https://doi.org/10.55343/CogSust.50

Spatial analysis of the BEV market and the corresponding charging infrastructure in Hungary

Zsuzsanna Wengritzky
Babeș-Bolyai University
Romania
zsuzsanna.wengritzky@econ.ubbcluj.ro

Abstract

The adoption of fuel-efficient vehicles, especially battery electric vehicles (BEVs), is becoming an emerging priority on the global level. At first, it may seem that the major issue from the consumer side is the high price of BEVs that are not competitive with internal combustion (IC) vehicles. However, aspects like technological developments, battery safety measures, implemented safety features, design, range anxiety, charging infrastructure, environmental consciousness and sustainability also play a significant role in the decision-making process of BEV purchasing. This paper examines the connection between BEV registrations and Hungary's available public charging infrastructure. Data on the number of new BEV registrations, public charging stations and energy consumption from public charging are gathered for each county and region in Hungary. Until 2020, a division between the Eastern and Western parts of the country can be detected considering BEV adoption, but in 2021 this difference will diminish. Even though it can be seen from the raw data that the number of BEV registrations is growing faster than the number of available charging stations, existing stations prove to be properly located, covering regions that either have high BEV registrations or are part of transit paths with high traffic. Also, it is shown that BEV registrations grow proportionately higher in regions where more charging stations are available.

Keywords

battery electric vehicles, adoption, charging infrastructure, charging station location, Hungary

1. Introduction

Cognitive sustainability has become increasingly important in various fields, including transportation and technology. Considering the Hungarian battery electric automotive market, this paper aims to analyse the importance of cognitive mobility, specifically regarding the development of charging infrastructure and the degree of its utilisation in the country. Decision-making processes regarding transportation are highly dependent on several cognitive aspects that affect key areas of mobility, such as cognitive sustainability, vehicles and infrastructures (*Zöldy and Baranyi, 2023*). Elements of these areas related to e-mobility, such as charging infrastructure, safety features, new technology adoption, and environmental consciousness, highly influence purchasing decisions and adoption of battery electric vehicles (BEVs) (*Li et al., 2017*). More than that, one of the most important factors in BEV adoption is the development level of the charging infrastructure (*Eberle and von Helmolt, 2010*), which is related to cognitive mobility in several ways. Examples include optimal route planning decision-making, reducing range anxiety and providing a more comfortable driving experience. For instance, range anxiety is one key driver in EV adoption (*Noel et al., 2019, 2020*), which can be solved with better battery capacity providing higher range, but yet this comes with a large expense for consumers that lowers EV adoption (*Adepetu and Keshav, 2017*).

Also, recent research shows new engineering solutions for increasing battery lifetime and efficiency by altering the design parameters of IPM (permanent interior magnet) motors (*Horváth and Nyerges, 2023*); however, these techniques are still in the phase of development. Therefore, building a complex EV charging infrastructure equipped with fast chargers placed in the appropriate locations (*Pevec et al., 2019*) may be the solution to reduce range anxiety and benefit the adoption of BEVs in the present. For example, *Illman and Kluge (2020)* examine Germany's new EV registrations and public charging infrastructure. They conclude that the charging speed influences EV adoption even more than the number of charging stations. Besides the charging speed, the location of public chargers is of great importance too. *Lucas et al. (2018)* also analyse the EV market in Germany and observe that 50% of the energy supplied comes from less than 20% of the available charging stations, which suggests an inadequate allocation of the existing charging stations.

https://doi.org/10.55343/CogSust.50

The paper is structured as follows. Section 2 presents the data and methods used, and section 3 briefly presents the evolution of the electric automotive market and compares it with the evolution of the charging infrastructure in the country. Section 4 shows spatial correlations between counties and regions considering three variables: number of BEV registrations, the number of publicly available charging stations, and kWh of energy used from public charging in 2020 and 2021. Section 5 is dedicated to discussion, and concludes the article.

2. Data and Methods

This paper uses a combination of privately owned and publicly available data and focuses on the connections between BEV adoption and the complexity of the charging infrastructure in Hungary. One part of the data comes from the data collector company, DATAHOUSE, which gave private information on the number of new BEV registrations in Hungary from 2017 to 2021 and new BEV sales from 2014 to 2016. The second database used for quantifying the evolution of the charging infrastructure in Hungary is a public database provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev). This database provides data on the number of publicly available electric charging stations and the energy used from public charging (kWh) from 2016 to 2022. Lastly, data on the number of total passenger automotive vehicle stocks are collected from the Hungarian Central Statistical Office (KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html).

After examining the data using Descriptive statistics tools, a spatial representation of the analysed variables is performed in the GeoDa statistical software. Data is divided into counties and regions to find significant spatial correlations among them using tests like local neighbor match connectivity and Moorans' I performed on the new BEV registration data in 2020. Further, I searched for connections between the number of charging stations, the amount of energy (kWh) consumed at these stations, and the number of new BEV registrations in the different regions by analysing the years 2020 and 2021 and comparing the maps resulting from the representation of the mentioned variables.

3. The evolution of the number of BEV registrations and the public charging stations in Hungary

The electric automotive market is globally emerging, and Hungary is not an exception. Based on the new registration and sales data provided by the DATAHOUSE private data collector company, *Figure 1* represents the number of new BEV registrations yearly in Hungary from 2014 to 2021.

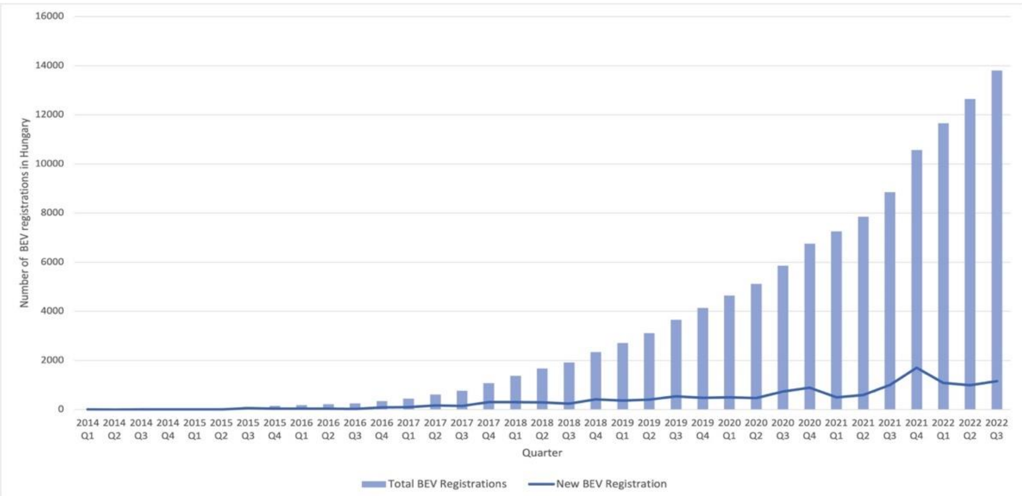

Figure 1. Number of registered BEVs in Hungary from 2014 to 2021.
(Source: Own data and compilation.)

The trend is increasing as the number of BEV registrations in the third quarter of 2022 is more than 30 times higher than in the first quarter of 2017. The minimum increase in BEV registrations is 7%, while the maximum is 120% from the second to the third quarter of 2015. Regarding the new quarterly BEV registration, there are periods of decrease, but the overall trend is increasing.

https://doi.org/10.55343/CogSust.50

One main factor influencing the purchase of BEVs is the availability of complex charging infrastructure. For instance, in Hungary in 2020, a total of 7.1 GWh of power was used from publicly available charging stations, an increase of 25% compared to the previous year (*MEKH, 2021*). We know from the data provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH) that the number of charging times in the country dropped significantly in the second and third quarters compared to the first quarter of 2020, both for the AC and DC charges. Similarly, the energy used for EV charging decreased in the mentioned quarters compared to the beginning of 2020. However, in 2020 the Covid-19 pandemic held back overall mobility, especially during severe lockdowns in the second quarter. However, the decrease in the next quarter's charging time is reasonable due to an increased share of home office work. Thus, it is probable that the increase of 25% in the energy used for EV charging would have been even higher without the pandemic. *Figure 2* shows the number of available charging stations in Hungary from 2016 to 2021. It is to be seen that both the number and type of charging stations grew remarkably, the number of charging stations being more than 100 times as high in 2021 compared to 2016 and 38 times higher compared to the end of the year 2017.

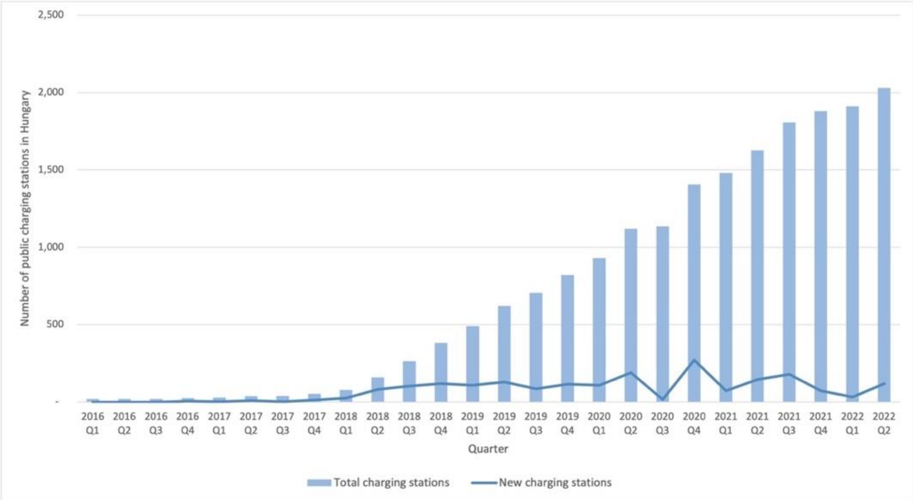

Figure 2. A number of electric vehicle charging stations in Hungary from 2013 to 2021 by type.
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation.)

Comparing the quarterly average growth rates, data shows that the average growth rate of BEVs, which is 25%, is three percentage points higher than the average growth rate of charging stations in the analysed period. Further, we can observe that the quarterly growth rate of public charging stations follows the growth rate of new BEV registrations with a time lag (*Figure 3*)[1]:

[1] Unfortunately, we do not have data on the number of charging stations between 2014 and 2016. However, the total number of charging stations in the first three quarters of 2016 was constantly equal to 20, and thus the growth rate in the previous period can be considered negligible.

https://doi.org/10.55343/CogSust.50

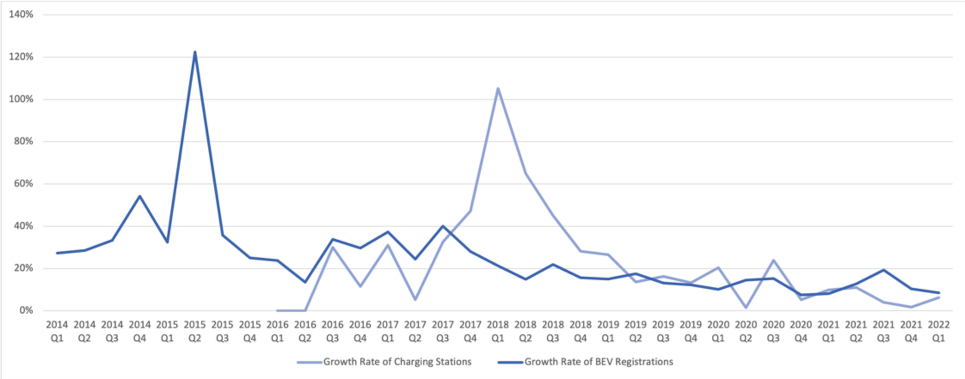

Figure 3. Quarterly growth rate of total BEV registrations and public charging stations in Hungary from 2014 to 2022.
(Source: own compilation.)

The highest growth rate of BEVs was witnessed in the third quarter of 2015 and was followed by a boom in the number of charging stations only three years later. That is an expected effect, as the government probably did not invest in public charging stations before the appearance of electric vehicles. After the boom periods, the variance of both rates decreases and keeps moving in the range of 0–22% quarterly growth. We can also observe that the growth rate of BEV registrations is followed by an increase in the public charging stations in the following quarters, which suggests that the number of stations adapts to the number of BEV registrations.

4. Spatial repartition of new BEV registration and the charging infrastructure

In this section, the number of BEV registrations, public charging stations and the consumed energy from charging (kWh) are analysed by dividing the country into regions and observing spatial connections between them according to the mentioned variables. Thus, besides the quantitative aspect of the charging infrastructure measured by the number of public charging stations, I implement a qualitative measure to show whether these stations are well-located in the country.

4.1 Spatial analysis of the total BEV registrations from 2014 to 2022

The BEV market in Hungary is a dynamically evolving sector. Here the territorial evolution of this market is analysed with a county-level resolution. Firstly, we can observe the number of total registered BEVs from January 2014 to June 2022 in each county (*Figure 4*). Note that the capital (Budapest) and the surrounding county (Pest) are outliers. This was expected, as Hungary is a relatively small country with a very high economic concentration around the capital.

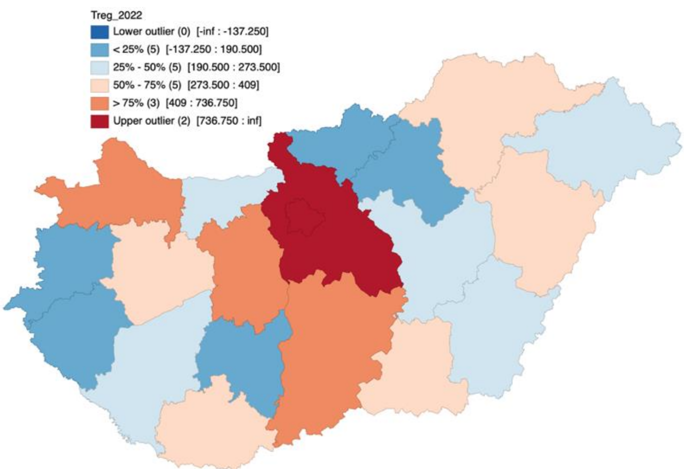

Figure 4. Total BEV registrations from January 2014 to June 2022 in Hungary by county.
(Source: Own data and compilation in GeoDa.)

https://doi.org/10.55343/CogSust.50

Further, note that the number of BEV registrations in the eastern part of the country is relatively low. This is also sustained by the result of Moran I's test (Moran's I = 0.324), where the contiguity weight is set to "Queen" of order 1, which defines neighbours by the existence of a common edge or vertex. We can observe on the LISA cluster map (*Figure 5*) that there is one county (Borsod-Abaúj-Zemplén) that has a significant positive (low-low) spatial association, showing that a low value of BEV registrations in this county is positively associated with the low values of the neighbouring counties.

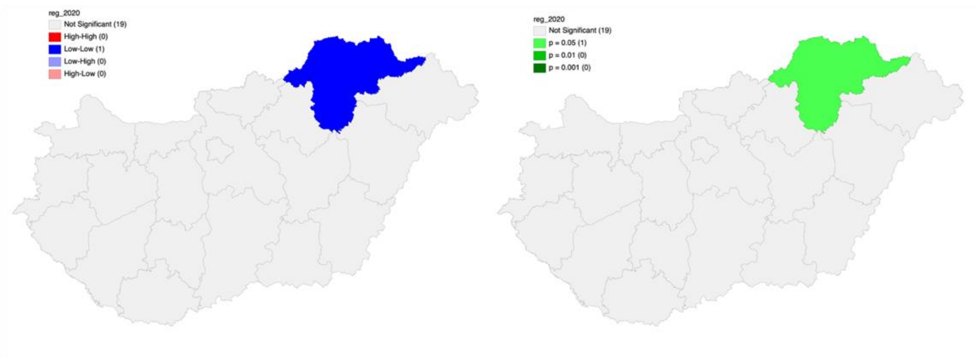

Figure 5. LISA Cluster Map and Significance Map for total BEV registrations from January 2014 to June 2022 in Hungary.
(Source: Own data and compilation in GeoDa.)

4.2 Spatial comparison of BEV registrations and the charging infrastructure in 2020

Due to the Covid-19 pandemic, 2020 was difficult, especially in the transportation sector. Still, the provided raw data shows that, except for the third quarter, new BEV registrations grew compared to the previous year (*Figure 1*). The repartition of new registrations by region this year is represented by the map on the left-hand side of *Figure 6*. As regions differ by size, population and density, the absolute values of BEV registrations are not the best when comparing EV adoption willingness across regions. Therefore, the map on the right side of *Figure 6* represents the number of new BEV registrations in 2020, divided by each region's total personal automotive vehicle stock. Thus, we get a value that expresses the per cent of new BEV registrations in 2020 compared to the total personal automotive vehicle stock in the specific region. When arranging the regions in four quantiles, we can observe that the lower values are in the Eastern, while the higher values are in the Western part of the country.

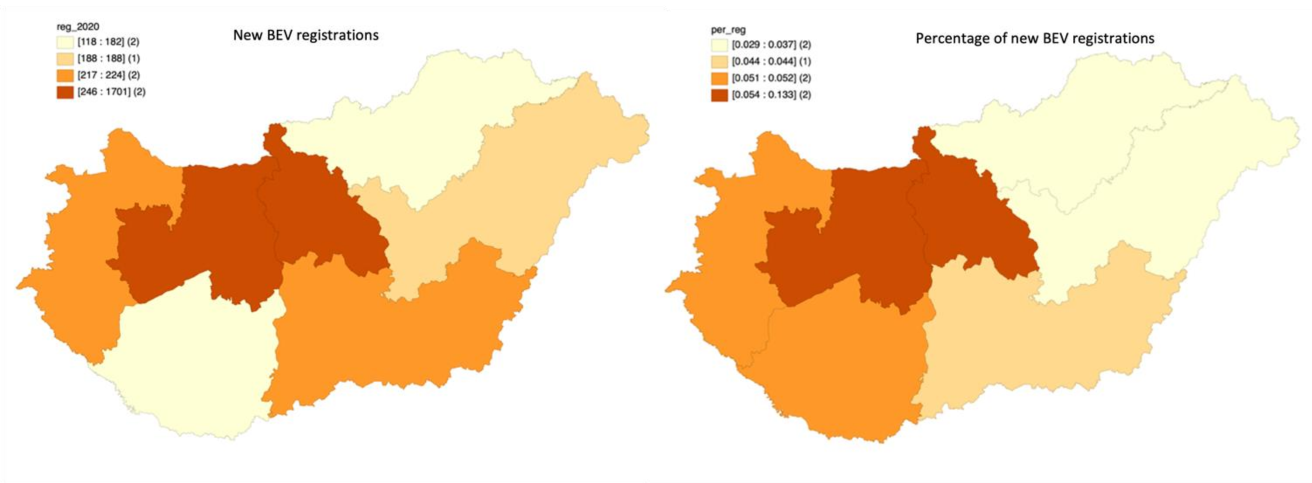

Figure 6. New BEV registrations and their ratio to the total personal automotive vehicle stock in Hungary in 2020 by region.
(Source: KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html, own data and compilation in GeoDa.)

https://doi.org/10.55343/CogSust.50

This means that relative to the overall usage of automotive vehicles, the ratio of newly registered BEVs is higher in the Western part of the country. I performed a local neighbour match test, suggested by *Anselin and Li (2020),* with two neighbours and Euclidean distances. The local neighbour match cardinality map shows that 6 out of 7 regions have at least one common neighbour with a connectivity link. However, not every connection is significant (Table 1):

Table 1 Local neighbour match cardinality and p-value

Region:	Card	CpVal
Southern Transdanubia	2	0.000
Western Transdanubia	2	0.000
Central Transdanubia	1	0.533
Central Hungary	1	0.533
Southern Great Plain	0	-
Northern Great Plain	2	0.000
Northern Hungary	1	0.5333

The map on the left side of *Figure 7* shows all matches, while the one on the right shows only significant connections. We can observe again that the Eastern part of the country is interconnected, with all regions having low values (*Figure 7*), while the western regions again have significant connections, all regions having high values (*Figure 7*). Central Hungary is the East-West divide region with extremely high values of new BEV registrations compared to the whole stock of personal automotive vehicles. This area has an insignificant connection to its western neighbour and no connection to other surrounding regions. This links back to the low-low spatial correlation found between the North-Eastern counties (*Figure 5*) that held for all BEV registrations in the country measured in absolute values.

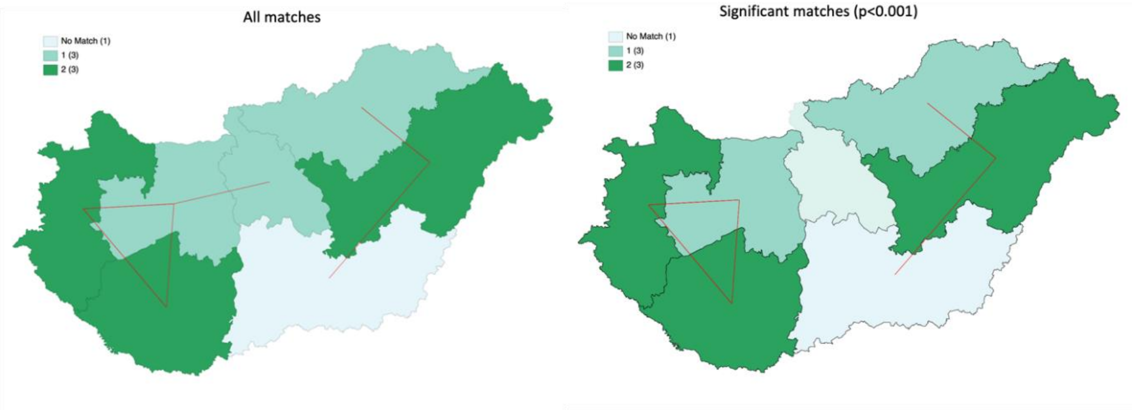

Figure 7. Local neighbour match connectivity and significant locations (p = 0.05).
(Source: KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html, own data and compilation in GeoDa.)

Figure 8 shows the number of public charging stations at the end of 2020. As expected, most public charging stations are located in Central Hungary. The most significant difference compared to the map representing the new BEV registrations (left side of *Figure 6*) is that even though in the Southern Great Plain the number of newly registered BEVs in 2020 was higher than in the Northern Great Plain, the number of charging stations is reversed.

https://doi.org/10.55343/CogSust.50

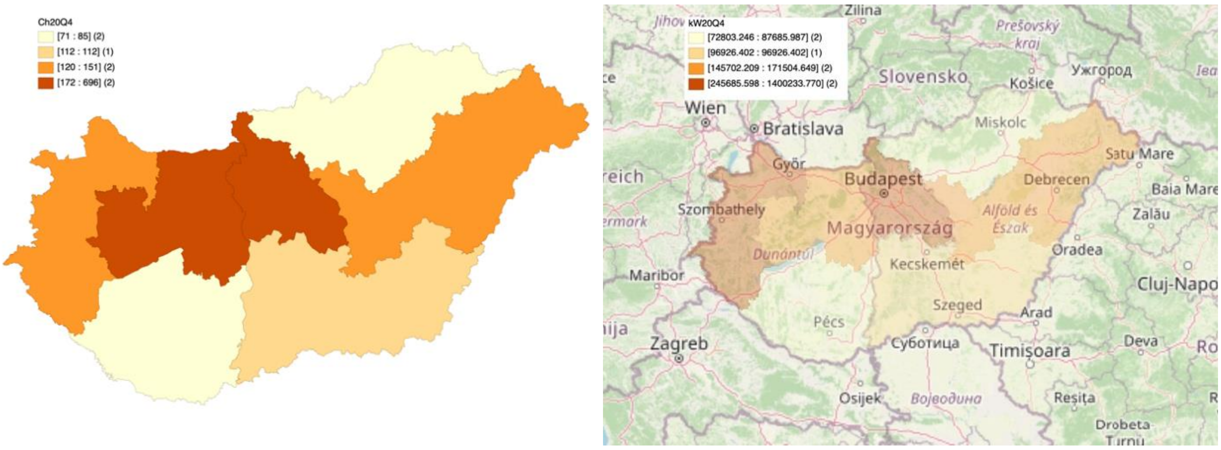

Figure 8. The total number of public charging stations located in Hungary in 2020.
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

One possible explanation is that the location of the charging stations was built near the highways for transiting vehicles that generated high traffic in the region. However, there are two major transit routes from Romania, one that crosses the border at the Northern Great Plain region and the other at the Southern Great Plain region (right side of *Figure 8*). Still, the number of charging stations is higher in the first one, probably due to the usual higher traffic of fuel-efficient vehicles. This assumption is sustained by the energy consumption value represented by *Figure 9*, in which we can also observe that the kWh consumption is higher in the Northern region. Of course, it is rational that EV owners charge their vehicles in places where chargers are available. However, if they were really badly located, the consumption would also be lower.

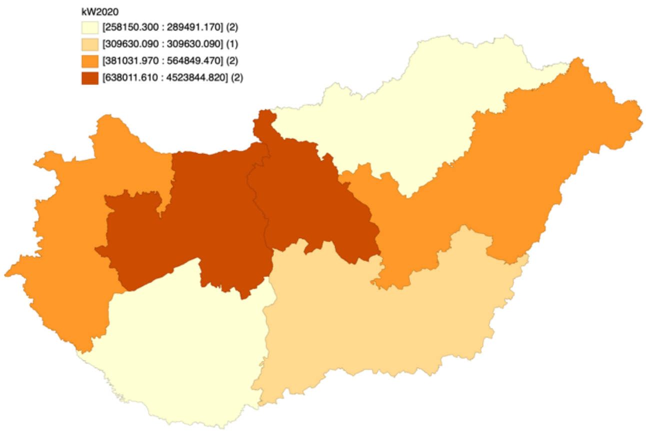

Figure 9. Total energy consumption at the public charging stations in Hungary in 2020 (kWh).
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

4.3. Spatial comparison of BEV registrations and charging infrastructure in 2021

Compared to 2020, in 2021, the difference between the Eastern and Western sides of the country is not that obvious. Analysing *Figure 10*, one can observe that in terms of absolute values, most BEV registrations were made in Northern Great Plain region after Central Hungary. More than that, even to the whole stock of personal automotive vehicles in the country, the ratio of new BEV registrations in this region is in the third quartile (*Figure 10*):

https://doi.org/10.55343/CogSust.50

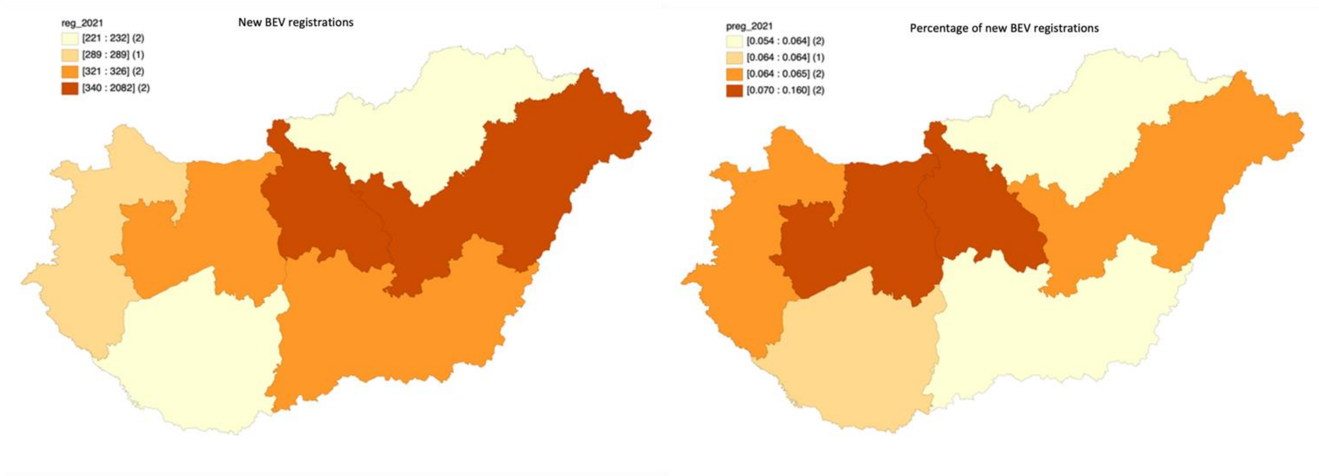

Figure 10. New BEV registrations and their ratio to the total personal automotive vehicle stock in Hungary in 2021 by region.
(Source: KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html, own data and compilation in GeoDa.)

Note that the mentioned region is where the number of charging stations in the previous year was relatively high compared to the number of new BEV registrations. Thus, registering the second highest number of BEVs within the regions can be due to the reduced range anxiety or positive marketing effects due to the visualisation of the high number of EV chargers on roads. More than that, the response to the lack of charging stations in the Southern Great Plain region came quickly, as by the end of 2021, it moved up from the second to the third quartile (*Figure 11*):

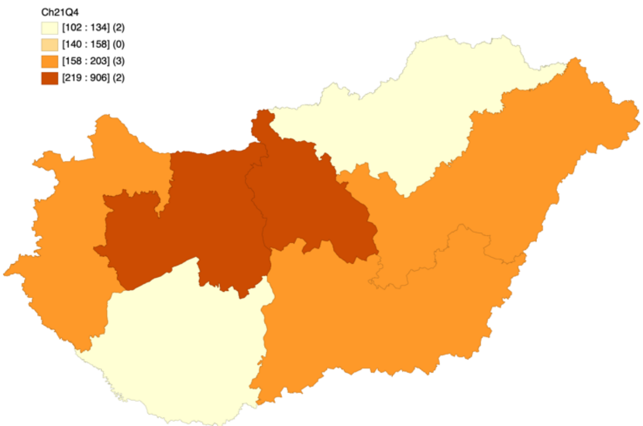

Figure 11. A total number of public charging stations located in Hungary in 2021.
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

With the growth in the number of public charging stations in the Southern region, the mentioned transit path connecting Hungary and Romania in the Southern Great Plain region became more frequented by EV drivers. This can be seen very well in Figure 12, as the energy consumption at the charging stations grew remarkably in the Southern region, probably because of the available high number of BEVs in the region and the growing number of charging stations on the transit lane.

https://doi.org/10.55343/CogSust.50

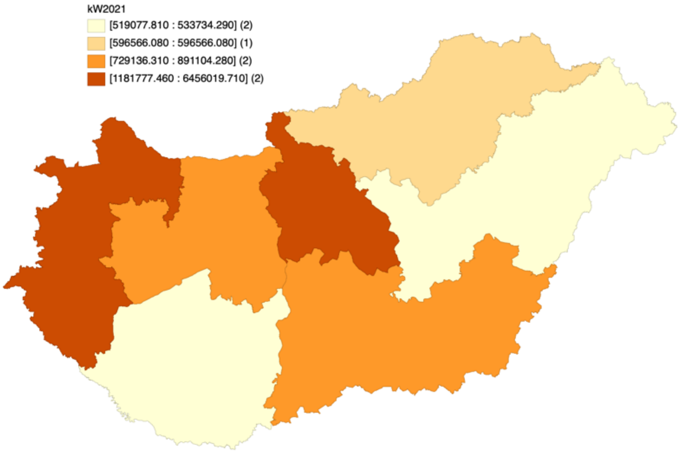

Figure 12. Total energy consumption at the public charging stations in Hungary in 2020 (kWh).
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

This result suggests that the location of the public charging stations influences the decision-making in optimal route planning and BEV purchasing.

5. Conclusion

It can be concluded that the Hungarian BEV market is fast-evolving in terms of new BEV registrations and the development of the charging infrastructure. Considering the absolute number of new BEV registrations in 2020, there was a significant low-low spatial correlation within counties in the North-Eastern part of the country. This suggests that in this region, the BEV adoption is slow-growing compared to other counties, which was expected as the overall development of the region is also lower. When considering the new BEV registration to the whole stock of personal automotive vehicles, a division of the country can be observed in the West and East. Significant connections can be found between Eastern and Western regions; however, the Central Hungarian region is not significantly connected to any sides, acting as a watershed between the East and the West. In 2021 this difference started to vanish as the new BEV registration on the Eastern side grew remarkably, probably due to the increase in public charging stations in this region.

Overall, the number of registered public charging stations follows the growth of BEV registrations. On the other hand, the average growth rate of BEVs is higher than that of public charging stations, with the quarterly average growth rate of BEVs being 25%, while this value for charging stations is 22%, showing the need for a faster developing charging infrastructure. Although the number of charging stations could grow faster, the location of the chargers is crucial: well-located stations provide optimal route planning for BEV owners. For instance, in the Southern Great Plain region, the energy consumption from public charging grew remarkably when the number of stations increased. Also, the number of public charging stations probably positively affected BEV adoption, as in the Northern Great Plain region, the high number of charging stations was followed in the next year with the increase in the number of BEV registrations in the second quartile. Future research providing a quantitative measure of the effect of the number of charging stations in 2020 on the number of BEV registrations in 2021 in the Southern Great Plain region could be useful in affirming this conclusion.

References

Adepetu, A., Keshav, S. (2017). The relative importance of price and driving range on electric vehicle adoption: Los Angeles case study. *Transportation*, 44, 353–373. DOI: https://doi.org/f9vhtc

Anselin, L., Li, X. (2020). Tobler's law in a multivariate world. *Geographical Analysis*, 52(4), 494–510. DOI: https://doi.org/ggw5xd

Eberle, U., von Helmolt, R. (2010). Sustainable transportation based on electric vehicle concepts: a brief overview. *Energy Environmental Science*, 3(6), 689–699. DOI: https://doi.org/c9dzx8

Horváth, P., Nyerges, Á. (2022). Design aspects for in-vehicle IPM motors for sustainable mobility. *Cognitive Sustainability*, 1(1). DOI: *https://doi.org/jm9m*

KSH – Hungarian Central Statistical Office. Road vehicle fleet by county and region, 31 December. URL: https://www.ksh.hu/stadat_files/sza/en/sza0040.html

https://doi.org/10.55343/CogSust.50

MEKH – Hungarian Energy and Public Utility Regulatory Authority (2021). Summary report on data collected by the Hungarian Energy and Public Utility Regulatory Office on electromobility. [in Hungarian: Összefoglaló jelentés a Magyar Energetikai és Közműszabályozási Hivatal elektromobilitás tárgyban gyűjtött adatairól]. URL: http://www.mekh.hu/download/3/0d/e0000/osszefoglalo_jelentes_mekh_elektromobilitas.pdf

MEKH – Hungarian Energy and Public Utility Regulatory Authority (2022). Report on electrical charging equipment subject to authorisation [in Hungarian: Beszámoló az engedélyköteles elektromos töltőberendezésekről – 2022. II. Negyedév]. URL: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev

Illmann, U., Kluge, J. (2020). Public charging infrastructure and the market diffusion of electric vehicles. *Transportation Research Part D: Transport and Environment*, 86, 102413. DOI: https://doi.org/j4n9

Li, W., Long, R., Chen, H., Geng, J. (2017). A review of factors influencing consumer intentions to adopt battery electric vehicles. *Renewable and Sustainable Energy Reviews*, 78, 318–328. DOI: https://doi.org/gbszqm

Lucas, A., Prettico, G., Flammini, M. G., Kotsakis, E., Fulli, G., Masera, M. (2018). Indicator-based methodology for assessing EV charging infrastructure using exploratory data analysis. *Energies*, 11(7), 1869. DOI: https://doi.org/gd66j9

Noel, L., de Rubens, G. Z., Sovacool, B. K., Kester, J. (2019). Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety. *Energy Research Social Science*, 48, 96–107. DOI: https://doi.org/j4pb

Noel, L., de Rubens, G. Z., Kester, J., Sovacool, B. K. (2020). Understanding the socio-technical nexus of Nordic electric vehicle (EV) barriers: A qualitative discussion of range, price, charging and knowledge. *Energy Policy*, 138, 111292. DOI: https://doi.org/gh5v7c

Pevec, D., Babic, J., Carvalho, A., Ghiassi-Farrokhfal, Y., Ketter, W., Podobnik, V. (2019, June). Electric vehicle range anxiety: An obstacle for the personal transportation (r) evolution?. *2019 4th International Conference on Smart and Sustainable Technologies (SPLITECH)*. IEEE. 1–8. DOI: https://doi.org/ghs7d3

Zöldy, M., Baranyi, P. (2023). The Cognitive Mobility Concept. Infocommunications Journal, 15(Special issue), 35–40. DOI: https://doi.org/j4pc