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TECHNOLOGICAL AND ECONOMIC ASPECTS OF ELECTRIC VEHICLE CHARGING IN HUNGARY

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Abstract: *One of the main barriers to the uptake of electric vehicles in Hungary is the infrastructure, which allows the transition to electric cars while maintaining the driving habits that have been established so far. The aim of this paper is to explore the technological and economic aspects of electric car charging, with a systematic review of the Hungarian and international literature, with a special focus on the Hungarian situation. The research compares the cost of charging electric vehicles with the fuel costs of conventional vehicles. Based on the results obtained, it will propose future research directions for strategic directions supporting sustainable transport, highlighting the role and future potential of solar systems.*

Keywords: *e-mobility, strategy, infrastructure, charging technologies, charging costs*

1. INTRODUCTION

At present, this infrastructure is still in its infancy in Hungary. Charging stations for electric cars are already available at many petrol stations, shopping centres and in the car parks of large retail chains and can be compared with home charging facilities [1]. However, the infrastructure available today the capacity of does not yet allow us to rely on traditional travel patterns when travelling by electric car [2].

The development of the necessary infrastructure will require significant investment and large-scale construction works to improve the backbone network. An alternative solution could be energy generated by local solar systems, which could be used to charge electric cars.

By creating communities with multi-stakeholder energy production systems, an economic, business community of interest can become a reality, in which actors can simultaneously act to implement the EU decarbonisation strategy [5] and achieve results that are partly investment stimulating and partly logistical cost reducing.

The aim of this article is to examine the current and future situation of the uptake of electric cars in terms of maintenance operating costs [11-14] and to propose a possible electromobility promotion strategy.

2. SYSTEMATIC LITERATURE SEARCH TO IDENTIFY THE SCIENTIFIC GAP

The methodology of a systematic literature review involves the search for relevant scientific publications on a given topic, their classification and analysis according to a set of criteria [41]. The aim of the literature review is to provide a transparent scientific presentation of the topic under study, while maintaining objectivity. A systematic literature search is a scientific investigation that requires prior planning and rigorous application of the method. The analysis includes the search for literature available in English and Hungarian [3]. The steps of the systematic literature search can be seen in Fig. 1.

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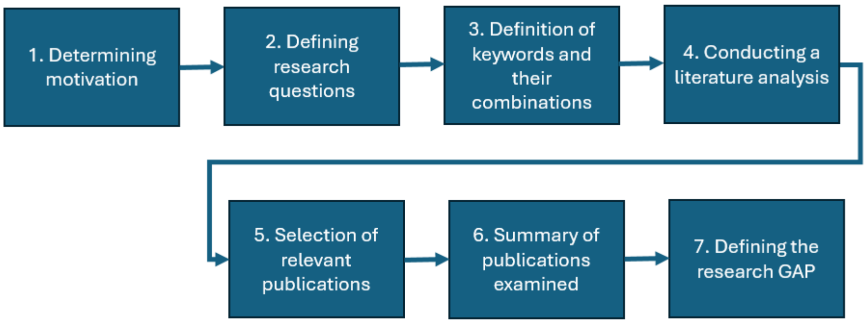

Figure 1. Steps to systematic literary research [own ed.]

Determining motivation

The aim of the current research is to identify new opportunities that are relevant for the development of energy communities and the promotion of electromobility, after analysing the relevant literature on electromobility and the costs of electric vehicle transport.

Defining research questions

What scientific research has been published in this area since 2020?
What research areas are relevant to this topic?
Which areas have not yet been scientifically investigated?
What changes might result from the research findings?

Definition of keywords and their combinations

The purpose of this section is to define the topics and the keywords within them, in English and in Hungarian. The relationships between scientific papers and keywords were examined. The keywords are:

"electro mobility " OR "strategy"
"infrastructure" OR "charging technologies"
"fuelling cost" OR "charging cost"

Keyword search combinations:

("electro mobility" OR "strategy")
("electro mobility" OR "strategy") AND ("infrastructure" OR "charging technologies")
("electro mobility" OR "strategy") AND ("infrastructure" OR "charging technologies") AND ("fuelling cost" OR "charging cost")

The two databases (Scopus and Google Scholar) used as the basis for the research were based on an analysis of the available literature. The analysis covers the period 2020-2025

Conduct a literature analysis

To carry out the literature analysis, we used the Scopus database, which is highly accepted in the international scientific community. Using the search functions of the Scopus database, we filtered articles by title, abstract and keywords simultaneously as shown in Fig. 2.

Using the search terms ("electro mobility" OR "strategy") AND ("infrastructure" OR "charging technologies") AND ("fuelling cost" OR "charging cost"), a total of 48 articles can be found between 2020 and 2025.

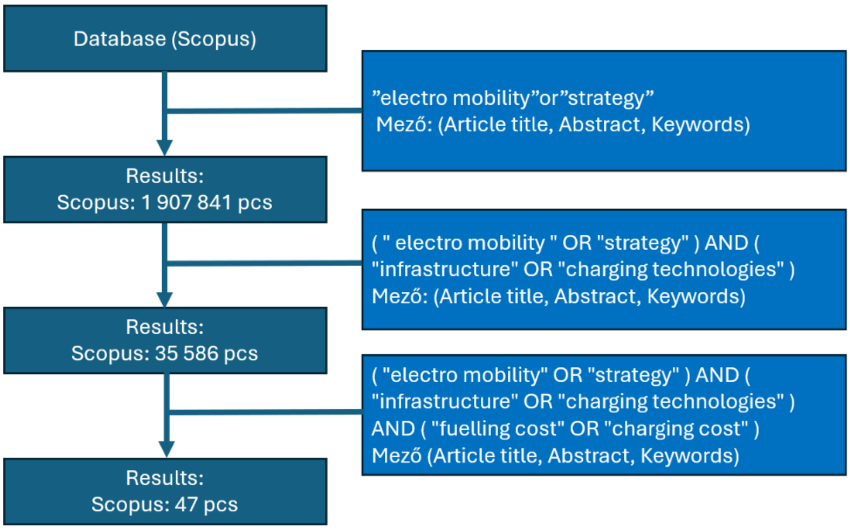

Figure 2. Literature analysis process [own ed.]

To ensure thoroughness, we also searched in Google Scholar and out of 6130 results, we searched the top 50 articles in google scholar based on relevance-based search, of which 10 relevant articles are summarized in the table.

In previous research, we have analysed several publications, including and we used [4] and [7] as contained relevant information on the topic under study.

Selection of relevant publications

The following inclusion and exclusion criteria were used to select the publications:

- Inclusion criteria:
  - year of release: 2020-2025,
  - the focus of the research was on charging technologies for electric vehicles, the costs or the impact of electromobility on the energy system,
  - the language of the publication is English or Hungarian,
  - contain data or conclusions relevant to charging infrastructure, costs or energy communities.
- Exclusion criteria:
  - short communications, conference summaries, which do not contain detailed methodological data,
  - works that have examined electric vehicles from a purely technical point of view, without looking at charging infrastructure or economic factors,
  - material from non-independent sources, such as market promotional material.

By applying the above criteria, we have ensured that we can only achieve the research objective based on scientific material containing relevant information on the topic.

Summary of publications examined

The results of the analysis of relevant publications in the search list according to the criteria defined earlier are summarised in Table I.

Table I.

Summary assessment of relevant data from the literature [own ed.]

Source citation	Technical solutions for electric chargers	Travel cost comparison	Energy sharing through energy communities	Geographical focus: Europe or Hungary	Solar car charger integration
[4]	No	No	No	Yes (Poland)	No
[7]	Yes	Yes	No	Yes	In part
[11]	Yes	No	No	No	No
[12]	No	Yes	No	Partly (Norway)	No
[13]	Yes	Yes	No	No (China)	No
[14]	Yes	No	No	No (China)	In part
[15]	Yes	No	No	No (India)	In part
[16]	Yes	Yes	No	No (USA)	No
[17]	Yes	No	No	No (India)	No
[18]	In part	No	Yes	No (New Zealand)	Yes
[19]	Yes	No	No	No (China)	No
[20]	Yes	No	No	No (Serbia)	Yes
[21]	In part	No	No	No (India, Canada)	No
[22]	Yes	In part	No	No (China)	No
[23]	Yes	No	No	No (India)	In part
[24]	Yes	Yes	No	No (India, UK)	No
[25]	In part	No	No	No (India)	Yes
[26]	Yes	No	No	Yes (Italy, Spain)	In part
[27]	In part	Yes	No	No (Canada)	No
[28]	No	Yes	No	Yes (Poland)	No
[29]	Yes	Yes	No	No (China, USA)	No
[30]	Yes	No	In part	Yes (EU, Croatia)	Yes
[31]	Yes	Yes	No	Not known	No
[32]	Yes	Yes	No	Not known	No
[33]	Yes	Yes	No	Not known	No
[34]	Yes	Yes	No	Not known	No
[35]	Yes	Yes	No	Not known	No
[36]	Yes	Yes	No	Not known	No
[37]	Yes	No	No	No (Indonesia)	No
[38]	Yes	Yes	No	Europe	Yes
[39]	No	No	Yes	Not known	In part
[40]	Yes	No	No	Czech Republic	Yes

After a content review of the publications, three main areas were summarised, namely:

1. The situation of electric vehicles in Europe and Hungary
2. Comparison of stitch types, filling and maintenance costs
3. Directions for action: the role of energy communities in e-mobility

3. The situation of electric vehicles in Europe and Hungary

During the research I analysed a number of articles on the current state of electromobility in the European Union, the EU. One of the key factors in achieving the objectives of the European Green Agreement [5] is the decarbonisation of transport.

The literature [4] examines the rate of uptake of electric cars in Poland. The study used the TRAMO-SEATS and ARIMA-X-12 time series analysis methods to analyse new and used registrations of electric vehicles.

To understand seasonal adjustment methods, it is worthwhile to refer to chapter 2 of the literature [6]: Thus, using the methods described above, the researchers examined both imported and domestically purchased versions of electric cars, assessing both seasonal variations and trends over time.

As a result of the research, it was found that the demand for electric vehicles has been steadily increasing, one of the main reasons being the government subsidy schemes and favourable tax parameters.

This study identifies infrastructure deficiencies as one of the barriers to the take-up of electromobility. There has been an increase in the number of chargers, but most public chargers are AC, while DC (fast) chargers are less common. These are discussed in more detail later in this article.

Although the study focuses on the growth of the share of electric vehicles in Poland, it also mentions that the development in the country in the last decade has lagged behind the development in Western European countries.

The study concludes that the development of electromobility in Poland shows a clear positive trend, while the expansion of the charging network and the increase in the share of renewable energy sources are high priorities for future decarbonisation success.

A similar trend is reported in the literature [38], which presents a comparison of charging costs for electric vehicles across European countries. Publication [7] predicts a 50% share of electric cars in passenger transport by 2040. Overall, it can therefore be concluded that a number of sources report an increase in the share of electric vehicles in many parts of the world and that, in general, this share is expected to continue to increase.

4. Classification of electric chargers

There are basically several types of electric car chargers. They can be divided into three main categories (Fig. 3).

AC chargers run on 230 V mains and charge your car in 6-12 hours. They come as standard equipment for most vehicles. Level 2 AC chargers (Type 2, IEC 62196-2 standard) are wall-mountable, faster and require professional installation. They can be used at home, at work, in public places and work without a solar system.

DC chargers are much faster, with power outputs of 50-350 kW. The two main types are CCS Combo 2 (European standard, widely used in new cars) and CHAdeMO (in older

Japanese models, on the decline). These charge the battery directly, bypassing the inverter, and can reach 80% charge in 15-45 minutes, mainly used in high-traffic areas.

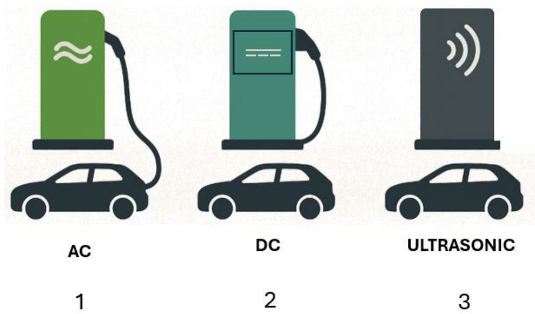

Figure 3. Electric car charger types [own ed.]

The **wireless ultrasonic DC chargers** are a new development, providing 80% charge in 10-12 minutes, with performance depending on battery size. For example, a Nissan Leaf is compatible with a 50-150 kW DC charger.

Table II.

Summary table of electric car chargers [own ed.]

Filler type	***Charging time***	***Power***	***Connected at***	***Installation site***	***Comment***
AC charger (basic)	6-12 hours	2-3 kW	230 V plug socket	At home, anywhere	Slow charging, low cost, mobile
AC charger (Type 2, Level 2)	3-6 hours	max. 7.4 kW (1 phase), max. 22 kW (3 phases)	Type 2 (IEC 62196-2)	Home, workplace, public places	Faster, fixed installation, specialist required
DC charger (general)	15-45 minutes (80%)	50-350 kW	CCS Combo 2, CHAdeMO	Motorways, shopping centres	Fast charging, serious licence and technical demand
Ultra fast DC charger	10-30 minutes (80%)	100-150 kW	CCS Combo 2	Speed sites, fleets	Recommended for large battery
Ultra-fast DC charger (top of the range)	15-20 minutes (80%)	Above 250 kW	CCS Combo 2	Mainly for Tesla, Porsche Tajkan	Fastest category, for advanced vehicles
Wireless DC charger	10-12 minutes (80%)	Variable, fast DC	Inductive (wireless)	Under development, new generation	Innovative, currently limited availability

5. CHARGING COSTS FOR ELECTRIC VEHICLES

One measure of the economics of electromobility is the cost of charging. If EVs are not cheaper to run than conventional vehicles, there is no justification for their purchase. Studies [1, 3, 7] analyse the charging costs and infrastructure of EVs. The EU target is for 50% of cars to be electric by 2040 [5]. Research [7] investigates three charging modes in Poland:

home, public AC and public DC charging. Vehicles analysed: Nissan Leaf, BMW i3, Renault Zoe, Tesla Model 3, Mercedes EQS.

The study compares EV charging costs with the fuel costs of conventional cars (at 2022 prices). The results are presented in Table III.

Table III.

Charging costs for electric car chargers [own ed.]

Filling mode / fuel	***Price (€/kWh)***	***Power***	***Comment***
Home charging (Poland)	0,16 €/kWh	~3,7 kW	Can be reduced by a separate tariff or solar panel
Public AC charger	0,28 €/kWh	3,7 - 22 kW	General public AC charger
Public DC charger (0-40 kW)	0,49 €/kWh	0-40 kW	Low-end DC fast charger
Public DC charger (40-150 kW)	0,54 €/kWh	40-150 kW	Higher category DC fast charger

Based on the 2024 data for Hungary, the charging costs of public AC, DC and DC chargers can be compared. Table V, based on the source [8] and the systematic analysis of the study [7], shows the average prices below:

- AC charging: average 225 Ft/kWh,
- DC charging: average 253 Ft/kWh,
- DC electricity charging: average 249 Ft/kWh.

These data allow an accurate comparison of charging costs by different types of chargers in Hungary in 2024 (Table IV.)

Table IV.

Analysis of charging costs of electric cars in Hungary [own ed.]

AC charger	Charging power	Filling fee min. [Ft/kWh]	Charge max [Ft/kWh]			
	Average dij	152	299	Average AC Charge	225	Ft/kWh

DC charger	Charging power	Filling fee min. [Ft/kWh]	Charge max [Ft/kWh]			
	Average dij	176	331	Average DC Charge	253	Ft/kWh

DC charger	Charging power	Filling fee min. [Ft/kWh]	Charge max [Ft/kWh]			
	Average dij	192	306	Shaft average DC Lightning charge	249	Ft/kWh

Averaged over these values, a comparative calculation can be made for the year 2024.

Table V.

Costs of refuelling / fuel for cars Poland 2022 - Hungary 2024 [Own ed.]

Electric vehicle	*Distance [km]*	*Consumption [kWh]*	*Energy price [€]*		*Energy price [Ft]*		*Cost [€/100 km]*		*Cost [Ft/100km]*	
			Poland	*Hungary*	*Poland*	*Hungary*	*Poland*	*Hungary*	*Poland*	*Hungary*
Home charging	100	15	0,16	0,09	64	36	2,4	1,4	960	540
Public AC charging	100	15	0,28	0,56	112	225	4,2	8,4	1680	3375
Public DC charging 0-40kW	100	15	0,49	0,63	196	253	7,35	9,5	2940	3795
Public DC charging 40-150 kW	100	15	0,54	0,62	216	249	8,1	9,3	3240	3735
Conventional car	*Distance [km]*	*Consumption [kWh]*	*Fuel price [€]*		*Fuel price [Ft]*		*Cost [€/100 km]*		*Cost [Ft/100km]*	
			Poland	*Hungary*	*Poland*	*Hungary*	*Poland*	*Hungary*	*Poland*	*Hungary*
Petrol-fuelled motor vehicle	100	6	1,42	1,52	568	608	8,52	9,1	3408	3648
Diesel vehicle	100	5	1,53	1,54	612	616	7,65	7,7	3060	3080

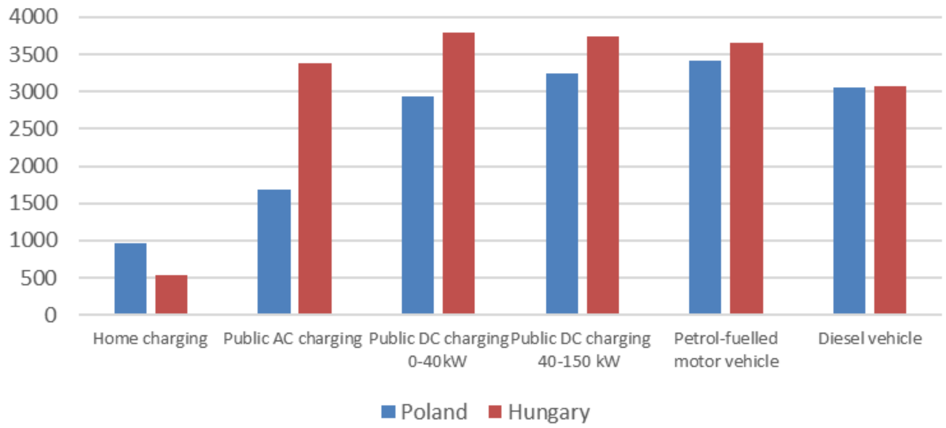

Figure 4. Cost of filling up (EUR) / fuel for cars Poland 2022 - Hungary 2024 [Own ed.]

In Fig. 4, we used the average cost of fuel in Hungary on data from the KSH website [9] but note that the website shows average monthly fuel prices for the year 2024 from April to December.

The tables show that in both Poland and Hungary, there is a significant cost advantage for electric vehicles in the cheapest charging mode at home. In Hungary, the discounted residential price of HUF 36/kWh rises to HUF 70.1 above 210 kWh per month, but it is still cheaper than fossil fuel. With fluctuating energy prices and fuel price rises, the integration of solar PV systems offers long-term cost reductions and energy independence.

6. DEFINING THE RESEARCH GAP

Solar PV systems and energy communities can provide a new alternative to existing infrastructure and development pathways to increase the pace of electromobility. Energy communities are a multi-stakeholder form of community that aim to coordinate the production, consumption and sharing of renewable energy. This could be a key factor in the future, both at residential and industrial level, from a functional, economic and environmental point of view.

The technologies available allow the creation of mixed energy communities based on local energy production, which can form the basis for sustainable transport, with the participation of both residential and industrial actors.

With the proliferation of solar PV systems and their combination with car chargers, new dimensions in both home and community environments are opening up, both in energy storage and charge control.

Possible future research directions:

- Optimising energy communities through real-time energy sharing and intelligent control.
- Modelling charging infrastructure and decentralised network solutions.
- Investigating the development of economically based, shared-interest charging points.

7. SUMMARY

In our paper we examined the situation, charging possibilities and costs of electric vehicles in Europe and in Hungary. Our analysis covered different types of charging and a comparison of maintenance costs. A new research direction was the relationship between energy communities and electromobility. The integration of energy communities is key not only from a technical but also from a social and economic point of view.

Our article shows that decentralised energy production offers an economical solution for the operation of electric vehicles. EU and national incentives to support the uptake of e-mobility are particularly important. It is worth further exploring the potential of energy sharing among economic and private actors. Linking energy communities and e-mobility is a future-shaping factor at technological and societal level.

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