Characteristics and factors of spatial differences in electric vehicle battery industry development among EU member states

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With the growing global focus on sustainable mobility, electric vehicles (EVs) have become the forefront of transport transformation, of which the battery industry is critical as a core link in the EV supply chain. The paper outlines the significant spatial differences among member states of the EU, in terms of production, supply chain, market consumption, preferences, research and development (R&D) and technological innovation in the development of the EV battery industry. Based on the research purpose of exploring the core factors of spatial differences, after using the global Moran's I index to diagnose the existence of spatial dependence, a spatial lag model was constructed and found that the ratio of direct employment in the automobile industry to manufacturing, natural gas supply, outward foreign direct investment stocks of China, corporate R&D expenditures, and private investment in the circular economy have a significant impact on the export value of battery products of EU member states. The partial effect of foreign direct investment (FDI) of China is weak, while the influence of private investment in the circular economy is suppressive. In order to promote the development of the EV battery industry in EU member states, this study argues that governments of EU member states need to promote venture capital investment to help increase R&D capacity, to optimize energy structure, and to reflect on the investment cooperation with China from its effect and influence path.

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factors,
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Introduction

With the severe situation of global climate change and the urgent need for emission reduction targets, the issue of carbon emissions in the transport sector has become increasingly prominent. As a mode of transport that can reduce carbon emissions and improve energy efficiency, electric vehicles (EVs), which can replace traditional internal combustion engine vehicles (Schreiber et al. 2023), are gradually attracting widespread attention and being actively promoted by governments, enterprises, and consumers around the world. Electrification that uses electrically powered equivalents to replace processes based on fossil fuels is expected to reshape the automobile industry (Szalavetz 2022). EV batteries are regarded as the core component of EVs, and their performance and cost not only directly affect the range, safety, and economy of EVs, but also directly relate to the popularity speed and market potential of EVs. Therefore, the healthy development of EV battery industry plays an important role in promoting the popularity and expansion of EV market.

As one of the global important economies, the EU has been actively promoting energy conservation, emission reduction and sustainable development goals, and has played a contributory role in advocating the development of new energy, environmental protection, scientific and technological innovation, and other fields. In the EV and its battery industry, the EU not only has a strong interest for further development, but also is trying to promote R&D capabilities on battery value chains. However, the degree of development of the EV battery industry in the member state is not consistent, and there are obvious differences in production capacity, technology level, market demand, policy support and other aspects. This spatial difference has not received sufficient attention and in-depth analysis.

This research aims to analyse the main reasons and internal mechanisms behind the spatial differences of the electric vehicle battery industry in the EU member states, and to put forward targeted policy recommendations and strategic directions through an in-depth exploration of the spatial differences of the industry. The study will focus on the following core issues: first, to describe and analyse the spatial distribution and development situation of the EU EV battery industry; second, to explore the main influencing factors behind the spatial differences of the industry, such as the policy environment, market demand, scientific and technological innovation capacity, and industry chain synergies; and third, to put forward strategies and measures to promote the synergistic development of EV battery industry.

The rationale of the study of spatial differences in the EV battery industry among EU member states is significant. EU member states have common interests and synergistic potential in the development of the EV battery industry, and a deeper understanding of the differences among them can help promote more effective allocation of resources, strengthen the synergy effect of the industrial chain, improve the overall global competitiveness of the EU, and provide new perspectives and paths for the global response to the challenges of climate change and the realization of sustainable development.

The article is organized as follows: it begins with a literature review, followed by a characterization of EV battery industry in the EU member states, the research design, and the empirical analysis and discussion. The article ends with a conclusion including policy recommendations, research limitations and future directions.

Literature review

The EV battery industry is an interdisciplinary field of study involving disciplines such as economics, engineering, and environmental science. Scholarly research on this topic has increased with the rapid development of EVs. International Energy Agency (2023a) reports that the sales of EVs continue to increase in the past year although the disruption of supply chain, especially in major markets such as Europe, China, and the United States, which is further fuelled by government policy support and increased consumer demand for clean energy.

Based on the history of the traction battery industry, Placke et al. (2017) analyse the advantages and disadvantages of traction batteries in various scenarios. As viewed from the perspective of start-ups, Sick et al. (2018) examine the development of the lithium-ion battery industry's value chain. They find that start-ups are limited in their ability to transfer technology and that their market opportunities are concentrated at the upper reaches of the battery value chain. The lack of adequate core technology, the low profitability of corporations, and the difficulty of recycling batteries pose challenges to the industry. Moreover, Sick et al. (2018) discuss the current situation and future trends of the new energy vehicle battery industry in terms of key resources, market development and traction battery cost and performance.

A number of scholars have also emphasized the importance of policy guidance in developing the battery market for new energy vehicles. For example, Melin et al. (2021) suggest that EU regulations intended to improve transparency and traceability throughout the battery life cycle could lead to an increase in the capacity of batteries to be produced sustainably. Based on an electricity trading market perspective, Martins–Miles (2021) assess the feasibility and profitability of deploying battery technology in the UK electricity market, highlighting the policy role in terms of institutional reform, battery costs, and volatility of electricity prices. The innovation of traction batteries and recycling is also influenced by different policies (Joshi et al. 2021, Wang et al. 2021).

Battery technology has also made significant progress in recent years, with the energy density of lithium-ion batteries increasing by nearly 70% over the past five years (Deshwal et al. 2022), while emerging technologies such as solid-state batteries and hydrogen fuel cells are also making breakthroughs (Schmuch et al. 2018). In addition, the significant decline in the cost of batteries has been one of the key drivers of the market growth (Bajolle et al. 2022), with the average cost of battery packs declining by 85% between 2009 and 2019 (Nykvist–Nilsson 2015). The geographical distribution of the global battery industry is also changing, gradually shifting from market dominance in Asia to Europe and North America, and governments have developed several strategic plans to promote the growth of the local battery industry (Lutsey–Nicholas 2019). Yet, despite the promising future of the global electric vehicle battery industry, there are many challenges that need to be addressed, such as the complexity of the raw material supply chain, the environmental impact of the battery production process, and battery recycling and secondary utilization (Lai et al. 2022).

EV market is expanding rapidly in Europe, fuelling growth in battery demand. According to International Energy Agency (2023b), the sales of EVs in the EU reached 2.7 million in 2022, a 17.39% increase from 2021. Countries such as Germany and France have already made achievements in battery production, R&D and have built battery production facilities in cooperation with several major global battery suppliers (Figenbaum 2017). The EU has introduced a series of policies and plans to promote the development of the EV battery industry, and to focus on the life cycle management and environmental impact of batteries, emphasizing the importance of sustainability. For example, the European Commission promoted the creation of the European Battery Alliance (EBA) by investing 1 billion EUR to enhance Europe's competitiveness in the global battery market (EC 2019). However, there are also researchers arguing that despite the positive progress in terms of market, technology, and policy, the EU still faces challenges, such as access to raw materials and supply chain management, recycling and reutilization of batteries, and competition with the major global battery producing countries, such as China and South Korea (Balali–Stegen 2021).

Current research on the development of the EV battery industry is becoming increasingly diverse. On the one hand, the focus of research is primarily on a single technical aspect, such as the improvement of battery performance and the application of new materials, but rarely is there any comprehensive consideration of the upstream, midstream, and downstream aspects of the development of the industry from the perspective of the industry chain, as well as a comprehensive analysis of the dynamic development of the EV battery industry. On the other hand, the existing studies, however, tend to concentrate on a single country's case study and do not provide a comparative analysis across regions. It is necessary to examine the development differences between different countries from a regional perspective so that development strategies can be better formulated to promote the development of the new energy battery industry. The EU, as the world's largest regional economic bloc, is also pursuing a strategic course in promoting the transition to electrification in the automotive sector. Increasingly stringent policies within the bloc contribute both to the sustainability of their member countries' economic development and climate change, while also serving as a valuable reference for other nations.

Spatial differences in the EV battery industry

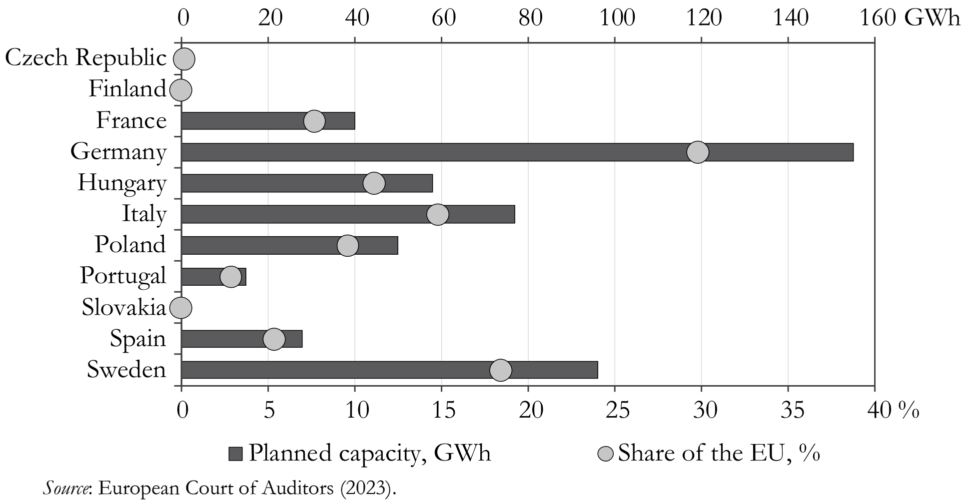
Spatial differences in the EV battery industry among EU member states are reflected in several facets, including production, consumption, R&D, government support and market access, due to the differences in economic, technological, policy and social factors across member countries.

Production capacity discrepancies

In terms of production scale, countries such as Hungary, Poland, and Sweden have become major producers of EV batteries in 2022. For example, Hungary's production of EV batteries reaches 38 GWh in 2022, accounting for 53.52% of the EU's total production. Sweden and Poland follow with output of 16GWh and 15GWh respectively. In contrast, other countries are lagging behind in battery production, with smaller production scales. Driven by factors such as policy support, growing market demand, large-scale investment and cooperation, EU's EV battery production will grow from 71GWh in 2022 to 520GWh in 2025, with an average annual growth rate of 93.3%. As shown in Figure 1, by then, Germany, Sweden, Italy, and Hungary will be the largest battery manufacturers in the EU, with the battery supply in the four countries accounting for 74.23% of the entire region. Central and Eastern European countries, especially the V4 (Visegrád Group), consistently supply to 20.96% of the production scale (European Court of Auditors 2023).

Figure 1

Planned battery production capacity per member state in 2025



Source: European Court of Auditors (2023).

Supply chain discrepancies

The battery industry chain involves a series of links from raw material extraction, processing, battery production, use and recycling. Raw materials such as lithium, nickel, cobalt, manganese and graphite are not only the basis for battery energy storage and output, determining key properties such as battery capacity, charge/discharge rate, stability and lifetime, but their price and availability directly affect the production cost of the battery (Helbig et al. 2018). With regard to the supply of raw materials, there are differences within the EU, with some countries having abundant raw materials, such as Finland and Sweden, which are rich in nickel and cobalt (EC 2021), helping support local battery production. Others rely mainly on the international market for supply and recycling. For example, Spain relies heavily on the international market for lithium supply (US Geological Survey 2020).

Table 1

Number of firms headquartered in battery supply chain per member state

Country	Raw materials	Battery packs	Active materials	Cell manufacturing	Application	Recycling
Austria	0	5	2	4	5	2
Belgium	3	5	7	7	6	8
Bulgaria	1	2	1	1	1	2
Croatia	0	1	0	0	2	0
Cyprus	0	1	0	0	1	0
Czechia	2	4	1	4	4	1
Denmark	1	0	1	0	2	0
Estonia	1	0	0	0	0	0
Finland	10	9	3	6	8	6
France	8	18	12	15	11	7
Germany	12	38	32	37	45	26
Greece	0	0	0	0	1	0
Hungary	3	5	2	2	4	5
Ireland	2	2	2	1	1	2
Italy	1	8	5	9	11	3
Latvia	0	0	0	0	0	0
Lithuania	0	1	0	0	1	1
Luxembourg	0	0	2	0	0	0
Malta	0	0	0	0	0	0
Netherlands	0	0	1	0	0	0
Poland	1	1	3	0	5	3
Portugal	2	0	1	0	3	1
Romania	0	1	0	1	1	1
Slovakia	0	3	0	0	4	2
Slovenia	0	1	1	0	0	1
Spain	2	10	7	9	18	8
Sweden	3	5	7	5	11	7

Source: own construction based on European Battery Alliance 250 network.

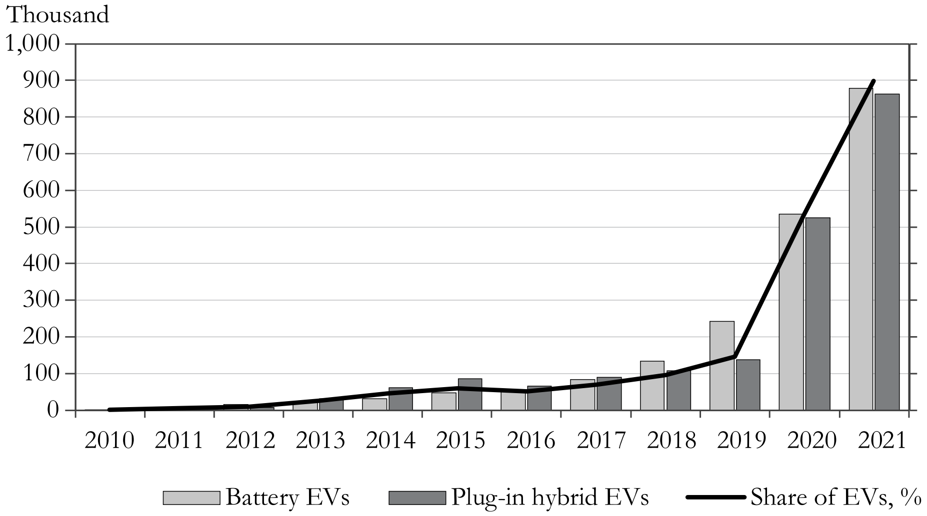
In terms of supply chain integration, 11 out of 27 EU member states have established a complete domestic supply chain for battery production, as shown in Table 2. With reference to geographical distribution, they are Nordic countries of Finland and Sweden, Western European countries of Belgium, France, Germany, Ireland, Italy, and Spain, along with Hungary, Czechia and Bulgaria in Central and Eastern Europe (CEE). The largest number of companies are engaged in the EV battery industry and are headquartered in Germany and France. The others specialize only in specific parts of the supply chain, such as battery packs in Slovakia, active material supply, application, and recycling operations in Poland.

Market consumption and preference differences

Differences in the development of the EV battery industry are also reflected in the number of EVs sold. Statistics published by the European Environment Agency (EEA [2022]) show that the EV market in the EU has been steadily increasing the number of new EV registrations per year since 2010, from 600 units in 2010 to 1.7 million newly registered EVs in 2021, accounting for 18% of the total new registrations, as shown in Figure 2.

Figure 2

Total new registrations of EVs in EU27



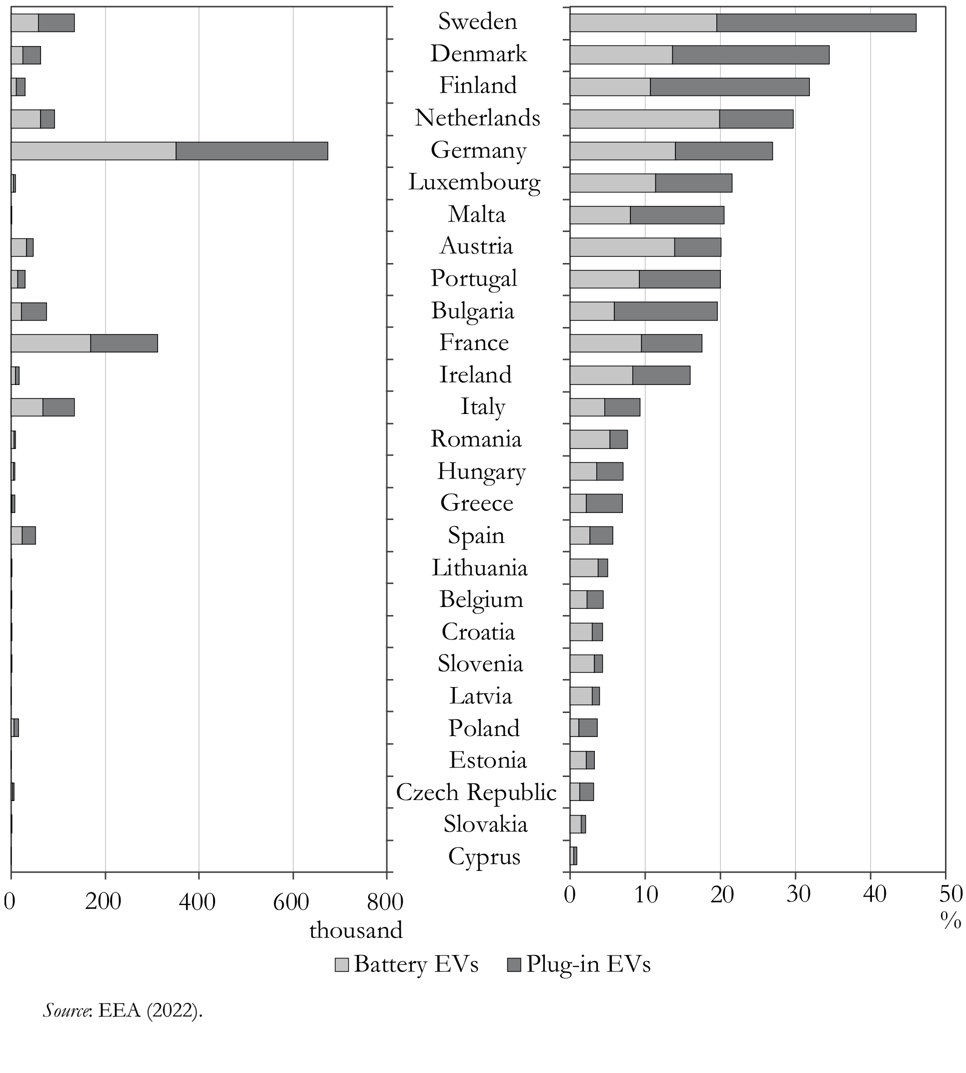
Source: EEA (2022).

However, the differences of the newly registered EVs among EU member states are significant. The Nordic countries are leading the way in EV consumption. In 2021, Sweden, Denmark and Finland have a larger market share of EVs than any other EU member state, with shares of 46%, 34.5% and 31.8% respectively. Comparatively, several CEE countries have a smaller market share of EVs. For example, in the same year, Cyprus, Slovakia, and Czechia sold relatively few EVs, with shares of 0.8%, 2.1%, and 3.2%, respectively (EEA 2022).

In terms of the number of newly registered EVs in 2021, Germany, France and Italy have the largest sales markets, with 0.67 million, 0.31 million and 0.13 million units respectively (see Figure 3). In terms of EV types, consumers in the Nordic countries prefer plug-in EVs, while other countries have a good mix of plug-in EVs and battery EVs.

Figure 3

Number and percentage of newly registered EVs by country in 2021



Source: EEA (2022).

In addition, the differences in consumption between luxury and economy vehicles coexist in the EV market. Several EU countries, notably Germany, France, and Italy, have become major markets for luxury EVs. German automakers, such as BMW, Audi, and Mercedes-Benz, have introduced several luxury EVs that are sold globally (European Automobile Manufacturers Association 2020). Tesla has also captured a significant share in many European markets, with premium models such as its Model S and Model X being popular (BloombergNEF 2023). Meanwhile, some Southern and Eastern European countries prefer budget electric vehicles. For example, the Renault ZOE is performing well in countries such as Spain and Portugal, where these models offer consumers a relatively reasonably priced EV option (Renault Group 2023). Brands such as Škoda in the Czech Republic and Slovakia and Dacia in Romania have also introduced affordable EVs (Škoda Auto 2020).

R&D and technological innovation differences

Germany is a world leader in EV battery technology, and the German government has invested a large amount of money to support battery R&D, such as the *National Electromobility Development Plan*, which plans to invest 3 billion euros in research on high energy density batteries and charging technology (German Federal Ministry of Economic Affairs and Energy 2009). The country's industrial giants such as Volkswagen, Daimler, BMW, and several other automotive groups are also actively involved in the innovation of battery technology, and work closely with academia to promote the rapid transformation of technology. While the French battery industry is also characterized by close collaboration between the government, big companies, and academia, such as the collaborative project between Renault and the French National Research Centre (CNRS) to improve battery reliability and lifetime (Lebrouhi et al. 2022), the industrial focus of the country is on reducing the cost and improving the efficiency of EV batteries. In Italy, the research on EV battery technology is relatively decentralized, including multiple directions such as improving energy density, reducing cost, and improving safety. Companies such as Fiat Chrysler are also actively exploring new battery technologies to meet the needs of different markets (Stellantis 2020).

Countries such as the Netherlands, Sweden and Norway focus on environmental protection and sustainability in battery technology development. The Dutch government has supported a number of battery R&D projects centered on the circular economy (Kalmykova et al. 2018). The Scandinavian countries, on the other hand, are jointly working on battery technology through the Nordic Electric Vehicle Initiative, focusing on sustainable access to raw materials and battery recycling (Nordic Energy Research 2018). The CEE countries, on the other hand, are lagging behind in R&D in the EV battery industry and are relying mainly on attracting foreign direct investment (FDI) and strengthening co-operation with and following Western European countries. However, the governments of these countries have the intention to develop the battery industry and are actively seeking opportunities to co-operate with large enterprises in order to enhance their R&D capabilities. For example, the Hungarian government (2022) regards it as a national strategy.

Research design

Research method and model construction

As a political and economic alliance, although the EU is committed to narrowing regional development gaps, there is still a huge heterogeneity in territorial capital across European space (Tóth 2023), and the differences in EV distribution between countries remain distinct (Shao–Mišić 2023). Electrification is reshaping the value chain of the automotive industry. The development of the battery industry, which is the core component of EV vehicles, will help alleviate the economic development gap among member countries. However, the problem of uneven distribution of production factors in the battery industry still exists. The development of the EV battery industry is not only limited by socioeconomic factors, but may also be affected by spatial interaction. Geographical location has an important impact on the development and competitiveness of the industry. The development of the battery industry, such as supply chain, raw material procurement, production facilities, etc., may be affected by interactions between countries that are geographically close, which involves spatial dependence. Besides, government policies and support measures for industrial development vary in geographical distribution, and policies in different countries or regions may have different impacts on the development of the battery industry. Due to the ordinary least squares (OLS) regression models cannot handle spatial dependence well, this article chooses to build a spatial econometric model to explore the factors influencing the development differences of the EV battery industry among EU member states.

Spatial econometrics argues that spatial correlation is ubiquitous. The first law of geography states that 'Everything is related to everything else, but near things are more related than distant things' (Tobler 1970). The prime task of conducting spatial econometric analysis is to establish a spatial weight matrix to measure the spatial correlation of economic variables. Common weight matrices are divided into based on contiguity, geographical distance matrix and economic distance. Considering the development of modern transportation industry and the differences in economic growth among countries, this paper selects the rook contiguity weight matrix to maintain its exogeneity. The weight matrix is as follows:

$$W_{ij} = \begin{cases} 1, \ when\ country\ i\ and\ country\ j\ are\ adjacent, \\ 0, \ when\ country\ i\ and\ country\ j\ are\ not\ adjacent. \end{cases} \quad (1)$$

In addition, in order to avoid mathematical problems such as matrix irreversibility and eigenvalue instability that affect the estimation and interpretation of the model, the paper row-standardized the spatial weight matrix to smooth the spatial spillover effects of different individuals to the average value of all research objects. The matrix W in the following part is the row-standardized one, where:

$$W = \frac{w_{ij}}{\sum_j w_{ij}} \tag{2}$$

For countries with neighbours, the sum of the elements in each row after row standardization is 1. For those without neighbours, both the elements and the sum are 0.

Hence, the spatial econometric model constructed in this article is:

$$Y = \rho WY + \beta X + \theta WX + \mu \tag{3}$$

$$\mu = \lambda W\mu + \varepsilon, \varepsilon \sim N\,[0, \sigma^2 I] \tag{4}$$

where, Y represents the dependent variable; X represents all independent variables; W represents the n×n–dimensional spatial contiguity weight matrix; β represents the correlation coefficient of X; ϱ and θ represent the spatial correlation coefficient; λ represents the spatial error coefficient; μ and ε represent random errors, and ε follows a normal distribution, while I is an n×n–dimensional unit matrix. When ϱ≠0, θ=0 and λ=0, it is consistent with the spatial autoregressive model (SAR), which is also knows as spatial lag model (SLM); when ϱ=0, θ=0 and λ≠0, it is consistent with the spatial error model (SEM); when ϱ≠0, θ≠0 and λ=0, it conforms to the spatial Durbin model (SDM). Subsequently, the model form is specifically selected based on the test and significance results.

Variable selection and data sources

For the dependent variable, this study uses battery products export value (bpev), which are categorized as the HS8506 and HS8507 product groups based on the Eurostat's Comext data, as a proxy variable to measure the development of the EV battery industry. Such the substitution is not the best indicator and might cause some estimation bias, while is an alternative in the absence of data on the EV battery production in many EU member states and it is reasonable in some cases. First of all, the export value of battery products can partially reflect the scale of a country's battery industry, for which larger industries usually produce more products for export, which reflects a certain level of industrial development. Secondly, high battery product exports may indicate that a country's battery industry is competitive in the international market, which may be related to the industry's innovation capabilities, product quality, and market share. Éltető (2023) also argues that the Hungarian government uses battery product export values as an indicator as a strategic reason when attracting foreign investment to build new battery factories in the country and enhance the competitiveness of the country's battery industry, pointing out that Hungary's battery supply will meet 35% of the European market demand.

There are five independent variables in the model as the following:

The first predictor variable is share of direct automotive employment in manufacturing industry (sodae). Direct employment in the automotive industry has a significant impact both on the development of a country's EV and EV battery industry. As the EV market grows, battery demand is rising rapidly, which is driving the expansion of the EV battery industry. The growth of the battery industry requires a large number of workers, including battery manufacturing, materials R&D, production line operations and other fields. The increase in employment in the automotive industry can provide a stable labour force for the battery industry and promote its development. Wen et al. (2021) analyse the impact of Covid-19 on China's electric vehicle market and also point out that the automobile industry is labour-intensive and relies heavily on labour. Restrictive measures during the epidemic have led to a reduction in labour supply, causing a sharp decline in China's battery car production. In addition, destroyed by the electrification revolution, the employment originally engaged in internal combustion engine manufacturing can also supply labour force for the EV battery industry.

The second is total natural gas supply (ngs). Natural gas supply may also have an important impact on the development of a country's EV battery industry. Natural gas is commonly used for power generation and industrial production, and EV battery manufacturing requires large amounts of electricity. In addition, natural gas is considered a cleaner energy source, and its use reduces greenhouse gas emissions compared with traditional fuel oil (IEA 2019). This is in line with the sustainability goals of the EV battery industry. Sufficient natural gas supply can ensure stable power supply and help support the production of the EV battery industry. also argue that battery production is an energy-intensive process. They estimate that an average of 41.5 kWh of energy cell capacity is required to produce 1 kWh of EV battery output, with natural gas and electricity each accounting for about half of the demand. However, electricity is used as a derivative to generate other energy products, and its original form is credited to the transformation output (Eurostat 2023). To avoid double counting, only the total natural gas supply is taken into consideration.

The third is outward FDI stocks of China in EU member country (odicn). There are different views on the outward FDI of China in the EU, especially in the Central and Eastern Europe (CEE) region. On the one hand, some scholars believe that Chinese investment has a positive impact on the economic development and infrastructure construction of CEE regions. It is a transformative actor in host countries during the early stages of economic transformation (Szakálné Kanó et al. 2019), which can promote employment, improve living standards, and increase economic growth (Antalóczy et al. 2022, Szunomár–Biedermann 2014). On the other hand, other researchers are worried that China's FDI may lead to problems such as over-exploitation of resources, environmental problems, debt traps, employment competition, and technology transfer (Weng et al. 2021). In addition, still others also express concerns about that China may turn CEE member states against EU unity by offering economic benefits (Matura 2019). While it is difficult to come up with a unanimous voice on the effect of FDI, it is undeniable that China has become the world's largest EV market and continues to lead in battery manufacturing technology nowadays. It is projected that the more contact the host country has with the Chinese outward FDI stock, the more chance it will get to absorb greenfield investment, technology, and management experience in EV battery industry to stimulate the development of domestic EV battery industry.

The fourth is business enterprise expenditure on R&D (berd). EV battery technology is a rapidly developing and technology-intensive field (Wang–Mah 2022), and a company's innovation capabilities and R&D activities determine its position in global competition (Papanastassiou et al. 2020). Corporate R&D expenditures can reflect the innovation potential and prospects of a country or region's battery industry. A high level of R&D expenditure usually means that companies invest more resources in technological innovation and product improvement. It helps technological innovation, product quality improvement, cost reduction and market share expansion, thereby promoting the competitiveness and innovation capabilities of the EV battery industry. Catenacci et al. (2013) indicate that an additional 1 million USD in public R&D expenditure would result in a reduction in battery costs of $0.49 to $0.59 per kWh.

The fifth is private investment related to circular economy sectors (pice). The battery industry is closely related to the circular economy, especially in terms of battery life cycle management, resource recovery and reuse (Glöser–Chahoud et al. 2021). Private investment in the circular economy can promote R&D of sustainable materials and resource management, and promote the development of waste battery recycling and reuse technology, thereby reducing resource waste and environmental impact. Research from European Commission (2020) shows that investment in circular economy can improve the sustainability of battery materials, reduce production costs, and increase the life cycle of products, which is crucial for the long-term development of the electric vehicle battery industry. However, private investment in the circular economy may also have a crowding-out effect, leading to a reduction in R&D expenditures for the battery industry, and overly stringent standards may also delay the development of the industry.

As for the data sources for the variables, sodae is from the European Automobile Manufacturers' Association (ACEA), odicn is from the Ministry of Commerce of the People's Republic of China (MOFCOM), and the other data are from the Eurostat and OECD. Due to the availability of data, this paper is based on 23 countries in the EU: Austria, Belgium, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden, of which the cross-sectional data is for 2021.

In order to reduce the heteroscedasticity of the data, this article first took the logarithm of bpev, ngs, odicn, berd and pice before building the model. The descriptive statistical characteristics of each variable are shown in Table 2, which suggests that in 2021, there are significant differences in the export industries of the battery industry in the EU member states, with the maximum logarithmic value being 22.76, the average logarithmic value being 19.66, and the minimum logarithmic value being only 16.16. The rest of selected variables also show obvious discrepancies geographically.

Table 2

Descriptive statistics of research variables

Variable	Unit	Mean	Standard deviation	Minimum	Maximum
Lnbpev	EUR	19.66	1.85	16.16	22.76
sodae	%	6.42	5.05	0.00	16.00
Lnngs	thousand tons of oil equivalent	8.65	1.50	5.98	11.27
Lnodicn	million USD	6.12	2.46	1.48	10.26
Lnberd	million EUR	7.98	1.73	4.33	11.23
Lnpice	million EUR	7.44	1.58	4.68	10.36

Empirical analysis and discussion

Diagnostics for spatial dependence diagnosis

The global Moran's I index was used to conduct spatial dependence test on the export value of battery products of the 23 EU member states in 2021. The index can effectively detect the regression residuals between entire spatial adjacent areas and determine whether EU member states are positively corrected, negatively correlated, or uncorrelated. The value range of the global Moran'I index is [–1, 1]. A positive value indicates a positive spatial correlation, a negative value indicates a negative spatial correlation, and 0 indicates no correlation. The larger the absolute value, the stronger the spatial correlation. The index is defined as:

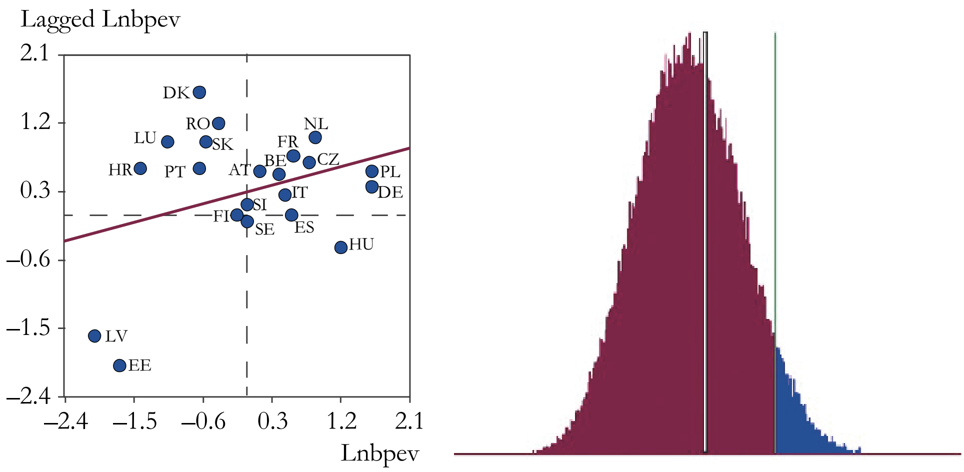
$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}}, \tag{5}$$

where, n is the total number of regions; S^2 is the sample variance; W_{ij} is the spatial weight matrix; x is the value of the variable, and $\bar{x}$ is the sample mean of the variable.

The spatial correlation of the logarithmic value of EU member states' battery industry export amounts calculated based on the row-standardized contiguity matrix is shown in Figure 4. In 2021, its Moran's I value is 0.2802, passing the significance test of about 5%, indicating that EU member states have significant spatial positive correlation characteristics in the export of battery products, which are specifically manifested in two characteristics: one is that countries with high levels are adjacent to each other, and the other is that a certain country is low but neighbouring countries are high. A noteworthy phenomenon is that Hungary's own battery product export value is large, while its neighbouring countries are relatively smaller.

Figure 4

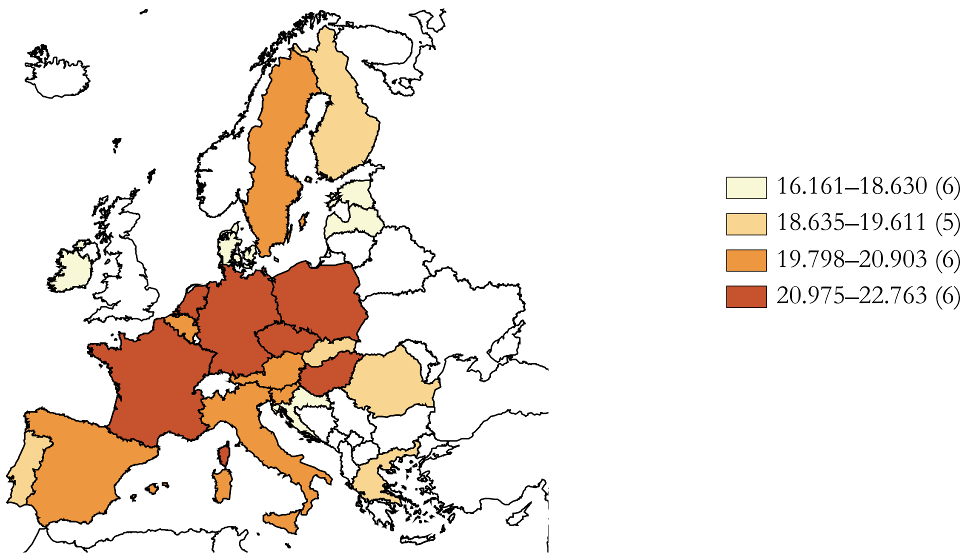
Global Moran's I value of Lnbpev and its permutations



Note: Ireland and Greece as isolates in weight are removed when generating Moran's I.

Figure 5

Quantile map of Lnbpev



The quantile map (shown in Figure 5) also reveals that the 23 EU member states in the study have spatially differentiated attributes in battery product export indicator. However, a point worthy of attention is that both Figure 4 and Figure 5 show that Hungary's domestic battery product export value is large, while the exports of neighbouring countries are small.

Selection of spatial econometric models

Since member states have significant spatial correlation in their export levels of battery products, it is appropriate to establish a spatial econometric model to measure its factors. However, the specific model form still requires further diagnosis. Following Anselin (2005), two Lagrange multiplier (LM) tests and their robust counterparts can be employed to test for the presence of two possible forms of spatial autocorrelation: LM lag for spatial lagged autocorrelation and LM error for spatial error autocorrelation. If LM lag is significant but LM error is not significant, the spatial lagged autoregression model should be used; if LM error is significant but LM lag is not significant, the spatial error model should be chosen; if both LM lag and LM error are not statistically significant, the significance of robust LM lag and robust LM error is further compared; if both LM lag and LM error are significant, then their robust counterparts should be further compared to selected the more significant one (Hu et al. 2014, Nugraha et al. 2021). According to Table 3, since the LM lag value is significant at the 5% significance level, while the LM error value is not significant, indicating that the spatial lagged autoregression model (SLM) will be more effective in this topic, and the related spatial econometric model is set as the following equation (6):

$$Lnbpev = \rho WLnbpev + \beta_0 + \beta_1 sodae + \beta_2 Lnngs + \beta_3 Lnodicn + \beta_4 Lnberd + \beta_5 Lnpice + \mu \quad (6)$$

Table 3

Lagrange multiplier (LM) test

LM test statistics	Value	PROB
LM lag	4.7351	0.0296
LM error	1.1045	0.2933

Analysis of regression results and discussion

By comparing the regression results of the OLS model and SLM (see Table 4), it is found that all the five relevant explanatory variables have a significant impact on the export values of battery products of EU member states. From the perspective of the direction of influence, only the amount of private investment in the circular economy has a negative correlation with the amount of exports of battery products. Besides, that the estimation results of SLM, which is the most suitable model, show the ratio of direct employment in the automobile industry to the manufacturing industry, total supply of natural gas, outward FDI of China in member countries, the amount of R&D expenditures of business enterprises, private investment in the circular economic sector, and the spatial lagged autocorrelation effect influence the development of battery industry among EU member states.

Table 4

Comparison of model regression results

Variables	(1) OLS			(2) SLM		
	coefficients	standard error	p-values	coefficients	standard error	p-values
W_Lnbpev	–		–	0.0741	0.0298	0.0128
constant	11.4610	1.1689	0.0000	10.2668	1.0084	0.0000
sodae	0.0982	0.0413	0.0295	0.0583	0.0350	0.0957
Lnngs	0.7588	0.2301	0.0043	0.8763	0.1830	0.0000
Lnodicn	0.2060	0.1129	0.0857	0.1737	0.0870	0.0460
Lnberd	0.7306	0.2501	0.0095	0.8803	0.1975	0.0000
Lnpice	–0.8176	0.3205	0.0207	–1.0788	0.2648	0.0001

From the estimated regression coefficients, it appears that the coefficient of the spatial lag term is 0.0741, indicating that there is a positive spatial interdependence in the export value of battery products of the 23 EU member states. When other independent variables remain unchanged, when the export of battery products in a region increases by 1%, the export value of battery products in neighbouring regions will increase by 7.41% on average.

When all other factors being unchanged, every 1% increase in the ratio of direct employment in the automotive industry to manufacturing, the expected value of a country's battery product exports will increase by 3.5%. The reason for the strong effect may be that electrification is considered an important revolution that determines the future development of the traditional automobile industry (Szalavetz 2022). Driven by policy constraints and the transformation of traditional manufacturers, the automobile industry's direct employment in the manufacturing industry also indirectly reflects the labor supply situation in the EV and EV battery industry. The partial effects of the total supply of natural gas and the R&D expenditure of business enterprises are roughly the same. When each increase by 1%, the export value of a country's battery products will increase by an average of 0.8763% and 0.8803%, respectively.

When all else equal, every 1% increase in China's FDI in EU member states will push the member states' battery product export value to increase by an average of 0.1737% in the same direction. Although China is building battery factories in member countries, such as Hungary, it has indeed boosted local employment and increased the supply of battery products in the country, the positive effect is statistically weak is probably because that China's FDI in the EU focus more on rental and business services, mining, wholesale, and retail etc. (Szunomár–Biedermann 2014), rather than the battery industry. This will reduce the direct impact on the battery industry. In addition, when Chinese companies invest in the EU, they may not conduct sufficient technology transfer or cooperate with local companies, thereby failing to play a greater role in the battery industry.

However, private sector investment in the circular economy has a dampening effect on the export values of battery products. For every 1% increase in the former, the latter will decrease by 1.0788%, *ceteris paribus*. This may be due to firstly, emphasis on the circular economy may bring about increased costs for raw material recycling and disposal, thus affecting the competitiveness of the battery products export. Secondly, when the circular economy is mainly orientated towards the domestic market, the battery industry may focus more on meeting domestic demand than on exports. Stringent regulations and standards introduced by the governments and trade associations may also raise the production and export thresholds of the battery industry, which might delay the current export value of battery product. Thirdly, private investment strategies may favor areas where quick returns are expected, while the battery industry's long lead times for R&D and market penetration may not meet such expectations, leading to underfunding and reduced export production.

Regression diagnostics

The diagnostic results of the model show that under OLS estimation, the condition number is 37.1424, which is less than 100, indicating that the model doesn't have serious multicollinearity problems (Suhail et al. 2023). In addition, the residuals perform well in terms of normality and heteroscedasticity. The p-value of the Jarque–Bera test is 0.1381, indicating that the residuals conform to the normal distribution; while the p-values of the Breusch–Pagan test and the Koenker–Bassett test are 0.8922 and 0.9663, respectively, both indicating that the model has no significant heteroscedasticity problems (see Table 5).

Table 5

Regression diagnostics

(1) Ordinary least squares (OLS) estimation			
Multicollinearity condition number	37.1424		
Test on normality of errors			
	df	value	PROB
Jarque–Bera test	2	3.9590	0.1381
Diagnostics for heteroskedasticity			
	df	value	PROB
Breusch–Pagan test	5	1.6735	0.8922
Koenker–Bassett test	5	0.9529	0.9663
(2) Spatial lag model (SLM) – maximum likelihood estimation			
Diagnostics for heteroskedasticity			
	df	value	PROB
Breusch–Pagan test	5	5.2719	0.3836
Diagnostics for spatial dependence for weight matrix: rook (row-standardized)			
	df	value	PROB
Likelihood-ratio test	1	5.4404	0.0197

For SLM, the error term also does not have significant heteroscedasticity (the p-value of the Breusch–Pagan test is 0.3836), and there is significant spatial autocorrelation (the p-value of the likelihood-ratio test is 0.0197). This shows that spatial effects play an important role. SLM provides a deeper understanding and more reliable results than the OLS model in exploring the spatial differences in EV battery industry development among EU member states.

Conclusion

With the global growth of the EV market, battery, which is at the centre part, has become the focus of attention and investment in EU. Against this backdrop, the pattern of development and spatial differences between EU member states in the EV battery industry have attracted widespread attention. This study portrays in detail the differences in the development of EU member states in the EV battery industry along four dimensions: production, supply chain, market consumption and preference, R&D and technological innovation.

In terms of research design, this article first uses Moran's I index to diagnose the spatial dependence of the battery product export values and detects the existence of spatial correlation. Secondly, the suitability of constructing a spatial lag model was determined through four Lagrange multiplier tests. Finally, the regression coefficients of the models are compared and interpreted. The results show that the spatial lag term, the ratio of direct employment in the automobile industry to the manufacturing industry, total natural gas supply, China's FDI in EU member states, and corporate R&D expenditures have a significant positive correlation with the export value of battery products. However, the partial effect of China's investment volume is weak. In contrast, private investment related to the circular economy has a significant negative effect on the export of battery products.

Based on the regression results, this article argues that in order to promote the development of the EV battery industry in EU member states, it is necessary to:

The first is to promote venture capital investment, especially corporate venture capital, and to strengthen skills training of labor force. There is a significant positive correlation between employment in automobile industry, corporate R&D expenditure, and battery product exports. This shows that experienced labor and technological innovation is the key to promoting the development of the battery industry. The government can provide tax incentives, subsidies or low-interest loans to encourage companies to increase venture capital investment, especially advanced battery technology and materials research. Corporate venture capital is helpful to promote technological innovation and market promotion as it provides funds for the EV battery industry to support R&D, which disperses technology and market risks (Kostopulosz 2023). The government also needs to guide the education market to strengthen skills training for workers and increase the supply of talents in the battery industry.

The second is to optimize the energy structure and ensure stable energy supply. The supply of natural gas has a significant impact on the export volume of battery products. In order to ensure the continued growth of the battery industry, it is necessary to optimize the energy structure and ensure its stable supply. Governments need to formulate clear energy policies and plans to invest in energy infrastructure to improve energy efficiency while promoting the development of renewable energy, energy reserves and energy storage technologies. Strengthening international cooperation to share energy resources and technologies also provides more energy choices and supply channels for the stable supply of domestic energy.

The third is to reflect on China–EU investment cooperation. Although the amount of China's FDI in the EU continues to increase, and a number of greenfield investments have been implemented in the battery industry, the impact on the export value of battery products of EU member states is relatively weak. In order to ensure mutual benefit and win-win results for both parties in this electrification revolution, it is necessary to establish fair and compliant market access standards, promote technology sharing and cooperation, pay attention to environmental protection and sustainable development, while examine the impact of greenfield investment on the host country and further measure its impact path.

However, in this study, there are some limitations that may affect the results and inferences of the study. The paper uses the export value of battery products as a proxy variable for the development of the EV battery industry to solve the problem of data availability. However, this proxy variable may have certain estimation bias because it does not directly reflect the total production volume or internal market demand of the battery industry. Future research can strive to obtain more accurate battery industry production data to further improve the accuracy of the research. Besides, the research focuses on analyzing the cross-sectional relationships between various influencing factors but does not consider the dynamic relationships and time series changes between these factors. It would be better to introduce the time dimension and conduct panel data analysis to more fully understand how these influencing factors evolve over time and the dynamic interactions between them in the further research, especially in the context of the rapid evolution of the EV battery industry, to understand how they influence and adjust each other. Moreover, the future research direction can also be expanded to analyse the synergy and interrelationships between the battery industry and other related industries. And lastly, to provide more useful information for policy formulation, the impact of the EV battery industry on a country's social and economic development can be further studied as well, for which the development of the industry is closely linked to employment, economic growth, environmental protection.

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REFERENCES

ANTALÓCZY, K.–BIRIZDÓ, I.–SASS, M. (2022): Local investment promotion in a Hungarian medium-sized town and the implications of the Covid pandemic *Regional Statistics* 12 (1): 27–50. https://doi.org/10.15196/RS120104

BAJOLLE, H.–LAGADIC, M.–LOUVET, N. (2022): The future of lithium-ion batteries: exploring expert conceptions, market trends, and price scenarios *Energy Research & Social Science* 93: 102850. https://doi.org/10.1016/j.erss.2022.102850

BALALI, Y.–STEGEN, S. (2021): Review of energy storage systems for vehicles based on technology, environmental impacts, and costs *Renewable and Sustainable Energy Reviews* 135: 110185. https://doi.org/10.1016/j.rser.2020.110185

CATENACCI, M.–VERDOLINI, E.–BOSETTI, V.–FIORESE, G. (2013): Going electric: expert survey on the future of battery technologies for electric vehicles *Energy Policy* 61: 403–413. https://doi.org/10.1016/j.enpol.2013.06.078

DESHWAL, D.–SANGWAN, P.–DAHIYA, N. (2022): Economic analysis of lithium-ion battery recycling in India *Wireless Personal Communications* 124 (4): 3263–3286. https://doi.org/10.1007/s11277-022-09512-5

FIGENBAUM, E. (2017): Perspectives on Norway's supercharged electric vehicle policy *Environmental Innovation and Societal Transitions* 25: 14–34. https://doi.org/10.1016/j.eist.2016.11.002

GLÖSER-CHAHOUD, S.–HUSTER, S.–ROSENBERG, S.–BAAZOUZI,S.–KIEMEL, S.–SINGH, S.–SCHNEIDER, C.–WEEBER, M.–MIEHE, R.–SCHULTMANN, F. (2021): Industrial disassembling as a key enabler of circular economy solutions for obsolete electric vehicle battery systems *Resources, Conservation and Recycling* 174: 105735. https://doi.org/10.1016/j.resconrec.2021.105735

HELBIG, C.–BRADSHAW, A. M.–WIETSCHEL, L.–HORENZ, A.–TUMA, A. (2018): Supply risks associated with lithium-ion battery materials *Journal of Cleaner Production* 172: 274–286. https://doi.org/10.1016/j.jclepro.2017.10.122

HU, J.–TAN, C.–ZHU, W.–ZHANG, Y.–HAN, Z. (2014): *Research on the mechanism system of regional coordinated development in China* pp. 266–267. China Social Sciences Press.

JOSHI, B. V.–VIPIN, B.–RAMKUMAR, J.–AMIT, R. (2021): Impact of policy instruments on lead-acid battery recycling: A system dynamics approach *Resources, Conservation and Recycling* 169: 105528. https://doi.org/10.1016/j.resconrec.2021.105528

KALMYKOVA, Y.–SADAGOPAN, M.–ROSADO, L. (2018): Circular economy – From review of theories and practices to development of implementation tools *Resources conservation and recycling* 135: 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

KOSTOPULOSZ, A. (2023): *A kockázati tőke szerepe az elektromos jármű akkumulátor ipari startup vállalkozások finanszírozásában és fejlesztésében, különös tekintettel a vállalati kockázatitőke-befektetésekre* Szegedi Tudományegyetem.

LAI, X.–GU, H.–CHEN, Q.–TANG, X.–ZHOU, Y.–GAO, F.–HAN, X.–GUO, Y.–BHAGAT, R.–ZHENG, Y. (2022): Investigating greenhouse gas emissions and environmental impacts from the production of lithium-ion batteries in China *Journal of Cleaner Production* 372: 133756. https://doi.org/10.1016/j.jclepro.2022.133756

LEBROUHI, B. E.–SCHALL, E.–LAMRANI, B.–CHAIBI, Y.–KOUSKSOU, T. (2022): Energy transition in France *Sustainability* 14 (10): 5818. https://doi.org/10.3390/su14105818

MARTINS, J.–MILES, J. (2021): A techno-economic assessment of battery business models in the UK electricity market *Energy Policy* 148: 111938. https://doi.org/10.1016/j.enpol.2020.111938

MATURA, T. (2019): China–CEE trade, investment and politics *Europe-Asia Studies* 71 (3): 388–407. https://doi.org/10.1080/09668136.2019.1571166

MELIN, H. E.–RAJAEIFAR, M. A.–KU, A. Y.–KENDALL, A.–HARPER, G.–HEIDRICH, O. (2021): Global implications of the EU battery regulation *Science* 373 (6553): 384–387. https://doi.org/10.1126/science.abh1416

NUGRAHA, A. T.–PRAYITNO, G.–NANDHIKO, L.-NASUTION, A. R. (2021): Socioeconomic conditions on poverty levels a case study: Central Java Province and Yogyakarta in 2016 *Revista de Economia e Sociologia Rural* 60: e233206. https://doi.org/10.1590/1806-9479.2021.233206

NYKVIST, B.–NILSSON, M. (2015): Rapidly falling costs of battery packs for electric vehicles *Nature Climate Change* 5 (4): 329–332. http://dx.doi.org/10.1038/nclimate2564

PAPANASTASSIOU, M.–PEARCE, R.–ZANFEI, A. (2020): Changing perspectives on the internationalization of R&D and innovation by multinational enterprises: A review of the literature *Journal of International Business Studies* 51: 623–664. https://doi.org/10.1057/s41267-019-00258-0

PLACKE, T.–KLOEPSCH, R.–DÜHNEN, S.–WINTER, M. (2017): Lithium ion, lithium metal, and alternative rechargeable battery technologies: the odyssey for high energy density *Journal of Solid-State Electrochemistry* 21: 1939–1964. https://doi.org/10.1007/s10008-017-3610-7

SCHMUCH, R.–WAGNER, R.–HÖRPEL, G.–PLACKE, T.–WINTER, M. (2018): Performance and cost of materials for lithium-based rechargeable automotive batteries *Nature Energy* 3 (4): 267–278. https://doi.org/10.1038/s41560-018-0107-2

SCHREIBER, J.–SCHERRER, A.–BREETZ, H. L. (2023): Driving discussion: Media framing of electric, hydrogen, and conventional vehicles in German newspapers and Twitter *Energy Research & Social Science* 103: 103193. https://doi.org/10.1016/j.erss.2023.103193

SHAO, J.–MIŠIĆ, M. (2023): Why does electric vehicle deployment vary so much within a nation? Comparing Chinese provinces by policy, economics, and socio-demographics *Energy Research & Social Science* 102: 103196. https://doi.org/10.1016/j.erss.2023.103196

SICK, N.–BRÖRING, S.–FIGGEMEIER, E. (2018): Start-ups as technology life cycle indicator for the early stage of application: An analysis of the battery value chain *Journal of Cleaner Production* 201: 325–333. https://doi.org/10.1016/j.jclepro.2018.08.036

SZAKÁLNÉ KANÓ, I.–LENGYEL, B.–ELEKES, Z.–LENGYEL, I. (2019): Agglomeration, foreign firms and firm exit in regions under transition: the increasing importance of related variety in Hungary *European Planning Studies* 27 (11): 2099–2122. https://doi.org/10.1080/09654313.2019.1606897

SZALAVETZ, A. (2022): Transition to electric vehicles in Hungary: A devastating crisis or business as usual? *Technological Forecasting and Social Change* 184: 122029. https://doi.org/10.1016/j.techfore.2022.122029

SUHAIL, M.–CHAND, S.–ASLAM, M. (2023): New quantile-based ridge M-estimator for linear regression models with multicollinearity and outliers *Communications in Statistics-Simulation and Computation* 52 (4): 1417–1434. https://doi.org/10.1080/03610918.2021.1884715

TOBLER, W. R. (1970): A computer movie simulating urban growth in the Detroit region *Economic geography* 46 (sup1): 234–240. https://doi.org/10.2307/143141

TÓTH, B. I. (2023): Territorial capital in the European Union: Measuring the territorial endowments of the EU-28 NUTS 2 regions over the 2010s *Regional Statistics* 13 (1): 3–35. https://doi.org/10.15196/RS130101

US GEOLOGICAL SURVEY (2020): *Mineral commodity summaries* pp. 98–99., U.S. Government Publishing Office.

WANG, Q.–MAH, J. S. (2022): The Role of the Government in Development of the Electric Vehicle Industry of China *China Report* 58 (2): 194–210. https://doi.org/10.1177/00094455211031685

WANG, X. W.–CAO, Y. M.–ZHANG, N. (2021): The influences of incentive policy perceptions and consumer social attributes on battery electric vehicle purchase intentions *Energy Policy* 151: 112163. https://doi.org/10.1016/j.enpol.2021.112163

WEN, W.–YANG, S.–ZHOU, P.–GAO, S. (2021): Impacts of Covid-19 on the electric vehicle industry: Evidence from China *Renewable and Sustainable Energy Reviews* 144: 111024. https://doi.org/10.1016/j.rser.2021.111024

WENG, L.–XUE, L.–SAYER, J.–RIGGS, R. A.–LANGSTON, J. D.–BOEDHIHARTONO, A. K. (2021): Challenges faced by Chinese firms implementing the 'Belt and Road Initiative': Evidence from three railway projects. *Research in Globalization* 3: 100074. https://doi.org/10.1016/j.resglo.2021.100074

INTERNET SOURCES

ANSELIN, L. (2005): *Exploring spatial data with GeoDaTM: a workbook.* https://www.geos.ed.ac.uk/~gisteac/fspat/geodaworkbook.pdf (downloaded: July 2023)

BLOOMBERGNEF (2023): *Electric Vehicle Outlook 2023.* https://about.bnef.com/electric-vehicle-outlook/ (downloaded: October 2023)

EUROPEAN AUTOMOBILE MANUFACTURERS ASSOCIATION (2020): *Economic and Market Report. EU Automotive Industry Full-year 2020.* https://www.acea.auto/files/Economic_and_Market_Report_full-year_2020.pdf (downloaded: October 2023)

EUROPEAN COMMISSION [EC] (2019): *A European Green Deal - Striving to be the first climate-neutral continent.* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (downloaded: October 2023)

EUROPEAN COMMISSION [EC] (2020): *Green Deal: Sustainable batteries for a circular and climate neutral economy.* https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312 (downloaded: October 2023)

EUROPEAN COMMISSION [EC] (2021): *3rd Raw Materials Scoreboard – European innovation partnership on raw materials.* https://data.europa.eu/doi/10.2873/567799 (downloaded: October 2023)

EUROPEAN COURT OF AUDITORS (2023): *Special report 15/2023: The EU's industrial policy on batteries – New strategic impetus needed.* https://www.eca.europa.eu/en/publications?ref=SR-2023-15 (downloaded: July 2023)

EUROPEAN ENVIRONMENT AGENCY [EEA] (2022). *New registrations of electric vehicles in Europe.* https://www.eea.europa.eu/ims/new-registrations-of-electric-vehicles (downloaded: July 2023)

EUROSTAT (2023): *Total energy supply by product.* https://ec.europa.eu/eurostat/databrowser/view/ten00122/default/table?lang=en (downloaded: July 2023)

ÉLTETŐ, A. (2023): *Aspects of electric vehicle battery production in Hungary* Working Paper No. 271. Institute for World Economics-Centre for Economic and Regional Studies. https://vgi.krtk.hu/wp-content/uploads/2023/06/Elteto_WP_271.pdf (downloaded: January 2024)

GERMAN FEDERAL MINISTRY OF ECONOMIC AFFAIRS AND ENERGY (2009): *National Electromobility Development Plan.* https://bmdv.bund.de/blaetterkatalog/catalogs/219118/pdf/complete.pdf (downloaded: October 2023)

HUNGARIAN GOVERNMENT (2022): *National Battery Industry Strategy 2030.* https://cdn.kormany.hu/uploads/document/c/c6/c61/c61e79e054c555b6e11fad171e99d0ad691a2b81.pdf (downloaded: October 2023)

INTERNATIONAL ENERGY AGENCY [IEA] (2019): *The Role of Gas in Today's Energy Transitions.* https://www.iea.org/reports/the-role-of-gas-in-todays-energy-transitions (downloaded: October 2023)

INTERNATIONAL ENERGY AGENCY [IEA] (2023a): *Global EV Outlook 2023.* https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf (downloaded: May 2023)

INTERNATIONAL ENERGY AGENCY [IEA] (2023b): *Electric car sales break new records with momentum expected to continue through 2023.* https://www.iea.org/energy-system/transport/electric-vehicles (downloaded: January 2024)

LUTSEY, N.–NICHOLAS, M. (2019): *Update on electric vehicle costs in the United States through 2030* (Working Paper 2019-06). International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf (downloaded: January 2024)

NORDIC ENERGY RESEARCH (2018): *Nordic EV outlook 2018*. https://www.nordicenergy.org/publications/nordic-ev-outlook-2018/ (downloaded: January 2024)

RENAULT GROUP (2023): *Earnings report full year 2022*. https://www.renaultgroup.com/wp-content/uploads/2023/02/rg_2022_fy_results_earnings-report_en.pdf (downloaded: January 2024)

ŠKODA AUTO (2022). *Annual reports*. https://www.skoda-storyboard.com/en/annual-reports/ (downloaded: January 2024)

STELLANTIS (2020): *Sustainability report 2020*. https://www.stellantis.com/content/dam/stellantis-corporate/sustainability/csr-disclosure/fca/fca_2020_sustainability_report.pdf (downloaded: January 2024)

SZUNOMÁR, Á.–BIEDERMANN, Z. (2014): *Chinese outward FDI in Europe and the Central and Eastern European region within a global context* (Working Paper 207). Institute of World Economics, Centre for Economic and Regional Studies. https://real.mtak.hu/13578/1/Szunom%C3%A1r-Biedermann_WP_207.pdf (downloaded: January 2024)

DATABASES/WEBSITES

EUROSTAT: https://ec.europa.eu/eurostat/web/main/data/database (downloaded: October 2023)

MINISTRY OF COMMERCE PEOPLE'S REPUBLIC OF CHINA: http://english.mofcom.gov.cn/statistic/charts.shtml (downloaded: December 2023)

EUROPEAN AUTOMOBILE MANUFACTURERS ASSOCIATION: https://www.acea.auto/reliable-data-statistics/ (downloaded: December 2023)

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT [OECD]: https://www.oecd.org/en/data.html (downloaded: November 2023)