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Characteristics of Household Energy Consumption in the Shadow of the Russia-Ukraine War - A Case Study from Hungary

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ABSTRACT

This study aims to identify the factors affecting household energy consumption by applying spatial econometric models. Our findings suggest that sharp energy price growth is followed by significant reductions in household energy consumption, but it is difficult to distinguish specific consumer groups. Weather conditions are of particular importance (compared to the EU average). The results highlight two things: a) the problem of obsolete housing stock and the need for energy efficiency improvements and b) the low energy awareness of households, especially before the energy crisis. Furthermore, hotspots with higher per capita gas consumption are also identified in Hungary. The geographical dimension is crucial, and it is not possible to make and general decisions on energy efficiency issues. Effective results can be achieved through spatially concentrated interventions.

Keywords

Household energy consumption;
Spatial econometric models;
Hungary;
Energy efficiency;
Dual fuel trap

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Highlights

- The highest price elasticity of energy use is observed for middle-income households.
- The impact of weather on household energy use is higher than the EU average.
- 1°C growth in annual mean temperature results in 170 m^3 less gas consumption.
- Spatially concentrated interventions are needed in Hungarian energy policy.
- The decentralisation of energy policy must be accompanied by greater energy awareness.

1. Introduction

Global energy prices have sharply increased since the second half of 2021. Although the economic recovery after the COVID-19 crisis and the increased demand associated with the gradual lifting of travel restrictions had fuelled expectations that energy prices would rise, reality has exceeded the projections. Improving consumption and travel data, together with other factors, have become major drivers of growth. The price increases that started in 2021 did not stop in 2022 and were further aggravated by the Russia-Ukraine war. As a result, the overall picture for energy supply across the European Union has become bleak, with more uncertainties and challenges. Governments are facing an energy crisis that has not been seen since the 1970s interdependence-based energy security has become fragile [1]. The current energy crisis challenges the energy policy in all components of the 4A concept (accessibility, availability, affordability, and

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acceptability). The Russian invasion of Ukraine put accessibility at risk and threatened the availability of fossil fuels. Acceptability brings up moral issues, and the consumption of Russian fossil fuels indirectly supports the war and suffering. From a social and economic point of view, it is important that households have to be able to cope with high utility costs and have limited options to increase their disposable income, which also influences GDP through final consumption expenditure. This is connected to the affordability of energy services, which is the focal point of the current study.

Under the current circumstances, household energy prices have risen significantly, and there are considerable differences across European countries. The drastic price rises have indirect (producer price growth) and direct inflation impacts, further deepening the economic and social implications of the Russia-Ukraine war. Energy poverty in the European Union will probably increase to unprecedented levels, and as the disposable income of the population shrinks, the consumption side of GDP will decline, leading to a higher probability of recession in some EU Member States.

However, Hungarian households and thus Hungary are in a favourable position in terms of average energy prices thanks to a decision taken nearly ten years earlier. The utility cost reduction program was introduced by the Hungarian government (Act LIV of 2013 on the implementation of the household utility price cap scheme, Act XI of 2014 amending certain acts related to the household utility price cap scheme and consumer protection) in three consecutive steps between 2013 and 2014 [2], [3]. Household prices fell by an average of 23-24% (25.2% for natural gas, 24.6% for electricity, 22.6% for district heating, and 10% for LPG) in 2013-2014. The prices remained fixed and did not change until 2022 (not even an inflation adjustment was made). The primary objective of the state intervention was to reduce energy poverty and the exposure of the residential sector to the price volatility of energy products, and to decrease the energy expenditures of households.

In practice, the utility cost reduction program meant a switch from market-based tariffs to regulated prices (a kind of price cap) for the end-consumer side of the energy and utilities sectors (water supply and sanitation, waste collection, and chimney sweep costs have also been involved in the program), with the difference between the regulated price and the market price being reimbursed to the electricity and gas suppliers from the state budget. The program was unique in the European Union in the sense that its endpoint was not defined (in its energy strategies and official communication, the program was permanent), the price reductions were unified, and there was no differentiation regarding the income levels or the social status of the households. It also meant that families with higher income and greater wealth (i.e. higher social status) experienced more privileges with lower energy prices [4].

Price caps always have a disadvantage in that the true costs have never been covered by the energy prices, threatening the viability of the system [5]. The prolonged war and high energy prices made this system unsustainable, and adjustment was unavoidable in 2022. The Hungarian Government, therefore, changed the scheme (Government Decree 259/2022 (VII. 21.) on setting certain universal service tariffs) to provide all consumers with the regulated price up to the national average household gas and electricity consumption (so-called block pricing). The national average is 144 m^3 of gas and 210 kWh of electricity per month per household. Above this consumption, everyone is obliged to pay the market price (but only for the above-average part). The regulated prices in the district heating did not change; therefore, this is not examined in the study. Thus, the impacts of energy price growth are also felt in Hungary, but to a lesser extent than in the European Union.

This study aims to examine how household consumers reacted to high gas and electricity prices and the main driving factors of household energy consumption is. It also highlights the situation that Hungarian decision-makers faced in the summer of 2022, which led to the change of the utility cost reduction program. In the analysis, we assume that households that have experienced higher price growth reduce their consumption more [6], [7]. The following research questions are answered in this article:

RQ1: To what extent can the responses of households be considered homogeneous regarding the adjustment of the regulated energy prices (2022)? Which characteristics of the households (e.g. income, dwelling, etc.) have the most influence on their energy consumption?

RQ2: How much does household gas consumption at the municipal level depend on the objective characteristics of dwellings and their inhabitants?

This research extends the current literature in several key ways. First, a significant number of analyses on the effects of COVID-19 have been published (e.g. [8], [9], [10]) since 2020. Due to the short time elapsed, there are far fewer articles analysing the impact of the 2021-2022 energy crisis and the specific policy measures taken to address it (e.g. [11]), and only a few that cover both events (e.g. [12]). It is also the case for Hungary: very little research has been published that focuses either on the impact of COVID-19 on energy consumption patterns (in this context, on the price elasticity of household energy demand) or on the current energy price growth in the household sector (i.e. [13]). However, because of the importance of the above-mentioned information, this study aims to fill this gap in the literature by providing more information for policymakers.

Second, although there are studies that examine a country region (e.g. [14], [15]) or several countries (e.g. [6], [16], [17], [18]), most studies focus on a single country (e.g. [8], [9], [11], [19], [20]). There are many lessons to be learned from the Hungarian situation and this single-country study. As explained earlier, socio-political elements were already prominent a decade earlier in the Hungarian energy policy. Regulated energy prices for all household consumers were in place as long as the favourable economic environment and global energy prices allowed it. However, it cannot be said that this was a completely unique case in the European Union, as many other Member States have also introduced price caps, albeit in differentiated ways. What makes the situation interesting is that regulated prices were partly phased out in Hungary at a time (in 2022) when other countries were deciding to introduce them in response to soaring energy prices. However, the lessons of the Hungarian scheme may be important for these countries, especially with regard to the conditions and timeframe under which it can be sustained. We already know that this state intervention significantly reduced household energy prices, pushed household energy consumption (mainly fossil fuel use) and made renewables less competitive [2], [13], [21]. Because of the regulated energy prices, the population has not truly had to face price shocks between 2013 and 2022. The current study aims to measure the impact of the price cap adjustment and identify the factors that influence the energy consumption of Hungarian households.

Third, the unique contribution of this study is that it analyses high-resolution and disaggregated municipal data beyond the sectoral level to identify the main driving factors affecting household energy consumption with special regard to gas consumption and to examine households consuming above and below the national average in the Hungarian gas and electricity market. Finally, a further important contribution of this research involves the identification of the most vulnerable social groups who need more attention and support to cope successfully with the challenges of rising prices. It also allows us to conclude the effect of the planned carbon taxes [20], [22].

The rest of the paper is organised as follows. Section 2 reveals the main residential energy consumption patterns in Hungary and highlights their changes during the 2021-2022 energy crisis. Section 3 (data and methods) introduces (i) the applied data (databases), (ii) the general model of spatial lags and spatial error autocorrelation model, and (iii) the Moran's I model. Section 4 presents the results, including our main findings on the main drivers of household energy consumption, with special regard to natural gas. Finally, the paper discusses the significance of the results of the work and offers conclusions and implications for policymakers in Sections 5 and 6.

2. Hungarian residential energy consumption patterns and their changes during the 2021-2022 energy crisis

The total final energy consumption in Hungary was 737 PJ in 2020 [23]. Direct use of gas represented 31% of total energy use (but with natural gas used for electricity and heat generation, it accounted for 45%). Oil and petroleum products contributed an additional 35% of the energy mix, while electricity and direct use of renewables contributed 18% and 10%, respectively. Hungary is heavily dependent on energy imports, with energy import dependency reaching 54.4% in 2020 [23] (Figure 1).

Industry and transport (which includes residential fuel use) represent 25-25% of final energy consumption. The household sector is responsible for 34%, and more than two-thirds (71%) of it is used for heating. In the household energy mix, natural gas contributed 52%, renewables (mainly firewood) 22%, and electricity and district heating contributed 18% and 8%, respectively, in 2020. Electric heating is not common; solid fuels and gas are more typical sources of heating (especially in rural areas), and district heating in urban areas. The high exposure to Russian fossil fuels and the low share of renewable energy sources (compared to neighbouring

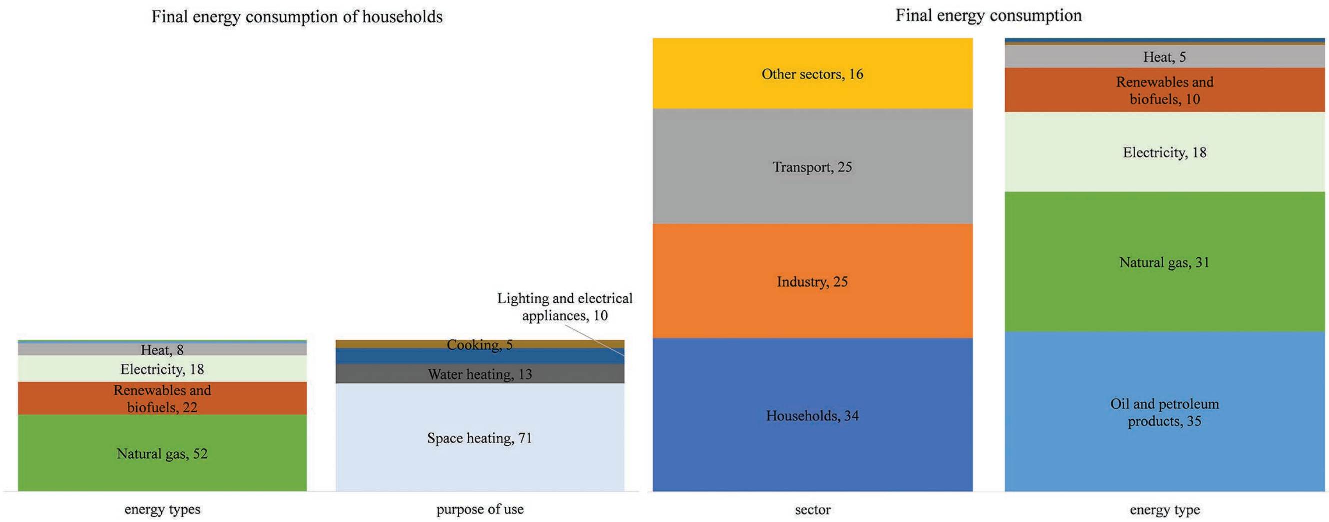

Figure 1: Final energy consumption by sector, energy type and purpose of use in Hungary (2020, %)

Source: Own compilation based on [23]

countries) make Hungary one of the most vulnerable countries in the European Union. The need to shift from fossil fuels to renewable energy sources is more urgent than ever.

In the current energy crisis, natural gas and electricity consumption are the main sources of high costs for households. Figure 2 presents the last 12 months of the utility cost reduction program before the adjustment. A total of 38.5% of households were already consuming within the current subsidised range (average consumption) for both electricity and gas before the partial withdrawal of the household utility price cap. They are, therefore, not directly affected by the new measure and will not see any change in energy prices. The remaining households also consume at least one energy source beyond the subsidised range: 6.8% of all households use gas only, 33.6% use electricity only and 21.0% use both. It means that 61.5% of Hungarian households were affected by the adjustment of the utility cost reduction program and finally, by the energy price growth. While the heating season usually starts in mid-October in Hungary, and the announcement about the phasing-out of regulated prices was made in July, the families had three months to prepare for the price growth. However, after the government's decision on 13 July to partially reduce the overhead reduction (presented in detail in Section 1), the households adapted quickly and started to consume more consciously. In 2022, natural gas consumption fell by 17%, and electricity consumption decreased by 3% compared to the previous year [24].

Obviously, from a fiscal point of view, the system was unsustainable; it significantly affected our external trade balance due to high energy imports, and it did not encourage energy savings and efficiency improvements. However, from a policy perspective, it remains unclear what the purpose of the regulatory change in 2022 was. According to Horváth [13], it could also result in a decrease in residential energy consumption, alleviating the budgetary burden or protecting vulnerable households. We would add one more factor, namely energy security considerations and, thus, energy availability. Horváth [13] also points out that a solution that is more effective than a block tariff would be a general increase in natural gas prices for all households to around one and a half times the regulated prices while providing direct income support for those in need.

3. Data and methods

Household energy use is influenced by several factors, including energy price, household income, willingness to save, energy mix, energy use, urbanisation, consumer habits, culture, energy efficiency and dwelling characteristics [2], [18], [26]. Since the publication of Haas [40], a pioneering work on the subject, a number of studies have been published (e.g. [28], [29], [30], [31], [32], [33] with the aim of determining the most important critical factors that affect residential energy use.

To assess the impact of the adjustment of the utility cost reduction programme on Hungarian households and

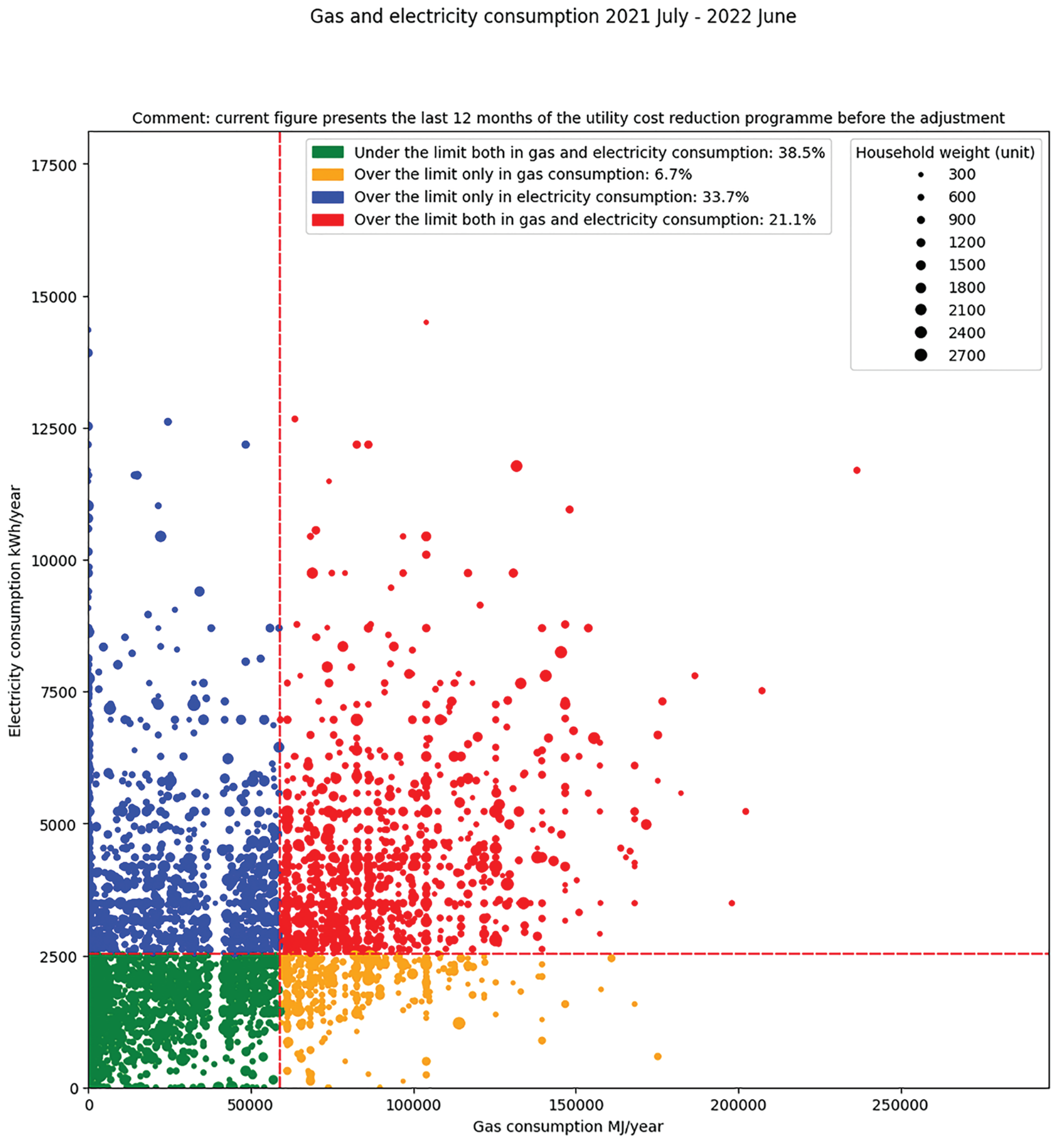

Figure 2: Consumption of gas and electricity by Hungarian households between July 2021 and June 2022

Source: Own compilation based on [25]

identify the factors influencing this effect, spatial econometric models are used. The analysis covers the years 2021-2022. Both monthly and annual data are applied. Beyond the time series analysis, cross-sectional data are also involved in the analysis of 2020 and 2021 with the aim of making the analysis more structured.

In relation to the descriptive energy statistics in Hungary, the following data are used in the research:

- Hungary's basic energy statistics on primary and final energy consumption highlight residential consumption in particular and natural gas consumption in particular [24], [25].
- Data from the household budget and living conditions survey (called HKÉF) 2021 [25], which is derived from weighted data from a completed household sample of approximately 8,000 households. The HKÉF survey provides detailed information on household expenditure and consumption characteristics and is also the basis for the European Union's harmonised statistics on income, living conditions (EU-SILC) and household budgets (EU-HBS) [34].
- Electricity market data (consumption) of the Hungarian Independent Transmission Operator

Table 1: Applied data for descriptive energy statistical analysis

Indicator	Types of data	Source	Explanation
Final energy consumption by sector (PJ, %)	Cross-sectional data (annual data)	[24]	2020
Final energy consumption by energy type (PJ, %)	Cross-sectional data (annual data)	[24]	2020
Final energy consumption in the household sector by purpose of use (PJ, %)	Cross-sectional data (annual data)	[24]	2020
Final energy consumption in the household sector by energy type (PJ, %)	Cross-sectional data (annual data)	[24]	2020
Annual gas consumption by households (100 m^3)	Survey microdata	[25]	2020
Annual disposable income of households' (100 000 HUF)	Survey microdata	[25]	2020
Characteristics of households	Survey microdata	[25]	2020
Electricity consumption in the household sector (kWh)	Time series (aggregated monthly data)	[34]	July 2021 – July 2022
Natural gas consumption in the household sector (MJ)	Time series (aggregated monthly data)	[24]	July 2021 – July 2022

Source: own compilation

Company Ltd. on monthly aggregated electricity consumption flows [34].

- Natural gas market data (consumption) of the Hungarian Energy and Public Utility Regulatory Authority on monthly aggregated natural gas consumption flows [24].

Table 1 presents these data in detail.

In addition, for the spatial econometric modelling, data from the HCSO dissemination database on settlement and district statistics, which are publicly available on the HCSO website, are applied. The following indicators are involved in the analysis at the municipality level for 2021 [35]:

- share of three- and more-bedroom dwellings (%),
- dwellings built between 2011 and 2021 Dummy; if dwellings were built in the municipality in the period under review, the value is 1; if not, the value is 0 between 2012 and 2021,
- share of dwellings with gas among dwellings built between 2012 and 2021 (%),
- population (persons),
- the share of people earning below HUF 1 million per year (%),
- share of retired persons (%).

Throughout the paper, the source and availability of the data are indicated at each point of use.

There is a strong consensus in Hungary that energy prices and the weather play some of the most important roles in changing household energy use, similar to other Central and Eastern European countries [2], [16], [26]. The energy consumption data are not weather-corrected because it was decided to use climatic conditions as a driving factor of household gas consumption (confirmed by Tsemekidi Tzeiranaki et al. [26] too). This article and the first calculations were made in late 2022 and early 2023, when everyone in Europe was just hoping for a mild winter. The Russia-Ukraine war disrupted the energy supply chains in 2022; the declining Russian fuel imports could not be fully replaced by other sources. The security of supply highly depended on the HDD in the winter months of 2022/2023. It is important to know how much difference a one-degree increase in mean annual temperature makes to household gas consumption. However, there are numerous examples in the literature for both weather correction of the data (e.g. [2]) and maintaining it as a separate driving factor (e.g. [18], [36]).

Beyond the general and well-known descriptive statistics, contingency analysis is carried out, and the Cramer association index is calculated.

3.1 Spatial econometric models – the general model of spatial lags and the spatial error autocorrelation model

For the spatial econometric analyses, two models were used. The first is the general model of spatial lags (SPATIAL LAG), which can be described as follows (Eq. 1):

$$y = \rho Wy + \beta Xa + \beta Xb + \beta Xc + \beta Xd + \beta Xe + \beta Xf + \varepsilon \quad (1)$$

where y is the vector of values of the outcome variable (it is the residential natural gas consumption per capita), ρ is the coefficient of the spatially lagged outcome variable (i.e. the spatial autoregression parameter). W is the row standardised weight matrix, and in this case, the queen contiguity was applied. Neighbours can be of type Queen if a single shared boundary point meets the contiguity condition. Contiguity means that two spatial units share a common border of non-zero length. β is the parameter vector of exogenous explanatory variables, X is the matrix of exogenous explanatory variables (municipal data for 2021), and ε is the vector of values of the error term [37], [38], [39]. Xa is the share of three- and more-bedroom dwellings (%), Xb is the dwellings built between 2011 and 2021 (dummy), Xc is the share of people earning below HUF 1 million a year (%), Xd is the population (person), Xe is the share of dwellings with gas among dwellings built between 2012 and 2021 (%), Xf is the share of retired people (%).

The other commonly used form of spatial econometric modelling is the spatial error autocorrelation model (ERROR). The general formula of this model is illustrated by the following (Eq. 2 and 3) equations:

$$y = \beta Xa + \beta Xb + \beta Xc + \beta Xd + \beta Xe + \beta Xf + \varepsilon \quad (2)$$

and

$$\varepsilon = \lambda W_{\varepsilon} + \xi \quad (3)$$

where ε is the vector of autoregressive error terms, λ is the spatially lagged parameter coefficient of the autoregressive error terms, and ξ is the vector of independent, identically distributed error terms with a zero expected value (Eq. 3) [38]. Spatial dependence can be indicated if λ is significant since interactions between nearby spatial units are reflected in the error term values. It should be noted that there is also a combination of the two spatial econometric models described above, in which both spatial lags and spatial error autocorrelation are included.

3.2 Identifying the main drivers of household gas consumption – measuring spatial dependence (Moran's I)

Since we assumed that spatial dependence could be present in this estimation, if so, then the geographic location would have an influence on the actual correlations, and thus, conventional econometric estimates would be biased. Moran's I was used to test for spatial dependence and to identify hot and cold spots of per capita gas consumption similar to Khalil and Fatmi [15]. Moran's I formula is as follows (Eq. 4) [40]:

$$I = \frac{n}{2A} * \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\delta_{ij}\left(y_i - \bar{y}\right)\left(y_j - \bar{y}\right)}{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2} \quad (4)$$

where n is the number of municipalities, y_i is the household gas consumption in each of the municipalities, $\bar{y}$ is the unweighted arithmetic average of the household gas consumption, the number of neighbourhood links is denoted by A, and the δ_{ij} coefficient is 1 if municipalities i and j are adjacent and 0 if they are not [41].

When interpreting the data, we have to note that the calculated indicator should be understood in the following ranges and ways:

- I > -1/N-1, positive spatial autocorrelation,
- I = -1/N-1, no spatial autocorrelation,
- I < -1/N-1, negative spatial autocorrelation.

3.3 Limitations of the study

Due to data limitations, a long time series analysis of the current energy crises (in 2021-2022) can only be carried out years later. However, cross-sectional data regarding household and dwelling characteristics are available. To answer RQ1, we present the data from the HKÉF survey comparing the magnitude of consumption with the aforementioned characteristics and findings from the literature. The results are used to build a spatial econometric model at the municipal level to explore which factors can explain most of the gas consumption per capita (and to answer RQ2).

Here, we note that this study does not take into consideration the impact of COVID-19 because, in 2021, the pandemic no longer had a significant impact on the Hungarian residential energy use, and it had certainly no impact on gas consumption. In Hungary, the vaccination campaign had an early start, and the reopening was relatively quick. The indicator selection was made to reflect the previous parts of the article, with the information established there at the municipal level. A long iteration and modelling process was carried out to avoid multicollinearity and to construct the most appropriate model with significant indicators. However, at the beginning of the Data and Methods Section, we only presented the final set of indicators.

4. Results

4.1 Characteristics affecting household energy use during the energy crises

Analysing the relationship between income and the amount of gas and electricity consumed (based on the HKÉF survey), we find that there are also households in the lowest income decile that overconsume and a significant number of households in the top decile that consume less. The energy consumption of the richest 10% falls below 80% of the threshold. This association is very well illustrated in the case of gas consumption (Figure 3). However, this is only an apparent contradiction, and one possible explanation is linked to the low energy efficiency of the poorest people's homes. They have a much higher energy consumption per m^2, which can be up to three times the average [42]. On the other hand, higher-income households are much more energy conscious, which results in a higher level of energy sufficiency [17], [22].

The income and living conditions of households significantly affect their adaptability to energy price growth. Low-income consumers are less sensitive to energy prices than higher-income consumers [43], and the highest price elasticity (in absolute terms) can be observed for middle-income households [44]. In practice, this means that low-income households often live in energy poverty, and they already strictly constrain their energy use. There is no further room for reducing energy use, and they cannot make adjustments [45]. However, price changes may also only indirectly affect them because firewood (which is a fuel commonly used by low-income people) is obtained illegally.

HKÉF data also allowed us to relate energy consumption to educational attainment and family structure. To measure the former, a contingency analysis was performed, resulting in a Cramer association index of 0.11. Thus, the educational attainment of the household reference person is not strongly associated with household energy consumption.

In Hungary, 80% of households using more than 120% of the average household gas consumption can be found in dwellings built before 1990. Some 27% of these households with high gas consumption are located in the capital, 18% in cities with county status, 37% in smaller cities, and 36% in smaller towns and

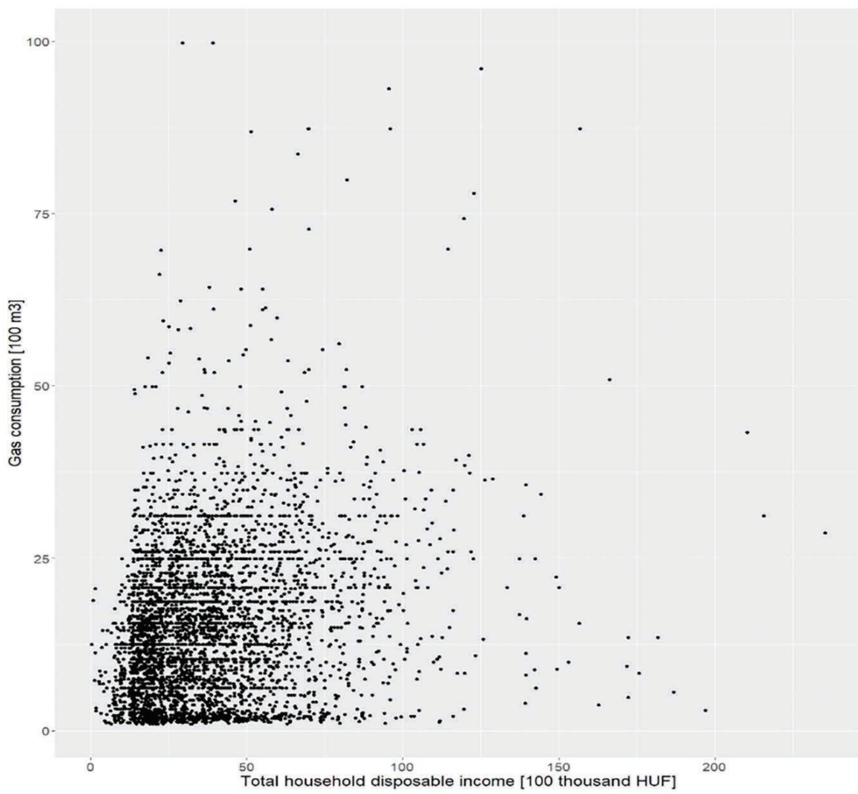

Figure 3: Annual gas consumption of Hungarian households by income, 2020

Source: Own compilation based on [25]

Figure 4: Average natural gas consumption of households (m^3) and relation of mean annual temperature (°C) and average gas consumption (m^3) (1990-2021)

Source: Own compilation based on [25]

settlements. In terms of age structure, 29% of households with high gas consumption (i.e. 271,000) consist exclusively of people aged 60 or over. However, 34% of households (approximately 752,000 households) that do not overconsume are made up only of elderly individuals. Overconsuming households made up only of older individuals represent a smaller number of people than households consisting of only older individuals, who are not overconsumers. But it is important to note that people in the former category typically belong to vulnerable groups, and their number is also significant, so their living conditions and any changes made to them deserve special attention (also confirmed by [4]).

4.2 Spatial econometric model of the factors affecting household gas consumption

Since the reduction of natural gas consumption is critical (both due to price growth and the availability of this energy source) [46], we focus on this type of energy in the following. Spatial econometric models are used to examine the main drivers of household gas consumption at the municipal level in Hungary and identify the characteristics of overconsuming households.

We start our analysis with the weather, which, in addition to the factors listed above, is one of the most important drivers of household gas consumption [7], [47]. In our sample, the weather in a given period partly explains the year-to-year change in per capita household gas consumption. As mentioned earlier, gas is mainly used for heating purposes in households. There is a linear relationship between the two-time series (R^2 = 0.4732). A one-degree difference in mean annual temperature represents a difference in household gas consumption of approximately 170 m^3 per year, which is approximately 14% of the long-term average of total consumption (Figure 4). The impact of weather is significant and much higher than the EU average [48], and inertia is high in the household sector. From our point of view, household gas consumption is tightly connected to the dual fuel trap [49] and the quality level of building stocks, and it is also in line with the much-vaunted fact that buildings play a prominent role in the achievement of energy efficiency targets.

The majority of the dwellings are energy-obsolete with low energy ratings. This impacts a minimum of two-thirds of the 4.6 million residences, where the energy requirement for space heating (i.e. heating consumption per square meter) exceeds the EU average by 59.7% due to inadequate energy efficiency [50]. More than half of the buildings have an energy rating of FF or worse. The energy savings potential of the sector is 40-50% (i.e. the energy used could be roughly halved). For some types of buildings, even higher savings could easily be achieved through deep renovation. For a conventional, 50-60-year-old, 100 m^2 Kádár block with poor energy efficiency, the energy demand of 500 kWh/m^2 could be reduced to 139 kWh/m^2 [42]. However, the annual average renewal rate of the housing stock is below 0.5%. The fact that the weather plays such a major role in gas consumption is clearly due to this.

Table 2: Results of the models used

Indicators	OLS	SPATIAL LAG
Constant	1.481***	0.525***
Share of three- and more-bedroom dwellings, %	0.005***	0.005***
Dwellings built between 2011 and 2021 Dummy	0.014	–0.006
Share of dwellings with gas among dwellings built between 2012 and 2021, %	0.002***	0.002***
Population, person	0.000***	0.000***
Share of people earning below HUF 1 million a year, %	–0.014***	–0.008***
Share of retired people, %	–0.010***	–0.005***
Spatial lag coefficient	–	0.590***
Pseudo R^2	0.28	0.56

*** p<0.001, ** p< 0.01, * p<0.1

Source: Own calculations

As a second step in our analysis, we use multivariate linear regression to examine the indicators of household gas consumption per consumer for municipalities in Hungary, which involves 3,177 territorial units in the calculations (3,154 municipalities and 23 districts of Budapest).

The fit of the multivariate linear regression model was not very strong (adjusted $R^2 = 0.28$), and the dummy variable for housing was only insignificant. The next step is testing the spatial dependence with Moran's I. It shows the global autocorrelation of household gas consumption per consumer for all municipalities in Hungary, and its value is Moran's I = 0.533. In our case, 0.533>-0.00031 (-1/3177-1) implies positive spatial autocorrelation. This means that the spatial concentration of similar values is higher than would be expected from natural processes. High gas-consuming municipalities are neighbouring other high gas-consuming municipalities, and low gas-consuming municipalities are neighbouring other low gas-consuming municipalities. Although we would consider household gas consumption as a general activity and assume that the magnitude of consumption has no spatial implications, this hypothesis has to be rejected. Indeed, the amount of gas consumption can be characterised by spatially distinct or spatial clusters. This is also confirmed by the study by Ata et al. [51], which shows that the spatial inequality of natural gas consumption is increasing.

Spatial dependence was therefore deemed necessary to explore further. This was also confirmed by the results of the normality and heteroscedasticity tests, which are significant. Our indicators show spatial dependence, and we can, therefore, state that it is necessary to build a spatial model that observes such characteristics.

The calculations were carried out using GeoDaSpace software with the application of queen contiguity. For heteroscedasticity, we used White's standard error. The multicollinearity of our model is 23.1, which is in line with expectations. Lagrange multiplier tests were significant for spatial delay and spatial error models. Since the coefficient values were higher for the spatial delay model, we continued our analysis with that model hereinafter (Table 2).

The explanatory power of the spatial models was significantly improved compared to conventional OLS, with Pseudo $R^2 = 0.56$. Only the dummy variable had no significant effect on gas consumption.

The explanatory variable with the longest lag in space has the largest effect. This means that there are hotbeds in the country with higher per capita gas use (similarly to Khalil and Fatmi [15]), and it is more likely that more gas is used in a given municipality if more is used in surrounding municipalities (or less if less is used in surrounding municipalities). The results could also be interpreted as suggesting that the decisive factor may be the collective energy awareness attitude of larger communities [51], which may be concentrated in a particular area of the country, and this background variable explains the differences in natural gas use. However, it is worth exploring this hypothesis in more detail in a future study. A very important finding for decision-makers is that it is not possible to adopt general decisions – general decisions for the whole country – when intervening, but spatially concentrated interventions are needed. The impact of other variables lags far behind the spatial lag.

Among the socioeconomic indicators (Table 1), the share of people earning below HUF 1 million per year (25% in 2021) has the largest impact on specific gas consumption. The negative sign indicates that the lower the share is, the higher the specific gas consumption is. In our previous models, we tested the impact of income (in nominal terms, not above a threshold level), which was found to be highly insignificant. This may suggest that gas consumption is slightly lower for those with lower incomes but no longer proportionally higher for those in the top deciles.

Although the effect is significant for both models on the variables for dwellings with gas-fired heating built in the last ten years, their explanatory power is small. Thus, the proportion of relatively recently built, basically well-insulated, and, in numerous cases, energy-efficient dwellings have no significant effect on gas consumption. This may be due to unchanged consumer attitudes or the fact that, although these dwellings are energy-efficient, they are so much larger than an older but smaller dwelling with gas-fired heating that, despite insulation, not much gas can be saved. It is also worth noting that there are few newly built properties, so their impact may not be significant. Our third strongest explanatory variable was the share of pensioners, which is in line with the results of Mandys [11]. The lower the share is, the higher the gas consumption is. This is essentially equal in importance to the share of dwellings with three or more rooms (52% of the housing stock), where the higher the share is, the higher the gas consumption is. Although the impact is significant for the two models, the coefficient on population is the smallest, meaning that the issue cannot be treated simply as an urban-rural problem.

The Anselin-Kelejian test for spatial error is not significant, i.e. no spatial structure is visible in the errors. Thus, there is no need to apply a combined model that also addresses the spatial structures of error. In the appendices, the results and residuals of the spatial lag are presented (Appendix 1-3). The detailed model results are in Appendix 4.

5. Discussion

Active citizen participation is increasingly at the heart of the debate on achieving a sustainable, just and fair energy transition, and is already prominent in EU energy policy. What is needed is a decentralised and democratic energy system based on renewable energy sources, where prosumers and energy communities are already present and residents live in efficient homes. Previous passive, one-way relationships are becoming dynamic, with energy citizens taking responsibility for energy production and consumption.

To achieve this vision, households must be made interested in change. The utility cost reduction programme in its original form did not support these aspirations; the price signals were muted by several measures. But the reform of the system and the introduction of block tariffs have greatly improved this.

According to the official communication, the most important purpose of the utility cost reduction programme, introduced in 2013-2014, was to protect Hungarian households from the energy price changes and actively help people living in energy poverty. However, the price fluctuation experienced in 2021-2022 became unbearable, and the price cap in its original form has become unsustainable. At the end, the programme failed to fulfil its most important goal, as it was partly phased out at the time of the price boom. The targeting of adjustment is still unclear, but we assume that they all played a role: reducing residential energy consumption, alleviating the budgetary burden, protecting the vulnerable households, or decreasing the energy security risks.

The programme was not fair at the beginning, it was not differentiated regarding the income levels or the social status of the households. Both the vulnerable and the wealthy were protected, and it did not decrease the social inequalities. As a result of low energy prices, energy consumption increased to a much greater extent in the upper income deciles than in the lower ones [2], [3]. The resulting savings were not used by households for energy investments, but instead, there has been a shift in consumer spending toward food and non-alcoholic beverages. There was no mass climbing of the energy ladder, which means that apart from a minor shift, households could not switch from low-quality fuels (mainly coal and firewood) to higher-quality energy sources (except for a slight rebound in gas). This leads to the conclusion that the programme has significantly hindered sustainable energy transition.

Policy recommendations often made in the past were to adjust the utility cost reduction programme by keeping the price cap only for the vulnerable households, also providing other incentives and social programmes, and promoting energy efficiency. They have been partially adopted. As a result of the adjustment, the price signals are easier to reach consumers, also motivating them to keep their consumption in the subsidised range. The adjusted system encourages the energy efficiency investments and the renewable energy investments through shorter payback periods. The block pricing is much more beneficial, contributing more to the achievement of the sustainable energy transition.

However, the lack of a precise definition of the target group is a major drawback of the programme. The setting of average consumption as a limit has tended to favour wealthier consumers living in newer and more energy efficient buildings. But a significant proportion of families with above average gas consumption live in obsolete buildings of at least 30 years. They benefit only to a limited extent from regulated prices, and their financial situation does not allow them to undertake major, deep renovations. The energy- saving potential in these dwellings built before 1990 is significant (ca. 40-50%), a further 6% energy savings in national gas consumption could be achieved by changing consumer habits [52]. It would be worthwhile to involve them as a target group in energy efficiency programmes and to promote fuel switching. The deep renovations should go first, so the insulation of the slab, basement and walls and, replacing the windows are critical. Hungary lags far behind regional trends, with only 25% of the family houses insulated compared to the Austrian 80% or Polish 59% [52]. If the renovations have been successful, the fuel switch through the modernisation of the heating system would be the next step. A particular attention must be paid to the energy mix, with traditional biomass being distinguished from modern renewables in every way and supporting the latter. The domestic sector is stuck in the so-called firewood trap, from which it would be desirable to break out as soon as possible by using other modern renewable energy sources. Energy efficiency and the more intensive use of the renewable energy sources would contribute to the fair and just transition.

Temporary measures (e.g. price caps, tax reductions, etc.) to offset or at least reduce the impact of energy price increases have been adopted in nearly all EU Member States. For them, the Hungarian programme can provide many lessons. The first and most important is that the price cap should be differentiated and targeted, unified, regulated prices have to be avoided. The introduced measures cannot become permanent; their temporary nature should be emphasised through clear communication. At the same time, the energy literacy of households and the, awareness of residential households should be improved. It also should be complemented by other energy efficiency programmes and other incentives for renewables.

6. Conclusion

The EU Member States have reacted in very different ways to the energy price growth. The European Commission released a toolkit to tackle the energy crises, most Member States introduced support mechanisms, such as price caps and tax exemptions, while others provided direct financial support for vulnerable households. As time goes by, there is a growing need to analyse their impact and provide appropriate feedback for decision-makers. Knowledge of households' response to energy price growth and the identification of the key drivers of residential electricity and gas consumption play an important role in the assessment and design of energy policy. Also, monitoring the effect of the policy changes may contribute to further improvements in policy measures.

This paper presents four main findings related to the two research questions (RQ1 and RQ2). First, before the adjustment of the utility cost reduction program, only 38.5% of households were consuming within the current subsidised range. It means that the gas and electricity consumption of these households was below the national average, and after the adjustment, they are still eligible for the regulated prices. The other households must pay market prices for at least one energy carrier and are the ones directly affected by the crisis. Even in the lowest income decile, some households overconsume (both electricity and gas). Most of them live in obsolete buildings and are more exposed to changes in energy prices. This is particularly true for gas consumers: 80% of families consuming more than 120% of the average household gas consumption live in buildings of at least 30 years. Nevertheless, we can conclude that it is very likely that middle-income households with very high levels of consumption will reduce their consumption to a larger extent.

Second, households are particularly sensitive to temperature changes in their gas consumption. A one-degree increase (or decrease) in mean annual temperature reduces (increases) annual gas consumption by 14%, equivalent to 170 m^3 of gas. The above-EU-average role of weather in gas consumption indicates two things: a) the problem of obsolete housing stock and the need for energy efficiency improvements and b) the low energy awareness of households, especially before the energy crisis.

Third, spatial hotbeds can be identified in the country where gas consumption is higher, and it is more likely that more gas is used in a given municipality if more is used in the surrounding municipalities. It means that high gas-consuming municipalities tend to neighbour other high gas-consuming municipalities, and low gas-consuming municipalities tend to neighbour other low gas-consuming municipalities. As objective indicators (income status, household structure, and type of dwellings) can explain household gas consumption only to a certain extent in Hungary, the energy policy should focus on spatially concentrated interventions and increased energy awareness among the population.

Fourth, municipalities with a relatively high share of people earning below HUF 1 million per year (more than 25%) tend to consume less natural gas. It sheds light on the acute problem of energy poverty. These households mainly use solid fuels (firewood and lignite) and waste for heating. In this regard, pensioners should be identified as a vulnerable social group who are heavily exposed to changes in energy prices. Municipalities with more pensioners also tend to consume less natural gas.

We build our policy recommendations on the four main findings of our research. Based on the results, we identify one vertical and two horizontal interventions: 1) complex energy efficiency improvement programmes, 2) spatially concentrated interventions, and 3) improving energy literacy.

Considering the energy performance of the Hungarian building stock and the importance of the weather (as one of the main driving factors of household gas consumption), intensive and complex energy efficiency improvement programmes must be launched in the household sector. Special attention should be paid to the deep renovations (achieving at least energy savings of 60%), however, many obstacles can be identified. The most obvious of these is that the majority of households do not have the necessary resources. According to the wealth survey, the median net worth per household was HUF 20 million (~ 59,700 EUR) in 2020 [53]. The picture is nuanced by the six-fold territorial disparities of the net worth per household between the poorest and richest parts of the country and other social inequalities (as the top two income deciles hold around 75% of these savings). In the current interest rate environment, the demand for housing loans has fallen. It also means that without launching integrated home renovation programmes and services, no significant change in energy efficiency is expected.

The territorial approach should play a more important role in Hungarian energy policy. More attention must be paid to the local conditions for the decentralisation of energy systems. All interventions should be spatially concentrated. It confirms the findings of Bouzarovski and Tirado Herrero (2017) and Bouzarovski and Simcock (2017) that between the spatial formations and the energy transition a bidirectional relationship can be identified [54], [55]. The spatial characteristics of the energy mix cannot be neglected, and the state interventions should be planned based on that.

Hungarian households are highly price-sensitive in energy terms, and social habits regarding energy use can change rapidly. After the adjustment of the utility cost reduction program, energy use, energy savings, and energy efficiency became the main topics of everyday conversation, and a search for a new path began. It should be further utilised. All interventions must be connected with energy awareness campaigns as a horizontal tool.

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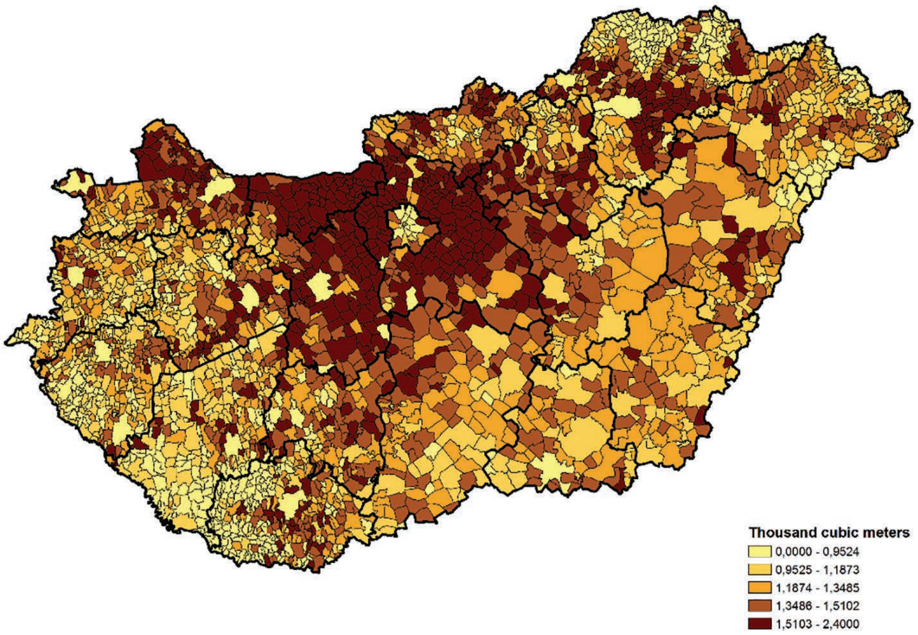
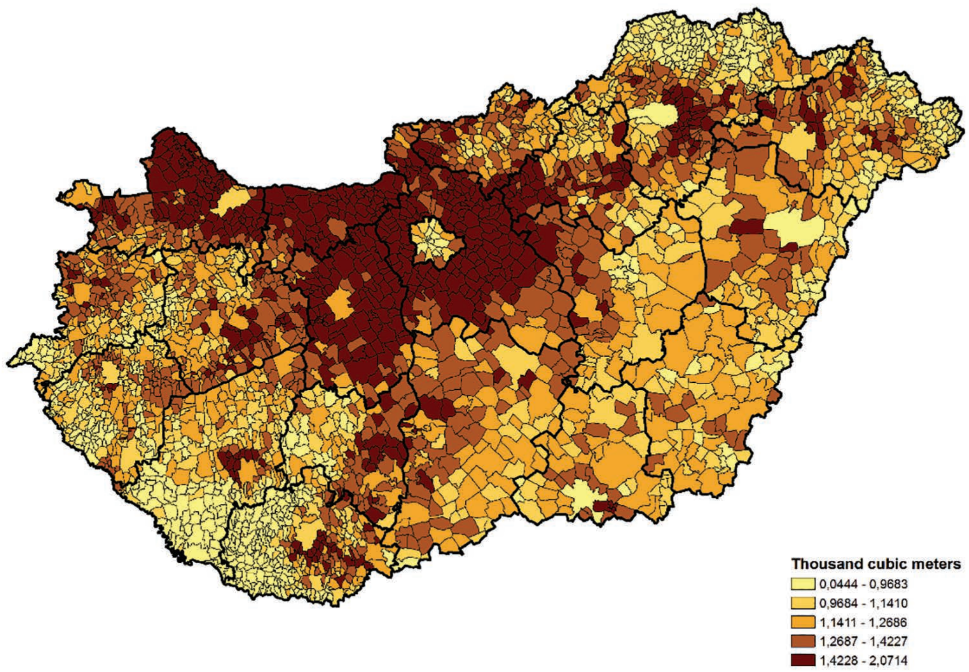
Appendices

Appendix 1: Gas Consumption per Consumer, 2021



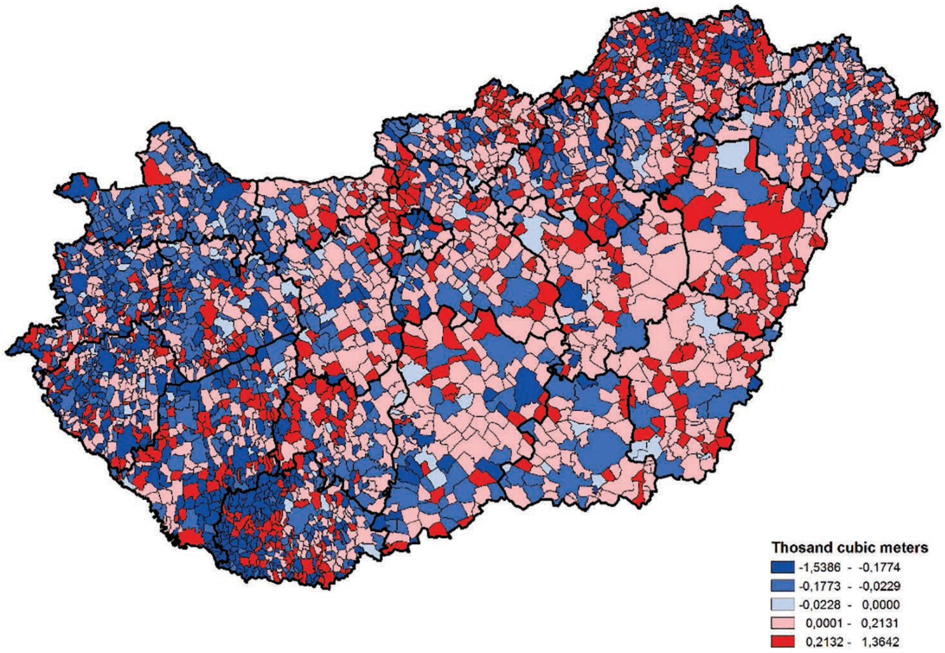
Source: Own compilation

Appendix 2: Results of the spatial (LAG) model estimating gas consumption, 2021



Source: Own compilation

Appendix 3: Residuals of the spatial (LAG) model estimating gas consumption, 2021



Source: Own compilation

Appendix 4: Model results

Regression

Summary of Output: Ordinary Least Squares Estimation

Dependent Variable:	GAS	Number of Observations:	3177
Mean dependent var:	1.17804	Number of Variables:	7
S.D. dependent var:	0.46546	Degrees of Freedom:	3170
R-squared:	0.287825	F-statistic:	213.525
Adjusted R-squared:	0.286477	Prob(F-statistic):	0
Sum squared residual:	490.195	Log likelihood:	–1539.24
Sigma-square:	0.154636	Akaike info criterion:	3092.47
S.E. of regression:	0.393237	Schwarz criterion:	3134.92
Sigma-square ML:	0.154295		
S.E of regression ML:	0.392804		

Variable	Coefficient	Std.Error	t-Statistic	Probability
CONSTANT	1.48142	0.0614358	24.1133	0.00000
a	0.00525117	0.000539279	9.7374	0.00000
b	0.0139404	0.0223135	0.62475	0.53223
c	–0.0143951	0.000786591	–18.3006	0.00000
d	–2.43136e-06	6.50394e-07	–3.7383	0.00019
e	0.00238177	0.000249726	9.53753	0.00000
f	–0.0100553	0.00119822	–8.39184	0.00000

Abbrevations:
- a: Share of three- and more-bedroom dwellings, %
- b: Dwellings built between 2011 and 2021 Dummy
- c: Share of people earning below HUF 1 million a year, %
- d: Population, person
- e: Share of dwellings with gas among dwellings built between 2012 and 2021, %
- f: Share of retired people, %

Regression Diagnostics

Multicollinearity Condition Number 23.112766

Test on Normality Of Errors

Test	Df	Value	Prob
Jarque-Bera	2	615.3103	0.00000

Diagnostics for Heteroskedasticity

Random Coefficients

Test	Df	Value	Prob
Breusch-Pagan test	6	512.8820	0.00000
Koenker-Bassett test	6	302.0849	0.00000

Diagnostics for Spatial Dependence

Test	Mi/Df	Value	Prob
Moran's I (error)	0.4175	39.3314	0.00000
Lagrange Multiplier (lag)	1	1567.7171	0.00000
Robust LM (lag)	1	120.0898	0.00000
Lagrange Multiplier (error)	1	1531.7451	0.00000
Robust LM (error)	1	84.1178	0.00000
Lagrange Multiplier (SARMA)	2	1651.8349	0.00000

End of Report

Summary of Output: Spatial Lag Model - Maximum Likelihood Estimation

Dependent Variable:	GAS	Number of Observations:	3177
Mean dependent var:	1.17804	Number of Variables:	8
S.D. dependent var:	0.46546	Degrees of Freedom:	3169
Lag coeff. (Rho):	0.64769		
R-squared:	0.558973	Log likelihood:	–923.115
Sq. Correlation:		Akaike info criterion:	1862.23
Sigma-square:	0.0955497	Schwarz criterion:	1910.74
S.E of regression:	0.309111		

Variable	**Coefficient**	**Std. Error**	**z-value**	**Probability**
W_gaz	0.64769	0.0154876	41.8199	0.00000
Constant	0.431158	0.0534554	8.06575	0.00000
a	0.00477533	0.000430694	11.0875	0.00000
b	–0.0077382	0.0175455	–0.441037	0.65919
c	–0.00684648	0.000651168	–10.5142	0.00000
d	–2.78041e-06	5.11341e-07	–5.43749	0.00000
e	0.00146876	0.000196563	7.47218	0.00000
f	–0.00498819	0.000951237	–5.2439	0.00000

Abbrevations:
- a: Share of three- and more-bedroom dwellings, %
- b: Dwellings built between 2011 and 2021 Dummy
- c: Share of people earning below HUF 1 million a year, %
- d: Population, person
- e: Share of dwellings with gas among dwellings built between 2012 and 2021, %
- f: Share of retired people, %

Regression Diagnostics

Diagnostics For Heteroskedasticity

Random Coefficients

Test	Df	Value	Prob
Breusch-Pagan Test	6	486.8162	0.00000

Diagnostics For Spatial Dependence

Spatial Lag Dependence For Weight Matrix : Alap

Test	Df	Value	Prob
Likelihood Ratio Test	1	1232.2420	0.00000

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