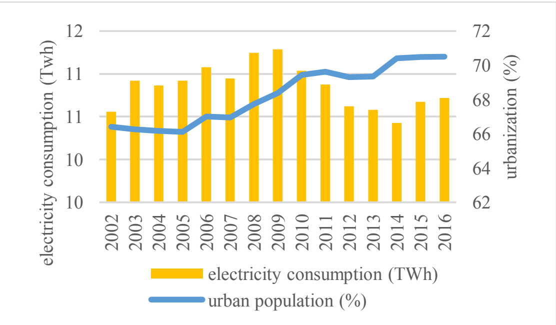


Figure 3: Residential electricity consumption (TWh) and the urban population (%) in Hungary between 2000 and 2018

During the examined period, electricity consumption increased in every type of settlement. In 2018, the lowest consumption was in the major cities and the highest consumption was in the village households. The growth rate was the highest in the medium towns. After the global economic crisis, electricity consumption began to plummet. (Figure 3) During recent years, the consumption increased again, while the urban population grows at a lower rate.

MODEL DESCRIPTION

We have prepared a forecast of electricity consumption of the Hungarian population for the period of 2019 to 2051. Our first hypothesis is that electricity consumption differs in the various stages of the urbanization (urban area, countryside). Income changes not only between the two extremes (the rich and the poor), but it also differs by the income deciles. Thus, our second hypothesis is that future electricity consumption can be predicted quite reliably from the urbanization (regional) distribution of the electricity expenditures and the electricity expenditures of the income deciles. In the case of Hungary, detailed information on household electricity consumption has only been available since 2010. Thus, long-term historical regressions offer limited aid in predicting future amounts of consumption. We used data on Hungarian household electricity consumption for the period between 2010 to 2018 in two breakdowns: income deciles and types of settlement. As in the case of deciles, only data on electricity expenditures were available; we used the annual historically established selling prices for standard electricity consumption (EC) to estimate electricity consumption (kWh per capita) per decile (d). As no data on the settlement breakdown of the population from deciles were available, we calculated the consumption of an average household at the national level by equally weighting electricity consumption of the ten deciles.

$$EC_d = \frac{Electricity\ expenditures\ by\ deciles\ \left(\frac{HUF}{capita}\right)}{Average\ consumer\ price\ of\ electricity\ \left(\frac{HUF}{kWh}\right)} \qquad (1)$$

Besides the consumption per decile, we also mapped the household distribution across settlement types (EC_s).

$$EC_s = \frac{Electricity\ expenditures\ by\ settlement\ type\ \left(\frac{kWh}{capita}\right)}{average\ consumer\ price\ of\ electricity\ \left(\frac{HUF}{kWh}\right)} \qquad (2)$$

Then contrasting the average household consumption for each settlement type to the estimated national average, we received a correction factor (CF):

$$CF = \frac{EC_s\ \left(\frac{kWh}{capita}\right)}{EC_d\ \left(\frac{kWh}{capita}\right) * income\ deciles\ (\%)} \qquad (3)$$

The correction factor (%) would cover two effects: (1) based on the literature, the different settlement types imply different consumption figures even in the same income deciles and (2) deciles are not evenly represented in all settlement types. Thus, the average correction factor value of 103.34 percent for the capital city means that the average household in Budapest consumed 3.34 percent more electricity (kWh) than the national average. That may be due to (1) the average household having higher than the national average income and (2) citizens in major cities using more electricity per capita because of the smaller than average household size. Estimating the future change of these three inputs made it possible for us to give an estimate of the total electricity consumption of Hungarian households (EC_T):

$$EC_T = \frac{Electricity\ expenditures\ by\ settlement\ type\ (\frac{kWh}{capita})}{average\ consumer\ price\ of\ electricity\ (\frac{HUF}{kWh})} \quad (4)$$

Luckily, in the literature, we found robust professional estimates for these three factors separately that allowed us to build scenarios by using the combination of the alternative paths of the three factors. By processing literature and statistics together, we estimated both low (L) and high (H) outcomes for the future electricity expenditures and the urbanization. In the case of the population, we allowed for a medium (M) level, too. Table 5 shows the 12 scenarios made for forecast future residential electricity consumption in Hungary.

Table 5: Scenarios examined

#	1	2	3	4	5	6
I	L	L	H	H	L	L
U	L	H	L	H	L	H
P	L	L	L	L	M	M
#	**7**	**8**	**9**	**10**	**11**	**12**
I	H	H	L	L	H	H
U	L	H	L	H	L	H
P	M	M	H	H	H	H

I=income, U=urbanization, P=population

In this paper, the urbanization level is measured by the proportion of urban residents in the total population. These categories meet the requirements of the international standards and the interpretation of the Hungarian Central Statistical Office (KSH, 2018). The population is the entire population of Hungary (number of people). The data originate from the website of the KSH.

BASE SCENARIO

In the base scenario (HLL), the income is high (H), urbanization is low (L), and the population is also low (Table 6). The gap between the income extremes is growing because in the case of the deciles of 6 to 10, the growth can even be over 80% (GKI, 2019) and this is also reflected by electricity consumption (Szép 2013). In our forecast, similarly to the UN (2020), we project increasing social inequalities, so we calculated a higher rate of income growth (4%) In the case of the top deciles and a lower rate of income growth (1-3%) In the case of the lower deciles. The extremely high income of the rich is expected to increase electricity consumption up until about the middle of the period. However, the electricity consumption of the wealthiest deciles will begin to decline by 0.5%-1% from 2040 on. The rate of poor people will grow, but this will not significantly reduce or affect the level of the electricity use (Borozan et al. 2017; Rosas et al. 2010), or the price of electricity either (Atalla and Hunt 2016; Yang et al. 2019)

Table 6: Base (HLL) Scenario (yearly changes, rounded)

	2018 (fact)	2030	2051
Electricity use decile 1	10%	2%	2%
Electricity use decile 2	17%	1%	1%
Electricity use decile 3	8%	2%	2%
Electricity use decile 4	0%	2%	2%
Electricity use decile 5	4%	3%	3%
Electricity use decile 6	5%	3%	3%
Electricity use decile 7	-1%	3%	3%
Electricity use decile 8	3%	5%	4%
Electricity use decile 9	-3%	6%	4%
Electricity use decile 10	8%	6%	5%
urbanization rate	67%	75%	84%
capital	17%	19%	14%
major cities	19%	21%	17%
small and medium towns	31%	35%	54%
villages	33%	25%	16%
Population	-0.2%	-0.5%	-0.6%
Total consumption (TWh)	12,40	17,50	29,01

The low (L) urbanization estimate envisions suburbanization toward the medium towns. In Hungary, even 160,000 people could move to new places of living by 2051 (Lennert 2019). The population of the capital will decrease by 10%, and the people will migrate to urban areas where the climate is more pleasant, and the workplaces are easily accessible. The villages will suffer the consequences of the population growth in the towns, and by 2051, 84% of the population will live in towns and cities (Lennert 2019). The correction factor shows the consumption deviating from the national average by the types of settlements and as the average of the past years with the income and settlement type effects. Compared to small and medium-sized cities, large cities consume less electricity. (Table 7). In the capital, we assume a minimum-level growth of the electricity expenses because wealthier people will use energy-efficient appliances (Rosas et al. 2010; Santamouris et al. 2007). The major cities will consume less electricity compared to the small and medium towns (Table 7).

Table 7: An estimate of the correction factor

	Capital	Major cities	Small and medium towns	Villages
Urbanization rate (%)	17.5	19.18	30.74	32.59
Consumption (kWh/capita)	1313	1078	1316	1315
Relative consumption*	105	90	100	110
% of the national average	1.03	0.88	0.98	1.08

*Small and medium towns=100

We only allowed for three trends for the population. According to the pessimistic (L), the medium (M) and the optimistic (H), estimates, the population of the country in 2051 maybe 8.35 million, 8.75 million or 9.14 million people respectively. Most scenarios (Eurostat 2020; Lennert 2019; Obádovics 2018; Tagai 2015; Hablicsek 1998) agree that the population of Hungary will undergo an unprecedented decline. We think the pessimistic case is most likely to happen (8.35 million people).

MEGATRENDS

The second urbanization scenario was prepared following the megatrends (HHH). HHH is less by the Hungarian visions, but we created this scenario under the urbanization rate of the developed countries (Eurostat, 2020; UN, 2020). In this case, the entire population (and the population of every urban settlement type) will grow, while the population of the villages will drastically decline. Depending on the nature of the city, we predict a yearly growth of 0.5% to 2%. The population growth in the capital will continue up until 2032, and then it will drop to 0.5%. The growth of the major cities will be 2% all along, and most of the new growth of the capital is included here. The small and medium towns will have a minimum-level, 0.5% growth. The decline of the population in the villages will be at an average level of 5% each year. In the case of the urbanization, the high (H) scenario forecasts significant growth in the ratio of major cities. The income gap will keep growing, but according to our estimates, the wealthiest people will surely pass the income level by 2035 at which their electricity expenditures will drop. The increase in electricity consumption in the upper deciles is 1% higher than the average of previous years. From 2040, we planned a 0.5% reduction because of the disappearance of the rebound effect. The difference in energy consumption between the income deciles will be more significant from time to time (Rosas et al., 2010).

SMALL AND MEDIUM TOWNS

According to our forecast, the Hungarian settlements will have undergone a significant transformation by 2051 (Figure 4). In the coming decades, the dominant settlement type will be the small and medium town due to the Hungarian suburbanization peculiarities. The population decline of the villages will not slow down, and the gap will be wider and wider between the population of the towns and the villages.

By 2051, 84% of the Hungarian population will live in towns and cities, following the UN (2020) forecast. The population of the villages will drop to half of the current 33% rate. The population of the capital and the major cities will not significantly change due to the Hungarian urbanization peculiarities.

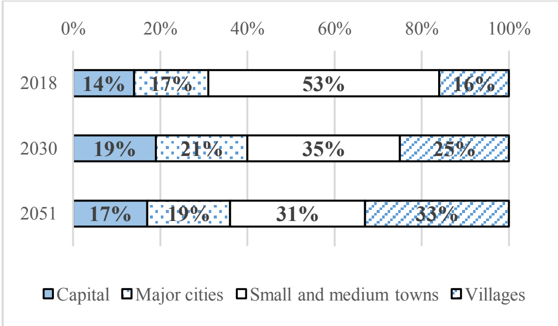


Figure 4: Settlement structure of Hungary between 2018 and 2051

BIDIRECTIONAL SCENARIOS

Our forecast shows a growing level of electricity consumption. By considering all the possible cases, electricity consumption might be around 18 to 25 TWh in Hungary by 2040 and 22 to 33 TWh by 2051. Compared to the base scenario (HLL), the other scenarios deviate downward. The first five scenarios predict a little more than half of the electricity consumption of the base scenario (Figure 5).

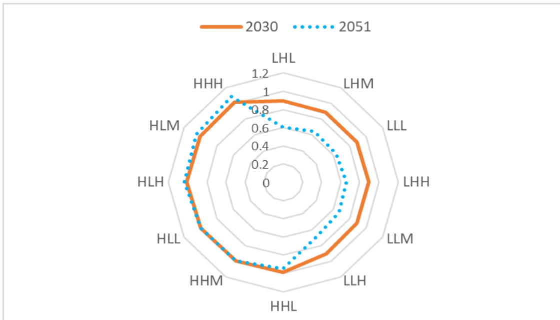


Figure 5: Deviations from the base scenario

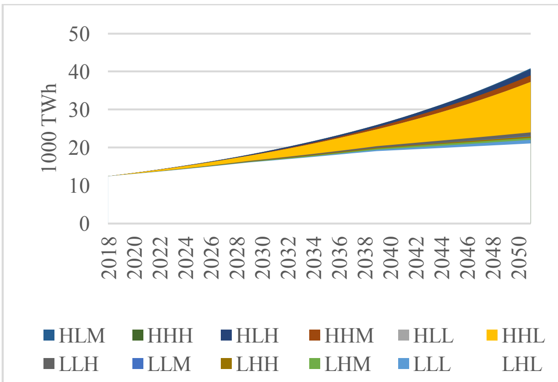


Figure 6: Scenarios for electricity consumption (1000 TWh) of Hungary between 2018 and 2051

The scenarios forecasting low energy consumption all calculate low energy expenditures. The deviation will grow with time, so the widening gap between the income levels, the more and more different consumption habits and expenditures and the changes of the settlement structure all have an effect on electricity consumption (Figures 5 and 6). The scenarios grow together with small differences until 2025 (Figure 7), which is the starting year of the trend-deviations in the suburbanization migration process. The population of the villages will drop to nearly to the half of the current level. The lowest electricity consumption is forecast by the LHL scenario, the LHM is only slightly in advance, so income has a greater effect on electricity consumption than the number of the population. The conditions of the HHH scenario show the highest level of consumption. The extremes are not identical with the extreme scenarios, since the LLL does not produce not the lowest consumption level. When the suburbanization starts, the scenarios with lower income levels show declining curves, while the scenarios with higher income predict higher consumption.

CONCLUSIONS

Results show that urbanization reduces electricity consumption of the more deprived deciles (LHL and LLL) in the long run, and increases it in the richest deciles (HLH and HHH). Our results are consistent with Yang et al. (2019) and Wiedenhofer et al. (2013), but only partially confirm the Hungarian results of Poumayong and Kaneko (2010). Both hypotheses were validated. (1) In our estimation the residential electricity consumption differs at the levels of urbanization, and (2) the outcomes based on the income and urbanization data are in line with the forecasts of other scenarios (NES, EUCO). The 20-22000 Twh (NES) forecast corresponds to the BASE scenario and the 18000 Twh (EUCO) forecast to LHL. However, the results of the high income and urbanization paths (HHX and HLH) overestimate the consumption of known scenarios by 5-10%, which may be due to an overestimation of the rebound effect. Our model might be distorted due to various factors. Estimations used the average consumer electricity price as the ratio of the daytime and night electricity consumption is unknown. The time series are only available since 2010, and we assumed a balanced ratio of the deciles for all regions because of the lack of detailed data.

From a general perspective, the policy conclusions of our study highlight the risk of environmental pollution because of rising electricity consumption. However, residential electricity consumption has dropped significantly due to the pandemic. In Europe demand fell by an average of 4.4% and in Hungary the decline in electricity consumption was 1% in March compared with the same month last year (MEKH 2020). The impact of this shock, such as increased home office activity, can fundamentally change long-term estimates of residential electricity demand.

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