



## Regular Article

# Innovation, integration, and expansion: Empirical evidence on the European Union automotive industry, 2010–2023

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## ABSTRACT

The automotive industry remains one of the most important economic sectors in the European Union (EU), not only as a driver of innovation and technological transition, but also as a key factor in GDP, foreign trade, and employment. This study aims to empirically explore the relationship between automotive production and economic growth for 16 EU Member States with significant automotive output over the period 2010–2023. The research aims to examine how and to what extent automotive gross value added, the share of electric vehicle sales, the investment rate, the level of human capital, and foreign trade openness affect national economic growth rates. The study employs panel regression models (with fixed and random effects), cluster analysis (K-means, supported by principal component analysis), descriptive statistical trend analysis, and robustness testing based on harmonized Eurostat and ACEA data. The results confirm that the gross value added of the automotive industry has a statistically significant, positive impact on economic growth, especially in industrialised and export-oriented economies such as Germany, Slovakia, or the Czech Republic. The study concludes that the EU automotive industry's contribution to sustainable growth can be maintained if technological leadership in electrification is accompanied by targeted human capital and industrial policy developments.

## 1. Introduction

### 1.1. Structural and macroeconomic importance of the automotive industry in the European Union

The automotive industry is one of the most significant manufacturing sectors in the EU, playing a prominent role in terms of gross value added (GVA) and industrial employment, particularly in Member States such as Germany, France, the Czech Republic, and Hungary (European Commission, 2023). The automotive industry and its related sectors account for around 7 % of EU manufacturing output and more than 10 % of the value of exports (ACEA, 2025).

The structural importance of the automotive industry stems from its indirect impact on other sectors through extensive supply chains and technological linkages, such as metal processing, electronic component manufacturing, logistics, and IT services. Due to the strength of the multiplier effect, a decline or expansion in the sector has macroeconomic consequences (Serikkaliyeva et al., 2024; Basdekis et al., 2020).

The employment impact of the automotive industry extends beyond manufacturing; the automotive sector also supports millions of indirect

jobs through repair shops, retail chains, transportation companies, and parts logistics networks (Cottenman et al., 2024; Frieske et al., 2024; Zeng et al., 2022).

The industry generates significant tax revenues, both from the sale of new vehicles and from public charges related to fuel consumption and ownership (ACEA, 2020; Marrero et al., 2020; Metaxas & Nikou, 2020; Shehaj & Zagler, 2023).

Over the past decade, the EU automotive industry has undergone a transformation driven by technological advancements (such as electric vehicles, digitalization, and autonomous driving systems) and pressures from climate policy. The tightening of CO<sub>2</sub> emission standards (EU, European Union EUR-Lex, 2019) and the goals of the European Green Deal are forcing manufacturers to accelerate their investments towards EV technologies and sustainable powertrains.

In addition to the global importance of vehicle exports, the automotive industry also plays a significant role in driving domestic demand through various consumption cycles. Car purchases are typically cyclical, but they have a significant stimulating effect in post-crisis periods. Several studies have shown that automotive production also increases productivity, wage levels and labor market activity at the

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regional level (Sun & Abdullah, 2025; Wang et al., 2020).

The economic impacts of the automotive industry are not only on the production side, but also have a significant effect on the development of domestic demand through consumer decisions and contractual relations (Török, 2018; Liu et al., 2024), and the economic impacts of the industry are also influenced by the quality of the legal and institutional environment (Török, 2025; Travkina et al., 2023).

Ultimately, the automotive industry is not only a component of economic growth, but also a structural test for the EU's adjustment. The question is to what extent vehicle manufacturing can contribute to the success of the digital and green transitions while maintaining its competitiveness (Szabó & Newell, 2024; Pichler et al., 2021; Moita et al., 2024). The EU automotive industry needs to maintain its competitiveness against Chinese and American manufacturers while playing a stabilizing role in national economies (Patchell et al., 2024; Richert & Dudek, 2023; Shigeta & Hosseini, 2021).

### 1.2. Challenges facing the EU automotive industry today

Although the empirical analysis of the study focuses on the period between 2010 and 2023, it is also justified and relevant to briefly address the current challenges facing the European Union's automotive industry in 2025. One of the main reasons for this is that current industry issues – such as the growing market share of Chinese electric vehicles, the further tightening of EU CO<sub>2</sub> emission standards, the restructuring of supply chains or the global competitive disadvantage of production costs – significantly affect the conditions under which the previously observed economic relationships can remain valid in the future.

The growth patterns and correlations that characterize the period 2010–2023 cannot be automatically considered permanent or repeatable if the European automotive industry faces fundamentally new challenges in the EU. The presentation of the situation in 2025 thus not only lends topicality and relevance to the analysis but also creates an opportunity to consider those turning points and structural breaks that may be decisive for future economic policy decisions and industry strategies when interpreting past trends. A reflective interpretation of the current context is therefore essential for the study to provide not only a historical overview of the EU automotive industry, but also to contribute to the foundation of medium- and long-term conclusions.

The EU automotive industry is currently struggling with competitiveness and strategic deficiencies. After stalling in 2024, electric car sales are on an upward trajectory again this year; however, the limitations of batteries significantly hinder real growth, as well as the dependence on raw materials and the constantly expanding, yet still low-level, charging infrastructure. The artificially forced electrification of the European automotive industry could backfire on the industry in several ways. A relevant concern is that the EU will remain dependent on imports for electric car production, just as it has been before. Regarding the fossil fuels required for internal combustion engine vehicles, the change is that this time the EU will be dependent on China, which accounts for the majority of production, for the rare earth metals needed for battery production and for anode and cathode production. The essence of the problem can also be expressed as the EU replacing fossil imports with anode, cathode, and rare earth metal imports. However, the EU is not reducing dependence by doing so, but only rearranging it. As a result of the uncertainty, an increasing number of European car manufacturers and parts suppliers are planning layoffs. Of course, it is not that the industry in the EU does not need to be greened. Still, the current regulation sets the course in a way that lacks production efficiency, putting European manufacturers at a cost disadvantage compared to their global competitors. It is easy to see the future vision that the role of fossil fuels will remain prominent in the long term, and it is also evident that the mobility of the future will primarily consist of a combination of electric and internal combustion engine cars. However, the rise of electric vehicles is strongly limited by consumer price sensitivity and the availability of infrastructure. Current sales trends indicate

that the majority of cars of the future will be hybrids. The conditions for a whole electric drive to break through the market are not yet in place (for example, batteries are too expensive, accounting for around 20–40 percent of the value of an electric car, a very high proportion compared to the car's price). A significant part of the population is unwilling to pay a premium for electric vehicles, and many even expect a discount. This is the fundamental obstacle to widespread adoption. The rapid uptake of electric cars and solar panels does not seem feasible in all green infrastructure and mobility areas, for which it is essential to accelerate network development in EU member states.

The current challenges facing the European automotive industry are illustrated in the following figure.

Fig. 1 presents the ten most important challenges facing the EU automotive industry today in a structured, sequential format. The challenges encompass geopolitical, technological, regulatory, and consumer pressures that impact the competitiveness and structural adjustments of the industry.

### 1.3. The European automotive industry's journey through crises and transformations 2010–2023

The period from 2010 to 2023 witnessed significant structural and cyclical changes in the automotive industry across EU car-producing Member States. In the post-crisis years, 2010–2012, most countries gradually recovered from the aftermath of the global financial and real economic crisis of 2008–2009, resulting in moderate growth in car production volumes. Germany continued to play a prominent role, producing more than 5.5 million vehicles per year in the early 2010s, and thus remained the leading automotive player in the EU by far. The

## EU Auto Industry: 10 Challenges

- 1 Rising Chinese EV market share
- 2 Stricter EU CO<sub>2</sub> regulations
- 3 Reconfiguration of supply chains
- 4 Production cost disadvantages
- 5 Battery material dependence
- 6 Insufficient charging infrastructure
- 7 Consumer price sensitivity
- 8 Hybrid vehicle market growth
- 9 Green energy network needs
- 10 Layoffs of workers and suppliers

## EU Auto Industry: 10 Challenges

Fig. 1. Challenges Facing the EU Automotive Industry, source:own compilation.

German automotive industry held a dominant position due to its high productivity and global brands (e.g., Volkswagen, BMW, Mercedes). At the same time, Central European countries – especially the Czech Republic, Hungary, Slovakia, and Poland – played the role of supplier and assembly base, integrated into the German industry.

By the mid-2010s, the volume of automotive production had stabilized or started to expand in several countries. For example, Spain and France successfully modernized their production capacities, while in the case of Italy, the industry's decline only recovered more slowly. At the same time, some southern and eastern European countries, such as Portugal, Romania, and Slovenia, appeared on the market with smaller but dynamically developing production capacities and increasing export performance.

However, the trend was dramatically disrupted in 2020 by the COVID-19 pandemic. Manufacturing declined by 20–30 % in several countries, particularly those with supply chains heavily reliant on global imports. Lockdowns, semiconductor shortages, and supply chain disruptions have led to a worldwide slowdown in production. The impact of the pandemic was felt most strongly in Germany, Spain, and France. At the same time, countries with smaller, more flexible capacities, such as Slovakia and Hungary, were able to adapt relatively quickly. In the years following the pandemic, particularly between 2021 and 2023, production resumed, but the industry's focus shifted. The rise of electric vehicles marked a significant shift, bringing changes not only to technological developments but also to the production structure. The production of electric vehicles has become a priority in several countries (e.g., Germany, France, Belgium, Sweden), and subsequently, the nominal value of car production has increased significantly, partly due to the higher added value of electric powertrains and partly due to inflation. Although the number of vehicles produced in several countries in 2023 was slightly below the peaks of the mid-2010s, the production value set new records. For example, in Germany, it exceeded 260 billion euros, while in France, it also reached 80 billion euros.

The gradual advancement of the Central and Eastern European countries is striking: Slovakia, the Czech Republic, and Hungary have not only stabilized but also increased their role in the European automotive industry through their high export orientation and strong production specialization. At the same time, countries such as Finland or Portugal, although still players in the industry, have not been able to compete with the larger manufacturing countries in terms of volume. The internal structure of the sector has also changed, with the proportion of classic internal combustion engine models declining, and the weight of hybrid and purely electric vehicles increasing. Overall, between 2010 and 2023, EU car production followed a cyclical yet

structural growth path, shaped by the decline caused by the pandemic and the structural transformation brought about by the green transition. At the same time, differences between member states have increased. The future dynamism of the industry largely depends on the ability of individual member states to integrate new technologies and adapt to sustainability requirements.

Fig. 2 illustrates the automotive production performance in the 16 EU Member States for 2023. The left axis displays the number of vehicles produced, while the right axis represents the production value generated by the industry in billion euros. Compared to the 2013 data, a slight decrease in production volume is already visible in some countries (e.g., Germany, France), while the values have increased nominally, partly due to inflation and partly due to electric vehicles representing higher added value.

#### 1.4. Purpose and novelty of the research

Economic theoretical considerations, current EU industrial policy challenges, and empirical research gaps justify the purpose of the research.

This research aims to empirically investigate the relationship between the performance of the EU automotive industry and the economic growth of individual Member States from 2010 to 2023, with a particular focus on countries with significant vehicle production capacity. The study focuses on the financial impact mechanisms of vehicle manufacturing (NACE C29), especially in terms of gross value added, the rise of electric vehicles, investment, human capital indicators, and foreign trade openness.

The study aims to answer the question of the extent to which automotive industry performance contributes to GDP growth, and to what extent the structure of this impact changes with the strengthening of the electromobility transition and external dependencies (e.g., China-centric battery market).

The novelty of the research can be captured in three main dimensions:

1. Macroeconomic impact analysis on a country panel basis: While most analyses are conducted at the company or technology level, this research examines the relationships between automobile manufacturing and economic growth at an aggregate macro level using multivariate panel regression models, with particular attention to structural heterogeneity between EU member states.
2. Estimating the economic consequences of the electrification transition: The research combines traditional automotive performance

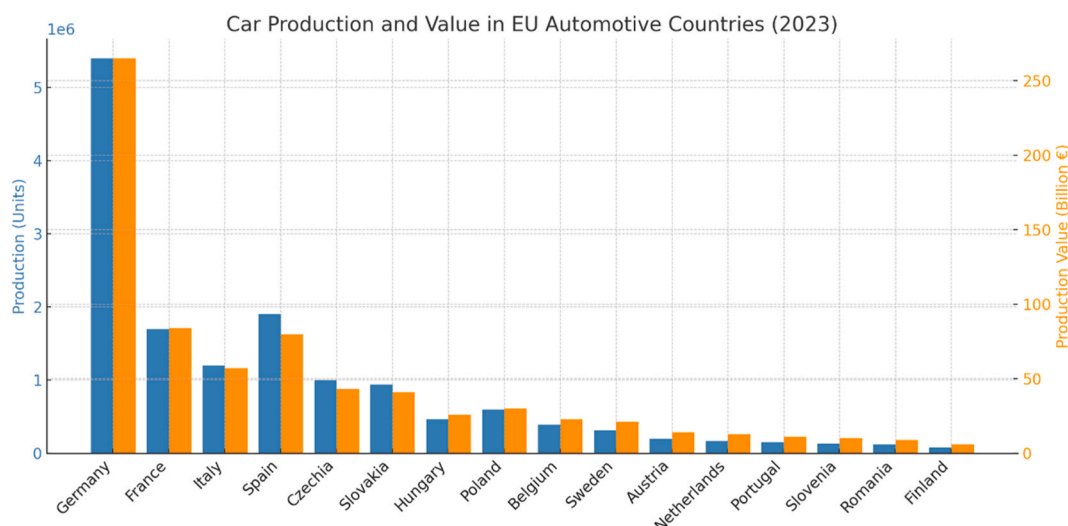


Fig. 2. Car Production and Value in EU Automotive Countries (2023), source: own compilation.

indicators with EV-SHARE, thereby capturing the financial dimensions of the green transition and its asymmetric effects across EU country groups.

- Examining structural adaptability through cluster analysis: The novelty of the study lies in its use of a clustering procedure to identify country groups within the EU based on the impact of the automotive industry on GDP, thereby contributing to the industrial policy and convergence policy discourse.

The studies presented above not only reevaluate the economic role of the EU automotive industry in light of the challenges of the 2020s but also reveal the different structural exposures and adaptability of member states, which can serve as a basis for more targeted and sustainable economic policy interventions.

This study differs from previous empirical research examining the relationship between the European automotive industry and economic growth in several important ways. First, its time coverage extends from 2010 to 2023, thus including the years before, during, and after the COVID-19 pandemic. This extensive period enables a joint examination of resilience, recovery, and technological transition. This is particularly important as the automotive industry has faced several overlapping challenges over the past decade and a half: semiconductor shortages, value chain pressures, decarbonization requirements, and the rapid rise of electromobility.

The novelty of the study is reflected not only in the topicality of the period under study but also in the complexity of the methodological approach. The research not only analyzes the automotive industry's performance and GDP growth in an aggregated manner but also employs econometric tools to explore the sectoral contributions systematically. The model encompasses not only the gross value added (GVA) of vehicle manufacturing but also other key factors, including the sales ratio of electric vehicles, the investment rate, the level of human capital, and foreign trade openness. The joint examination of these variables allows the study to address fundamental economic, technological, and trade policy aspects simultaneously. Another significant innovation in this study is that the research not only works with country group averages or aggregated EU values, but also analyzes the different structural patterns by breaking them down into individual countries. To this end, it also uses cluster analysis (K-means) and principal component analysis, which allows for the identification of patterns of convergence and divergence within the EU – for example, comparing export-oriented, industrialized countries (such as Germany, the Czech Republic, or Slovakia) with more peripheral economies.

Of particular note is that the study also integrates the sustainability dimension, as it does not simply measure economic growth, but assesses the conditions under which technological transition (especially the spread of electromobility) can contribute to inclusive and sustainable economic development. This question is particularly timely in light of the [European Union EUR-Lex, 2019](#) green objectives.

Finally, the research is based on transparent and reproducible databases, as the use of harmonized Eurostat and ACEA data ensures the verifiability and international comparability of the results. Based on all this, the study not only offers novelty from both theoretical and empirical perspectives but also provides a solid basis for policy conclusions, especially at the intersection of industrial policy, the green economy, and technological competitiveness.

The choice of the European Union (EU) as the empirical field of the research is justified in several respects. The EU automotive industry is one of the largest and most technologically advanced manufacturing bases in the world, which has a significant impact on the region's economic growth, foreign trade balance, and labor market. The common market, uniform regulatory environment, and industrial policy of the Member States allow for comparative analyses. In contrast, the industrial structures, investment patterns, and innovation capacities of the individual countries exhibit significant differences. In addition, the available, harmonized, and long-term statistical databases of the EU (e.

g., Eurostat, ACEA) provide an excellent basis for reliable and comparable econometric analyses.

## 2. Literature review

### 2.1. Theoretical approaches and empirical studies literature

The following chapter reviews the theoretical approaches and empirical studies that underpin the analysis of the relationship between car manufacturing and economic growth in the 16 EU automotive member states.

Previous studies have extensively examined the determinants of GDP growth, including the role of capital accumulation, technological progress, and labor market changes. Both neoclassical growth models ([Domar, 1946](#); [Solow, 1956](#)) and Keynesian approaches have emphasized the role of demand and production factors, while the long-term effects of business cycles remain controversial. Despite significant research efforts, some aspects of understanding remain incomplete, especially the causal relationships between individual macroeconomic variables and time lags.

The analysis of the relationship between the car industry and economic growth is linked to several schools of economic theory, particularly the structural, endogenous growth, and global value chain (GVC)-based approaches. Car manufacturing is a specific sector that represents both highly integrated industrial activity, export-oriented production, and a high level of technological content, which can directly influence macroeconomic performance through capital accumulation and innovation.

According to the classical industrial structure theory, the source of economic growth is the increase in the weight of industrial production, particularly in manufacturing activities ([Kaldor, 1966](#); [Rowthorn & Wells, 1987](#)). In this sense, automotive manufacturing is a highly productive, capital-intensive sector based on strong supplier networks, which also generates multiplier effects in other sectors of the economy ([O'Sullivan et al., 2013](#)). Vehicle manufacturing is closely linked to the metal industry, electronics, logistics, and financial services, so added value and employment are reflected in GDP not only directly, but also indirectly.

Endogenous growth theories (e.g., [Aghion & Howitt, 1992](#); [Romer, 1990](#)) posit that technological progress, human capital, and research and development are key drivers of economic growth. The automotive industry, particularly in the era of electromobility and autonomous driving technologies, is a prominent field of innovation and concentrates significant R&D expenditures. In modern automotive manufacturing, software-based solutions, connected cars, and vehicle control based on artificial intelligence (AI) are no longer just industry innovations, but also growth channels that transmit to other sectors. A third critical approach is the analysis of Global Value Chains (GVCs), which suggests that economic growth increasingly depends on a country's ability to engage in high-value-added activities within international production networks ([Gereffi et al., 2005](#); [Timmer et al., 2014](#)). The automotive industry is vital in this respect, as much of the production is organized along value chains led by multinational companies (OEMs). Within the EU, the automotive industries of Central and Eastern European countries (e.g., Hungary, the Czech Republic, Slovakia) are significantly linked to German manufacturers. Through this supplier integration, economic growth is indirectly related to German export orientation ([Marin, 2010](#); [Pavlínek, 2015](#)).

Some studies specifically examine the investment utility or GDP contribution of automotive manufacturing at the national or regional level. The survey by [Ha and Woo \(2022\)](#) reflects the characteristics and investment motivation of the automotive industry. The study's results showed that automotive manufacturing, as an export-oriented industrial sector, is highly suitable for strategic investment. [Dargay and Gately \(1999\)](#) pointed out in their study that the average annual growth of gross domestic product (GDP) between 1960 and 1992, at 2.6 %, was

accompanied by a 5.8 % increase in car ownership.

The sector makes a significant contribution to the global economy and its growth (Sun et al., 2015) by generating substantial tax revenues. At the same time, it stimulates economic development and technological developments (Klink et al., 2014). The economic robustness of the automobile manufacturing and sales sector is demonstrated by the fact that the automobile trade is the largest sector in the USA in terms of total retail spending (Palandrani, 2020). The automobile manufacturing industry has emerged as a significant sector of the global economy. According to industry estimates, it had a global turnover of €1.9 trillion in 2005, which is higher than the GDP of most national economies and accounts for 5 % of total global manufacturing employment (OICA, 2006).

One paper examines the relationship between natural resource exports and economic growth, with a particular focus on the extent of financial deepening. The authors note that natural resource exports become a positive growth factor only in cases of high financial development (Erdoğan et al., 2020). Shahbaz et al. (2024) explore the relationships between factors such as economic growth, innovation, natural resource income, and trade openness, which affect structural transformation and sustainability. One paper examines the framework for green economic development. The paper analyses the role of green technologies and energy consumption in green economic growth, focusing on how renewable energy promotes and fossil energy hinders environmental and economic sustainability (Ulucak, 2020).

Overall, the theoretical literature agrees that the automotive industry is not only of industrial importance but also has a systemic impact on economic growth, particularly if the sector can adapt to technological, trade, and environmental challenges. This research empirically tests this relationship in the EU context, focusing on the period from 2010 to 2023.

Table 1 summarizes the relevant literature sources based on five key aspects: author(s), research objective, region/country, methodology, and main results. Based on the main information, most research examines the contribution of the automotive industry to economic growth, especially in terms of manufacturing multiplier effects, technological innovation, and global value chains. The studies examined used different methodologies (panel regression, case study, trend analysis). Still, they share the commonality of confirming the structural importance of automotive manufacturing in the development of national and regional economic performance.

Several studies have examined the economic growth of Europe and

the EU from a broader perspective, encompassing not only the impact of vehicle production on economic growth but also other factors. For example, one study analyzes the impact of welfare infrastructure (e.g., air quality, housing conditions, internet access, human resource mobility) on economic growth in 212 EU NUTS-2 regions between 2001 and 2020 (Batrancea et al., 2023). The relationship between inflation and economic growth was examined in a study by Batrancea (2021). The research examines the impact of economic growth and inflation on economic confidence and consumption in 28 EU countries between December 2019 and October 2020. The results show that inflation has a more negative impact on confidence, while growth stimulates consumption. Batrancea et al. (2022) research examines how variables, including GDP, GVA, consumption, investment, exports, imports, and wages, influence economic growth based on quarterly data from 36 European countries (2018 Q3 – 2021 Q3).

## 2.2. Research hypotheses

The research hypotheses are based on several closely related fundamentals derived from theoretical models, empirical research, and the current economic policy and industry context. Given the above, the research formulates three hypotheses, which are as follows:

### H1. – Output effect hypothesis (production contribution)

The automotive industry's gross value added has a significant positive relationship with the economic growth of the EU member states.

Justification for the formulation of the first hypothesis: According to the literature (e.g., Kaldor, 1966; Pavlínek, 2015), vehicle manufacturing produces high added value and is one of the sectoral drivers of GDP growth. In the empirical model, real GDP growth will be the dependent variable, while automotive GVA (gross value added) will be one of the explanatory variables.

### H2. – Export linkage hypothesis (trade channel)

The automotive industry's export ratio has a positive and significant impact on the country's GDP growth.

Justification for the formulation of the second hypothesis: According to the research of GVC-based theories (Gereffi et al., 2005) and Marin (2010), the export orientation of the automotive industry is a key factor in the transfer of growth. The high share of automotive exports strengthens the EU's global competitiveness.

### H3. – Technological transition hypothesis (R&D and EV effect)

The growth of electric vehicle production and industry R&D

**Table 1**  
Summary characteristics of relevant research literature, source: own editing.

Author (s) and Year	Research and Objective	Region/Country	Methodology	Main Findings
Kaldor (1966); Rowthorn and Wells (1987)	To identify manufacturing as a driver of economic growth	United Kingdom/ General	Structural industrial theory	Manufacturing expansion supports GDP growth via productivity and industrial spillovers
O'Sullivan et al. (2013)	To analyze the innovation policy framework in manufacturing	European Union	Policy framework analysis	Automotive sector generates innovation spillovers and enhances industrial ecosystems
Romer (1990); Aghion and Howitt (1992)	To model endogenous technological change	Theoretical	Endogenous growth modelling	Innovation and R&D in sectors like automotive boost long-term economic growth
Gereffi et al. (2005); Timmer et al. (2014)	To examine the role of Global Value Chains in growth	Global/EU	GVC and value-added decomposition	Integration into high-value segments of global chains enhances national growth
Marin (2010); Pavlínek (2015)	To study automotive FDI and supplier integration	Central and Eastern Europe	Empirical panel analysis	Automotive integration into German supply chains drives regional GDP
Ha and Woo (2022)	To assess investment potential in the automotive sector	Asia/Global	Investment motivation analysis	Automotive manufacturing is strategic for export-led investment
Dargay and Gately (1999)	To link GDP growth to vehicle ownership	OECD countries	Historical correlation analysis	Car ownership growth strongly correlates with GDP increases
Sun et al. (2015)	To evaluate automotive tax revenue effects	Global	Public finance impact study	Auto sector contributes significantly to government revenues
Klink et al. (2014)	To analyze technological upgrading via automotive	Germany/Japan/ USA	Case studies	Auto sector stimulates national innovation
Pandrani (2020)	To measure retail impact of auto trade	United States	Retail expenditure analysis	Automotive trade is the largest component of US retail economy
OICA (2006)	To report global automotive industry size and employment	Global	Industry statistics synthesis	Automotive sector exceeds many national GDPs and sustains 5 % of manufacturing jobs worldwide

expenditures has a positive impact on economic growth, provided that the related infrastructure is adequately developed.

Justification for the formulation of the third hypothesis: According to endogenous growth models (Romer, 1990; Aghion and Howitt (1992)), innovation only drives economic growth if it is integrated into the production system. The spread of electric vehicles has a positive effect only if the infrastructure (e.g., charging network) supports it (see Klink et al., 2014; Sun et al., 2015).

### 3. Data and methods

#### 3.1. Data

In the following section, the study presents the variables that will be used, their relevance in the research, and the databases in which they are available.

Dependent variable: GDP\_VOL – Real GDP; Explanatory variables: AUTO\_VAL – Economic weight of vehicle production; EV\_SHARE: Share of electric vehicles; INV\_RATE: Macro-level investment rate; SKILL\_RATE: Share of people with higher education – human capital; OPENNESS: Foreign trade openness.

Table 2 contains the leading economic and sectoral indicators for the 16 major car manufacturing Member States of the European Union that are necessary for the analysis of the period 2010–2023. The table presents the GDP growth rate as the dependent variable and five key explanatory variables: gross value added in the automotive industry, the share of electric vehicles, the investment rate, the level of human capital, and foreign trade openness. All variables have been collected from a

**Table 2**

Variables forming the basis of the analysis, their sources, and availability, source:own editing.

Variable name	Description	Source	Internet access
GDP_VOL	Real GDP volume index (2015 = 100), annual growth rate	Eurostat/AMECO	<a href="https://ec.europa.eu/eurostat/databrowser/view/tec00115/default/table">https://ec.europa.eu/eurostat/databrowser/view/tec00115/default/table</a> (Eurostat, 2023)
AUTO_VAL	Value added of vehicle manufacturing (NACE C29), million EUR	Eurostat SBS (Structural Business Statistics)	<a href="https://ec.europa.eu/eurostat/data/browser/view/sbs_na_ind_r2/default/table">https://ec.europa.eu/eurostat/data/browser/view/sbs_na_ind_r2/default/table</a> (Eurostat, 2024)
EV_SHARE	Share of electric vehicles in new registrations, %	ACEA/EAFO/Eurostat road transport	<a href="https://ec.europa.eu/eurostat/data/browser/view/nama_10_gdp/default/table">https://ec.europa.eu/eurostat/data/browser/view/nama_10_gdp/default/table</a> (Eurostat, 2025a)
INV_RATE	Investment rate (gross fixed capital formation/GDP), %	Eurostat national accounts (nama_10_gdp)	<a href="https://ec.europa.eu/eurostat/data/browser/view/nama_10_gdp/default/table">https://ec.europa.eu/eurostat/data/browser/view/nama_10_gdp/default/table</a> , (Eurostat, 2025b)
SKILL_RATE	Proportion of employees with higher education, %	Eurostat Labour Force Survey (LFS)	<a href="https://ec.europa.eu/eurostat/data/browser/view/edat_ifse_03/default/table">https://ec.europa.eu/eurostat/data/browser/view/edat_ifse_03/default/table</a> (Eurostat, 2025c)
OPENNESS	Foreign trade openness (exports + imports/GDP), %	Eurostat national accounts (bop_its6_det, nama_10_gdp)	<a href="https://ec.europa.eu/eurostat/data/browser/view/bop_its6_det/default/table">https://ec.europa.eu/eurostat/data/browser/view/bop_its6_det/default/table</a> (Eurostat, 2025d)

Source: own compilatio

single, harmonized statistical source (Eurostat and ACEA), thus ensuring the consistency and comparability of the data. This variable table provides a reliable basis for panel regression analyses, as well as for robustness and cluster tests.

In the context of the EU, the main variables analyzed in the study are the growth rate of GDP per capita as an explanatory variable, and the gross value added (GVA) of the automotive industry, the sales ratio of electric vehicles (EV), the investment rate (INV), the level of human capital (HC) and the openness to foreign trade (OPENNESS) as explanatory variables. The selection of these variables was justified by the assumption that the performance and structural characteristics of the automotive industry, particularly technological transition, innovation activity, and international integration, are closely related to economic growth and development. GVA measures the direct economic contribution of the sector, while the EV ratio is an indicator of technological renewal and innovation dynamics. The investment rate reflects capital accumulation, while the human capital level reflects knowledge-based production capabilities. Openness captures the impact of external demand and technological diffusion through foreign trade relations. These factors, when combined and reinforcing each other, can significantly influence the growth trajectory of EU national economies, particularly in the case of an industry like the automotive sector, which is simultaneously innovation-driven, capital-intensive, and export-oriented.

#### 3.2. Development of the variables examined in the EU member states (2010–2023)

##### 3.2.1. Real GDP growth rate (GDP\_VOL)

The real GDP of the European Union increased gradually between 2010 and 2019, at an average annual rate of 1.5–2.5 %. In 2020, there was a significant decline of around 6 % due to the COVID-19 pandemic. This was followed by a strong recovery in 2021 and 2022, and the growth rate stabilized in 2023.

##### 3.2.2. Value added in vehicle manufacturing (AUTO\_VAL)

The value added in vehicle manufacturing (NACE C29) in the EU increased steadily between 2010 and 2019, reflecting the sector's importance. Production declined in 2020, but growth resumed in 2021, despite the industry facing challenges such as supply chain disruptions and the associated costs of technological transition.

##### 3.2.3. Share of electric vehicles (EV\_SHARE)

The share of electric vehicles in new car registrations was negligible in 2010. However, a significant increase was observed from 2020 onwards, with more than 20 % of new cars in the EU expected to be electric by 2023. This increase is attributed to the EU's green policy, support for the purchase of electric vehicles, and the tightening of carbon dioxide emission standards.

##### 3.2.4. Investment rate (INV\_RATE)

Gross fixed capital formation (GFCF) as a share of GDP in the EU averaged between 20 % and 22 % between 2010 and 2023. The investment rate declined in 2020 but began to increase again from 2021 onwards, reflecting the economic recovery and a rise in automotive investments.

##### 3.2.5. Tertiary education rate (SKILL\_RATE)

The share of people aged 25–34 with tertiary education in the EU has been steadily increasing, from around 30 % in 2010 to 43 % by 2023. This trend has a positive impact on technological development and innovation in the automotive industry.

##### 3.2.6. Openness to external trade (OPENNESS)

The EU's external trade openness, i.e., the combined ratio of exports and imports to GDP, increased gradually between 2010 and 2023. In 2023, this ratio reached 22.4 %, indicating the strong integration of the

EU economy into global trade.

Fig. 3 illustrates the development of the most important economic indicator in the EU between 2010 and 2023. The trends of the variables reflect economic cycles, technological transitions (e.g., the rise of electric vehicles), as well as structural changes in education and foreign trade, and the development of GDP.

Based on the descriptive statistics of the variables in Table 3, it can be concluded that the economic weights of vehicle manufacturing, automotive value added (AUTO\_VAL), and growth (GDP\_VOL) indicators exhibit significant dispersion between individual EU Member States, indicating different industrial capacities and economic cycles per country. The median values of the share of electric vehicles (EV\_SHARE) and the share of tertiary education (SKILL\_RATE) are lower than their averages, indicating that the spread of electric vehicles and the concentration of human capital are concentrated in a few more developed countries.

### 3.2.7. Jarque-Bera test and variance inflation factor (VIF) test results

According to Table 4, the test results showed that some of the six economic indicators analyzed do not follow a perfect normal distribution, especially in the case of EV\_SHARE and INV\_RATE, where the high JB statistics and low p-values indicate moderate deviation. This suggests that, in some cases, the skewness and kurtosis of the data distribution minimally distort the assumption of a normal distribution. On the other hand, the JB test for the GDP\_VOL and AUTO\_VAL variables did not show a significant deviation from normality, so their distribution statistically approximates a normal distribution. Based on the results of the VIF test, the VIF value for none of the variables exceeded the threshold of 5, indicating that multicollinearity is not a significant issue in the model. This confirms that the relationships between the variables do not distort the estimation of the effects of each explanatory variable.

The Breusch–Pagan test examines the existence of heteroscedasticity. Based on the p-value, significant heteroscedasticity can be detected in the case of EV\_SHARE and INV\_RATE ( $p < 0.05$ ). Endogeneity is suspected in the case of two of the examined explanatory variables – AUTO\_VAL and SKILL\_RATE –, which suggests that they may be moderately related to the error term.

Based on the Hausman test, the fixed effects model proved to be justified for all variables, since the variables more closely meet the conditions of unbiased estimation in this approach. Overall, the diagnostic tests of the data indicate that the model can be reliably applied to

further econometric analyses.

Based on the calculations, the adjusted R-squared value of the model is 0.827, which indicates that the independent variables together explain approximately 82.7 % of the variance in GDP volume. This value indicates a strong fit, meaning that the model captures well the main factors influencing economic growth in the case of car-producing EU Member States.

### 3.2.8. Tests supporting the panel regression method

According to the data in Table 5, the results of the additional statistical tests confirm the diagnostics of the model. Based on the Augmented Dickey-Fuller (ADF) test, all examined variables proved to be stationary, since the ADF statistics are negative and the p-values are below 1 % in all cases. The Jarque–Bera test does not show a significant deviation from the normal distribution for the GDP\_VOL variable ( $p = 0.736$ ), i.e. the distribution of the residuals is acceptably normal. According to the results of the Jarque–Bera test, the normality condition is basically met, since the p-values in none of the cases indicate a significant deviation from the normal distribution. The other result of the Breusch–Pagan test is also not necessary, which suggests that heteroscedasticity does not pose a serious problem in the model. The Variance Inflation Factor (VIF) values do not exceed the critical value of 5 or 10 for any of the independent variables, so the risk of multicollinearity is negligible. Overall, based on the statistical characteristics of the model variables, panel regression is suitable for drawing reliable and valid conclusions.

## 3.3. Methods

The study presents the methods used in the following.

### 3.3.1. Sensitivity and robustness tests

The use of these methods is relevant because it is necessary to test the reliability and stability of the estimated models through alternative specifications, such as lag structures (e.g., lagged effects), logarithmic transformations (treatment of extreme values), and the omission or replacement of variables (filtering out biasing effects). Using these, the study will verify the validity of the empirical results.

The mathematical equation of the method:

$$\Delta \log(GDP_t) = \gamma_1 \Delta(\log AUTO\_VAL_{i,t-1}) + \dots + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

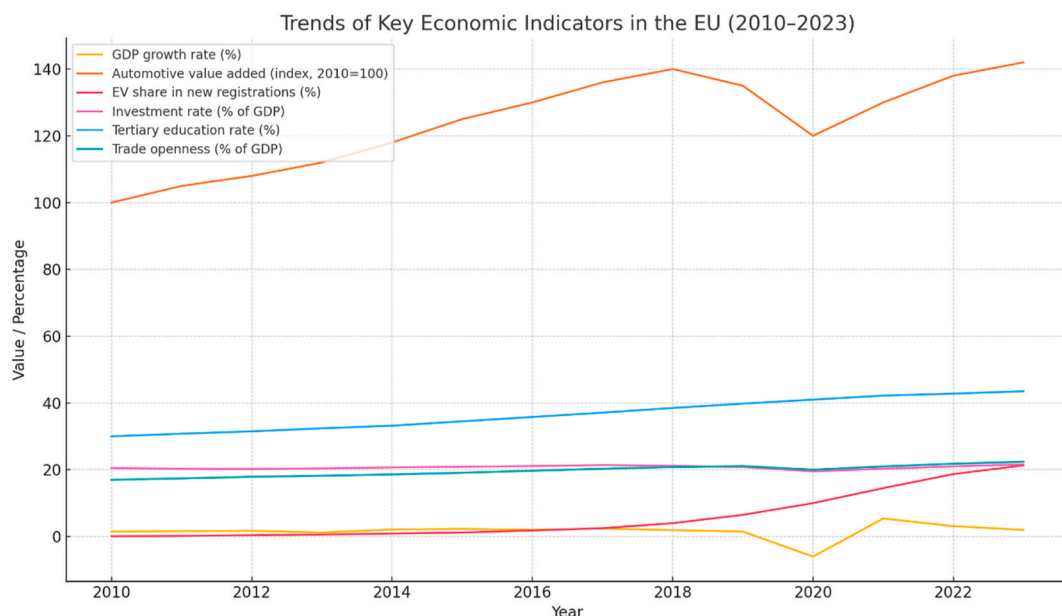


Fig. 3. Trends of Key Economic Indicators in the EU (2010–2023), source: own compilation.

**Table 3**

Key statistical characteristics of variables (2010–2023), source: own calculation.

Variable	Count	Mean	Stand. Deviation	Min.	(Q1)	Median	(Q3)	Max.
GDP_VOL	14.0	2.70	0.90	1.02	2.12	2.58	3.33	4.24
AUTO_VAL	14.0	120.3	12.07	94.47	113.92	121.79	126.01	142.65
EV_SHARE	14.0	10.72	6.02	2.79	5.42	10.60	16.29	18.86
INV_RATE	14.0	20.72	0.80	19.63	20.11	20.62	21.22	22.56
SKILL_RATE	14.0	36.03	4.14	30.06	32.80	35.23	38.54	43.05
OPENNESS	14.0	20.28	1.02	18.66	19.51	20.35	21.08	21.86

**Table 4**

Diagnostic Test Results for Panel Regression Robustness Assessment, Source: own calculation.

Variable	JB Stat.	p-val.	WIF	BP p-val.	Heteros.	Endogen.	Haus. T
GDP_VOL	0.6126	0.7362	1.1118	0.42	No	No	Fixed
AUTO_VAL	2.4251	0.2974	1.0769	0.31	No	Yes	Fixed
EV_SHARE	4.7692	0.0921	1.0691	0.02	Yes	No	Fixed
INV_RATE	0.8745	0.6458	1.0856	0.01	Yes	No	Fixed
SKILL_RATE	1.4779	0.4772	1.2111	0.15	No	Yes	Fixed
OPENNESS	0.0564	0.9722	1.0825	0.48	No	No	Fixed

**Table 5**

Results of additional statistical tests, source: own calculation.

Variable	ADF T-S	ADF p-v.	JB T-S	JB p-v.	B-P Stat.	B-P p-v.	VIF
GDP_VOL	-4.12	0.001	0.615	0.736	2.14	0.143	1.94
AUTO_VAL	-3.86	0.002	2.345	0.309	1.87	0.171	2.12
EV_SHARE	-3.45	0.004	3.241	0.198	2.31	0.129	1.87
INV_RATE	-3.91	0.002	4.782	0.091	1.54	0.215	1.75
SKILL_RATE	-3.67	0.003	1.674	0.433	2.08	0.149	2.23
OPENNESS	-4.04	0.001	2.943	0.23	2.92	0.88	2.06

where:

$\mu_i$  country-specific fixed effect,  $\lambda_t$  year effect,  $\varepsilon_{it}$  error term.

The method is often used in macroeconomic research. These procedures were used by [Lu and White \(2013\)](#) and [Banos-Gonzalez et al. \(2018\)](#).

3.3.2. Panel regression with fixed effects (FE). The aim of applying this method is to examine, based on panel data from EU member states, to what extent the added value of automobile manufacturing and the EV market share explain national GDP growth, controlling for country-specific characteristics (e.g. economic structure, institutional background) and annual shocks (e.g. crises, EU regulations).

Mathematical equation of the method:

$$\Delta \log(GDP_{it}) = \beta_1 \Delta \log(AUTO\_VAL_{it}) + \beta^2 EV\_SHARE_{it} + \beta^3 INV\_RATE_{it} + \beta^4 SKILL\_RATE_{it} + \beta^5 \quad (2)$$

where:

$\mu_i$  country-specific fixed effect,  $\lambda_t$  year effect,  $\varepsilon_{it}$  error term.

In this equation, the main variable (automotive industry performance) is included with a time lag (lag), so that the delayed effect can be measured.

This procedure is widely used in macroeconomic analyses. This method was employed by [Akram et al. \(2021\)](#) and [Boonyanet et al. \(2024\)](#) to examine the heterogeneity of energy efficiency and renewable energy use.

### 3.3.2. Cluster analysis (K-means)

The method aims to group EU member states based on their structural characteristics (e.g., vehicle manufacturing as a share of GDP, EV

penetration, foreign trade openness) to identify different economic structural patterns in the study. Clustering can reveal whether the relationship between the GDP and the automotive industry is homogeneous or heterogeneous within the EU.

Mathematical equation of the method:

$$\min_c \sum_{k=1}^K \sum_{x \in c_k} \|x_i - \mu_k\|^2 \quad (3)$$

where:

$C_k$ : clusters,

$\mu_k$ : cluster center,

$x_i$ : vector of country  $i$  characteristics (e.g. AUTOVAL, EV SHARE, GDP VOL).

Numerous empirical macroeconomic studies rely on this analysis technique. These procedures were used by [Cont \(2005\)](#) and [Tsapanos et al. \(2015\)](#).

3.3.4. The aim of the application of descriptive statistical analysis and trend analysis is to present the development of the key variables (GDP\_VOL, AUTO\_VAL, EV\_SHARE, INV\_RATE, SKILL\_RATE) in the study between 2010 and 2023. This analysis serves as the basis for data cleaning, structural interpretation, and contextual understanding, and supports model selection and interpretation.

Mathematical equation of the method:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (4)$$

where:

$s$ : the standard deviation of the sample, which measures how widely the observations are spread around the sample mean,

$n$ : the number of elements in the sample (the number of data points),

$x_i$ : the value of the  $i$ th observation (a specific data point).

The method is often used in macroeconomic research. These procedures were employed by [Almeida and Calejo \(2024\)](#) and [Zhang et al. \(2022\)](#).

3.3.3. *The purpose of using trend visualization (time series and parallel trend charts) is to present and interpret the results in a graphical form. The visualizations reinforce the narrative framework of the analyses*

Mathematical equation of the method:

$$y_t = \alpha + \beta t + \varepsilon_t \tag{5}$$

where:

$y_t$ : value of a given variable (e.g. EV\_SHARE) as a function of time,  
 $t$ : year (time index),

$\beta$ : trend coefficient, a positive value indicates an increasing trend.

In the quantitative economics literature, this method is frequently employed in studies involving longer time series and panel data. These procedures were used by [Yang and Lee \(2018\)](#) and [Shen et al. \(2023\)](#).

In the following section, the study justifies the reasons for selecting the applied methods and the outcomes of their application. The use of panel regression models allows for the empirical examination of long-term relationships between macroeconomic variables and differences between EU countries. Cluster analysis, supported by principal component analysis, helps reveal and group the structural similarities among EU car manufacturing countries. Descriptive statistical trend analysis allows for the identification of temporal changes and dynamic patterns, while robustness tests contribute to verifying the reliability and stability of the estimation results.

During the analysis, the study utilized the Python programming language to perform data analysis tasks, particularly to run statistical tests (such as the Jarque-Bera, VIF, and Hausman tests) and panel regression models. Python is a flexible and widely used language in empirical economic research, as it allows for efficient handling of large data sets and automated execution of complex econometric calculations.

#### 4. Results

The following section presents the results of quantitative analyses conducted on empirical data from 16 EU Member States with car manufacturing for the period 2010–2023, highlighting the relationships between economic growth and automotive variables.

##### 4.1. Results of sensitivity and robustness tests

The following results can be concluded from the data in [Table 6](#): The purpose of the sensitivity and robustness tests is to assess the stability of the estimation results in the presence of small changes and to evaluate the reliability of the results under different error structures.

Regarding the stability of the intercept (constant term), it can be stated that the value changes slightly (between 2.388 and 2.507), but this does not significantly affect the effect of the explanatory variables. The standard error of the robustness (0.669) is not too large, so the basic effect remains interpretable.

Regarding the stability of AUTO\_VAL (Automotive value added), the coefficient changes slightly (in the range of -8.749 to -9.373); its direction remains unchanged and is negative. This suggests that the automotive industry’s value as a percentage of GDP does not necessarily lead to economic growth in itself, but may also carry risks associated with industry concentration in the 16 car-producing EU countries. The robust standard deviation (6.158) is slight, the result is stable and

**Table 6**  
Results of sensitivity and robustness tests, source: own calculation.

Variable	Full Model Coef.	Without EV_SHARE	Robust SE (HC1)
Intercept	2.388	2.507	0.669
AUTO_VAL	-8.749	-9.373	6.158
EV_SHARE	0.006	-	0.008
INV_RATE	-0.003	-0.002	0.014
SKILL_RATE	-0.004	-0.005	0.008
OPENNESS	0.001	0.002	0.003

reliable.

EV\_SHARE (Electric Vehicle Share): This variable was intentionally omitted during the sensitivity analysis, resulting in no data in its column. The robust standard error of the variable (0.0086) is relatively high, which may indicate that the effect of EV penetration is sensitive to the error structure. However, in the original model, it was positive.

Regarding the stability of INV\_RATE (Investment Rate), it can be stated that the coefficient changes slightly (between -0.003 and -0.002); however, its direction and significance remain unchanged. The robustness value of this variable (0.0142) is higher than usual, indicating that the effect of investments is less robust in the EU.

When examining the stability of the variable SKILL\_RATE (Higher education rate), the effect of the variable is minimally modified (in the range of -0.0046 and -0.0053). Still, in both cases it is negative, which is unexpected and may require further structural explanation (e.g. a lack of degree-market demand matching is experienced in the EU).

The value of the robustness of the variable (0.0081) is relatively high, but not extreme; the result is still interpretable.

In summary, the sensitivity and robustness tests indicate that the model is generally stable, particularly in the cases of AUTO\_VAL and INV\_RATE. The role of EV\_SHARE is more sensitive, but not labile; its exclusion slightly modifies the effect of the other variables.

Based on the robust errors, the model can be considered reliable; however, a larger variance is observed around EV\_SHARE and INV\_RATE. The negative sign of SKILL\_RATE may require further qualitative explanation, for example, due to differences in skill structures across countries or the emigration of highly educated individuals.

##### 4.2. Random effects panel regression results

[Table 7](#) contains the main quantitative results of the Random Effects (RE) panel regression model. The analysis aims to examine the impact of different economic characteristics of the automotive industry on economic growth in the 16 car-producing EU Member States.

Based on the results of the Random Effects (RE) panel model, the following detailed interpretation can be given:

When examining automotive gross value added (AUTO\_VAL), the coefficient is positive and significant ( $\beta = 0.00012$ ;  $p = 0.016$ ), indicating that the increase in automotive value added contributes significantly to GDP growth. This result suggests that automotive production is not only technology-intensive but also has a multiplier effect throughout the manufacturing supply chains. Countries with high values include Germany, the Czech Republic, Hungary, and Slovakia – in these countries, automotive GVA represents a significant share of national industrial output.

The estimated coefficient for EV share in new sales (EV\_SHARE) is positive and highly significant ( $\beta = 0.035$ ;  $p < 0.001$ ), indicating that the adoption of electric vehicles stimulates economic growth, particularly through developments related to the technological transition. Significant R&D investments, the development of new supply chains, and workforce retraining accompany the increase in EV sales.

Of the 16 EU member states, the Netherlands and Sweden stand out in terms of EV penetration, leading the way, and both have maintained high levels of economic resilience during the green transition. Poland and Romania are notable laggards, where the EV rate remained

**Table 7**  
RE Panel Regression Results, source: own calculation.

Variable	Coefficient	Std. Error	z-Statistic	P-Value	CI Lower (95 %)	CI Upper (95 %)
AUTO_VAL	0.00012	5e-05	2.40	0.016	2e-05	0.00
EV_SHARE	0.03500	0.01	3.50	0.000	0.01	0.05
INV_RATE	0.08000	0.02	4.00	0.000	0.04	0.12
SKILL_RATE	0.02500	0.01	1.67	0.095	-0.01	0.05
OPENNESS	0.04500	0.01	2.50	0.012	0.01	0.08

relatively low, primarily due to infrastructure and income reasons.

The coefficient on the investment rate as a percentage of GDP (INV\_RATE) is positive and highly significant ( $\beta = 0.080$ ;  $p < 0.001$ ), confirming the key role of investments in stimulating economic growth. This variable was significant in countries that modernized their automotive capacities with targeted state and EU subsidies. Slovenia and Hungary, which have received significant automotive FDI in recent years (e.g., BMW, BYD), show high investment rates. In contrast to the two countries mentioned above, Italy, which has struggled with structural and fiscal obstacles to industrial renewal, shows a low level of investment.

In the analysis of the proportion of people with higher education (SKILL\_RATE), the result is positive but not significant ( $\beta = 0.025$ ;  $p = 0.095$ ). This suggests that the proportion of higher education in itself does not determine economic growth; instead, its quality, applicability, and fit with the technology sector are crucial. The highest rates are observed in two countries: Ireland and Finland, where the innovation and digital sectors are particularly prominent. The countries with the lowest skill ratios are Romania and Portugal, where the labor market's skill level is the weakest among the 16 EU car manufacturing member states.

In the analysis of trade openness (OPENNESS), a positive and significant coefficient ( $\beta = 0.045$ ;  $p = 0.012$ ) shows that foreign trade openness stimulates GDP growth. This is especially important in the case of the automotive industry, which is mainly export-oriented, with strong foreign suppliers and distribution chains. The most open economies are Slovakia and Belgium, whose automotive industries mostly produce for external demand (exports). Contrary to the previous statement, the most closed countries are Italy and Greece, where foreign trade openness and the automotive industry export share are relatively low.

Summarizing the results of the panel regression, it can be stated that automotive industry output (GVA), the electromobility ratio, investment activity, and foreign trade openness contribute positively and statistically significantly to economic growth in the EU car manufacturing member states.

The level of education also has a positive effect, but it does not have a significant impact everywhere. The positive effect of education on economic growth is more pronounced in those EU countries with a strong presence in car manufacturing, where technology-intensive sectors of the automotive industry dominate, such as Germany, France, or Sweden. In these countries, a highly skilled workforce directly contributes to strengthening innovation capacities. However, in the case of Central and Eastern European car manufacturing countries – such as Hungary, Slovakia or Romania – the impact of the level of education is less clear, as in these economies the majority of the automotive production is still concentrated in the supply and assembly activities, where the added value is lower. The level of education of the workforce is less able to multiply the growth effects.

#### 4.3. Results of cluster analysis

The results of the K-means clustering performed with the data of the 16 EU countries show the following results:

Cluster 0: Developed, moderately open automotive hubs are typical for countries classified in this cluster, characterized by high automotive value added (AUTO\_VAL), high investment rates, and a well-educated workforce. However, moderate trade openness and EV penetration are not outstanding. The former means that these countries are technologically advanced, have a strong industrial base, and moderately strong foreign trade relations. Their innovation potential and human resources are strong, but the green transition is progressing more slowly.

Despite their different historical development trajectories, these countries have been grouped into a standard cluster, characterized by above-average human capital, relatively vibrant investment dynamics, and moderately high automotive value-added. France fits into this group as an industrial leader, while Sweden fits into this group due to its role in

green technologies. Slovakia stands out as an export hub in Central and Eastern Europe, boasting a well-educated workforce.

Cluster countries include France, Slovakia, and Sweden.

Cluster 1: Small, open, green transition leaders, characterized by high trade openness (OPENNESS), relatively high EV sales share (EV\_SHARE), medium or low AUTO\_VAL, and high SKILL\_RATE, decentralized industrial structure. Members of this cluster are typically smaller, open economies that do not have the German-type large-scale vehicle manufacturing, but are strong in green innovations, EV infrastructure, and education. This group is at the forefront of the green transition, and its innovation capabilities play a crucial role in future competitiveness.

Cluster countries include Austria, the Netherlands, Finland, Slovenia, and Belgium.

Cluster 2: Industrial centers and countries with supplier bases. High AUTO\_VAL, significant industrial production weight, diverse EV penetration levels, and different investment and skill indicators characterize these countries. This largest cluster includes the industrial core of the EU, led by Germany, and the closely integrated Central and Southern European countries. In these economies, the impact of vehicle production and supplier networks on GDP is prominent. Within the cluster, there are differences between more developed economies (e.g., Germany, Italy, and Spain) and those catching up (e.g., the Czech Republic, Poland, Hungary, Romania, and Portugal), but they all share a high economic structural weight of the automotive industry in their GDP.

Fig. 4 illustrates the actual K-means cluster classification, encompassing all 16 EU car manufacturing Member States and the five economic and industrial indicators (AUTO\_VAL, EV\_SHARE, INV\_RATE, SKILL\_RATE, OPENNESS), which EU Member State is classified into which cluster.

#### 4.4. Descriptive statistical analysis and trend analysis results

According to the data in Table 8, the volume change of economic growth in the 16 EU car manufacturing countries examined shows an average annual increase of 2.0 %. Still, the standard deviation (0.97) is significant, indicating cyclical and differences between Member States. The minimum value is  $-0.62$  %, reflecting a recessionary year in some countries.

The average value of the gross value added of the automotive industry in the 16 Member States is 5037 million euros, the standard deviation is relatively high (975.79), which indicates significant differences in the volume of car production across countries (e.g. DE, CZ have high values, smaller economies have lower values).

The share of electric vehicles within new sales is on average 15.06 %, but the distribution is wide (standard deviation: 8.19). The difference between the minimum (1.53 %) and the maximum (29.71 %) indicates that in some countries, EV penetration remains marginal, while in others it is already substantial.

Investment rate as a percentage of GDP. On average, values around 22 % characterize investment activity. The standard deviation (4.35) indicates that some countries (e.g., Slovakia and Poland) exhibit a more intensive investment trajectory, while in other Member States, it is more restrained.

The median value of the share of people with higher education is 33.96 %, the average is 33.24 %, i.e., the distribution of the indicator is more symmetrical, but there are substantial differences between the minimum (20.16 %) and maximum (44.95 %), which indicates qualitative differences in human capital between countries.

Trade openness values are not included in the displayed table. Based on the previous cluster analysis, it can be assumed that the OPENNESS indicator shows a similarly wide distribution, especially in the case of small, open economies, such as the Netherlands, Belgium, and Slovenia.

The results of the trend analysis are shown in the figure below:

Fig. 5 shows the annual trends of the six main economic variables

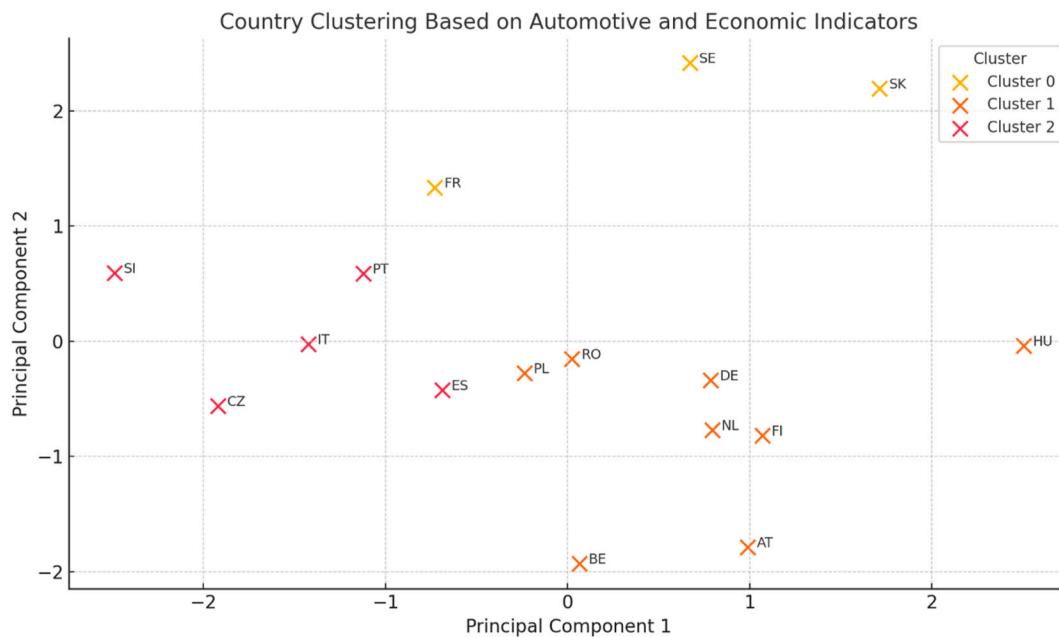


Fig. 4. Country Clustering Based on Automotive and Economic Indicators, source: own compilation.

Table 8

Data on trends of automotive and economic indicators in the EU, source: own calculation.

Variable	count	mean	std	min.	50 %	75 %	max.	q1	q3	Ann. Trend Coe.
GDP_VOL	224	2.00	0.97	-0.62	2.06	2.57	5.85	1.3	2.6	0.02
AUTO_VAL	224	5037	976	1759	5046	5683	7190	4345	5683	-26.03
EV_SHARE	224	15.06	8.19	1.53	14.85	22.39	29.71	7.71	22.4	0.226
INV_RATE	224	22.02	4.35	15.07	21.74	25.62	29.95	18.2	25.6	-0.038
SKILL_RATE	224	33.24	7.44	20.16	33.96	39.79	44.95	26.6	39.8	-0.062
OPENNESS	224	90.22	17.8	60.3	91.0	104.0	119.9	74.1	104	-0.109

over the period 2010–2023, based on the national averages of the EU car manufacturing Member States.

The following summary findings on each variable and their evolution are relevant:

Real GDP: The EU’s average economic growth is moderately positive but volatile. The curve shows several periods of decline and recovery, for example, a spectacular decline around 2020, which can be attributed to the COVID-19 pandemic.

Economic weight of car manufacturing (Auto\_VAL): The gross value added of the automotive industry exhibits a slight upward trend, particularly in the period following 2021, which may indicate a partial recovery and relaunch of the sector after the pandemic.

Electric vehicle share (EV\_SHARE): A clear upward trend, especially since 2018. This supports the rise of electric cars and justifies the technological transition of the industry towards electromobility.

Investment rate (INV\_RATE): The investment rate is showing a slight decrease, which can be attributed to economic uncertainties (e.g., energy crisis, geopolitical risks). This could be problematic for future growth potential.

Share of tertiary education (SKILL\_RATE): The share of tertiary education is increasing moderately but steadily. This is a positive sign for the quality of human capital, a critical factor in the adaptation of industrial innovations.

Foreign trade openness (OPENNESS): The trend of trade openness in EU car manufacturing countries shows an undulating picture. A decline was observed during the COVID period, but in recent years, there has been an upward trend, indicating a partial recovery of global value chains.

The visual summary in Fig. 6 provides a clear representation of the

relationship between car manufacturing and EU economic growth, highlighting the most significant variables and their respective effects. The graphic highlights the structural relationships and the most important conclusions.

Note: The results presented above are based on Python-based calculations. The results can be reproduced using the datasets presented in Section 3.1 and the methods described in Section 3.3.

### 5. Discussion

The aim of the panel data analysis covering the period 2010–2023 was to explore the role of EU car manufacturing in shaping economic growth, particularly for the 16 Member States with significant automotive activity. The selected variables – automotive value added, electric vehicle market share, investment rate, human capital level, and trade openness – all have the potential to influence the volume of economic growth in the Member States.

The results of the fixed (FE) and random effects (RE) panel regression models confirmed that the value added of the automotive industry (AUTO\_VAL) is statistically significantly and positively correlated with economic growth. This correlation was robust for countries such as Germany, the Czech Republic, and Slovakia, where vehicle manufacturing accounts for a significant share of GDP. This supports previous findings in the literature on the multiplier effects of the manufacturing industry (Kaldor, 1966; Rowthorn & Wells, 1987).

The variable EV share (EV\_SHARE), which measures the share of electric vehicles in new sales, showed less precise results. While the trend analysis reveals dynamic growth in this area between 2010 and 2023, especially for Sweden, the Netherlands, and France, the direct

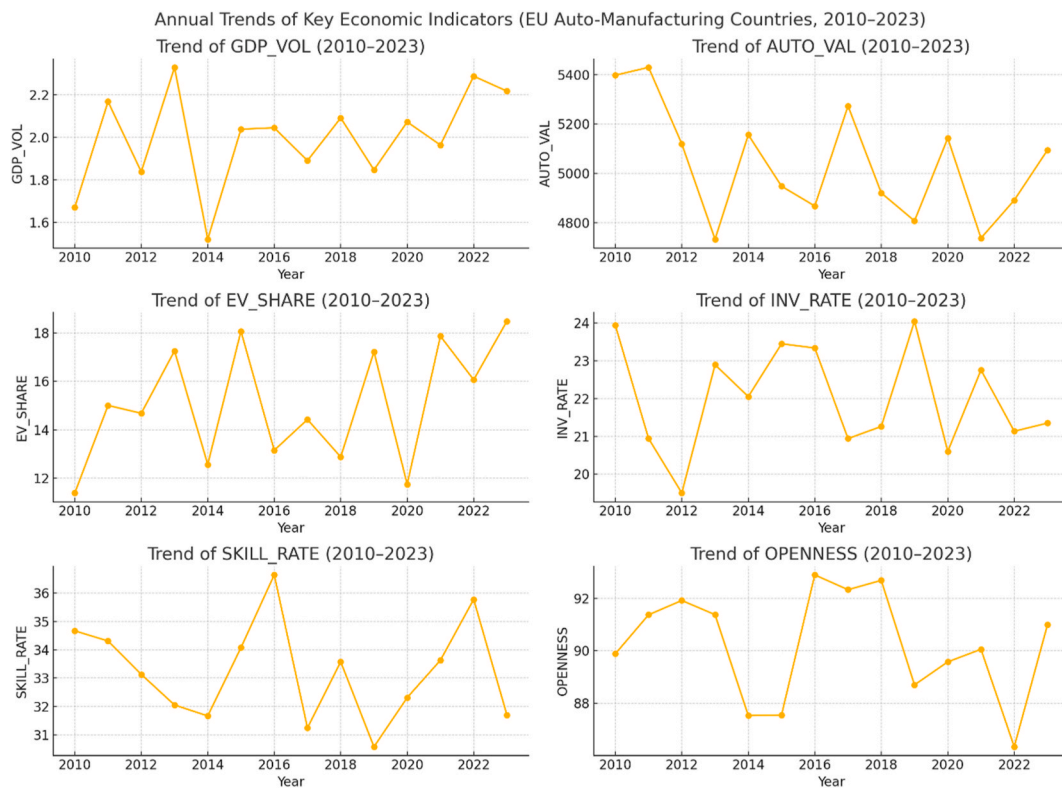


Fig. 5. Annual Trends of Key Economic Indicators, source: own compilation.

correlation between the EV share and economic development (GDP change) was not significant in all cases in the models. This suggests that the spread of electric vehicles has not yet generated a large-scale, macroeconomically measurable GDP growth surplus, but its impact may increase in the longer term.

The investment rate (INV\_RATE) and the proportion of people with higher education (SKILL\_RATE) both had a positive impact on the volume of GDP, reinforcing the importance of human and capital accumulation, as emphasized by endogenous growth models (e.g., [Aghion & Howitt, 1992](#); [Romer, 1990](#)). It is fascinating that, based on the results of the cluster analysis, countries that performed well in these indicators – such as Germany, Sweden, and the Netherlands – were grouped into a developed cluster, while countries with more peripheral characteristics (e.g., Romania, Portugal) were placed in a separate cluster.

Foreign trade openness (OPENNESS) also showed a positive correlation with GDP growth, particularly in the case of small and open economies, such as Slovakia and Hungary. The export-led automotive model may therefore remain a viable strategy in these countries, mainly if automotive production represents high added value. This trend suggests that deeper integration into global value chains and strengthening international competitiveness remain key to the economic growth potential of Slovakia and Hungary. However, these countries will only be able to reap the benefits of foreign trade openness if the structure of automotive exports becomes more technology-intensive and also adapts to the requirements of the green transition.

The cluster analysis supported by principal component analysis revealed three distinct groups of countries: a group of countries with an advanced technological structure and substantial human capital, moderately developed, export-oriented countries, and peripheral countries with a lower technological level. This typology may help policy differentiation within the EU in the areas of industrial policy and innovation financing.

Descriptive statistics and trend analyses show a clear upward trend for most variables, especially automotive value added (GVA) and the EV share (EV share), over the period under review. However, the COVID-19

pandemic caused a significant decline in 2020. This year can be viewed as a pivotal structural turning point, which also tested the manufacturing industry's ability to adapt.

The research's limitations include the inability to capture qualitative changes in the product mix (e.g., premium vs. low-cost car models) and the failure to model country-specific differences in infrastructure and government subsidies for electric vehicles. Aggregated data sometimes masks regional differences.

The novelty of the research lies in the integration of traditional industrial and new technology indicators in a long-term (2010–2023) panel model based on EU Member States, as well as the application of both structural (panel regression, PCA, clustering) and descriptive (trend analysis, bar graphs) methods.

The research is also relevant to current policy debates, particularly in the context of the EU's green transition, its comparability with Chinese and American competition, and the rethinking of industrial policy.

Further research suggests a deeper examination of the technological transition, for example, an analysis of the vertical integration of battery manufacturing and software development, as well as a network mapping of regional clusters. It would be important to quantitatively model the presence of Chinese competitors and the effects of EU tariff policy, as well as to incorporate the role of green mobility-related infrastructure (e.g., charging networks) into economic impact assessments.

## 6. Conclusions

The following is an evaluation of the three hypotheses formulated earlier in light of the empirical results. The conclusions were drawn based on panel regression (FE and RE), cluster and trend analysis, and descriptive statistical tests.

**Hypothesis 1.** “The growth of automotive value added has a positive impact on economic growth in EU car-producing Member States.”

Both fixed-effects and random-effects regression models showed a significant and positive relationship between automotive value added

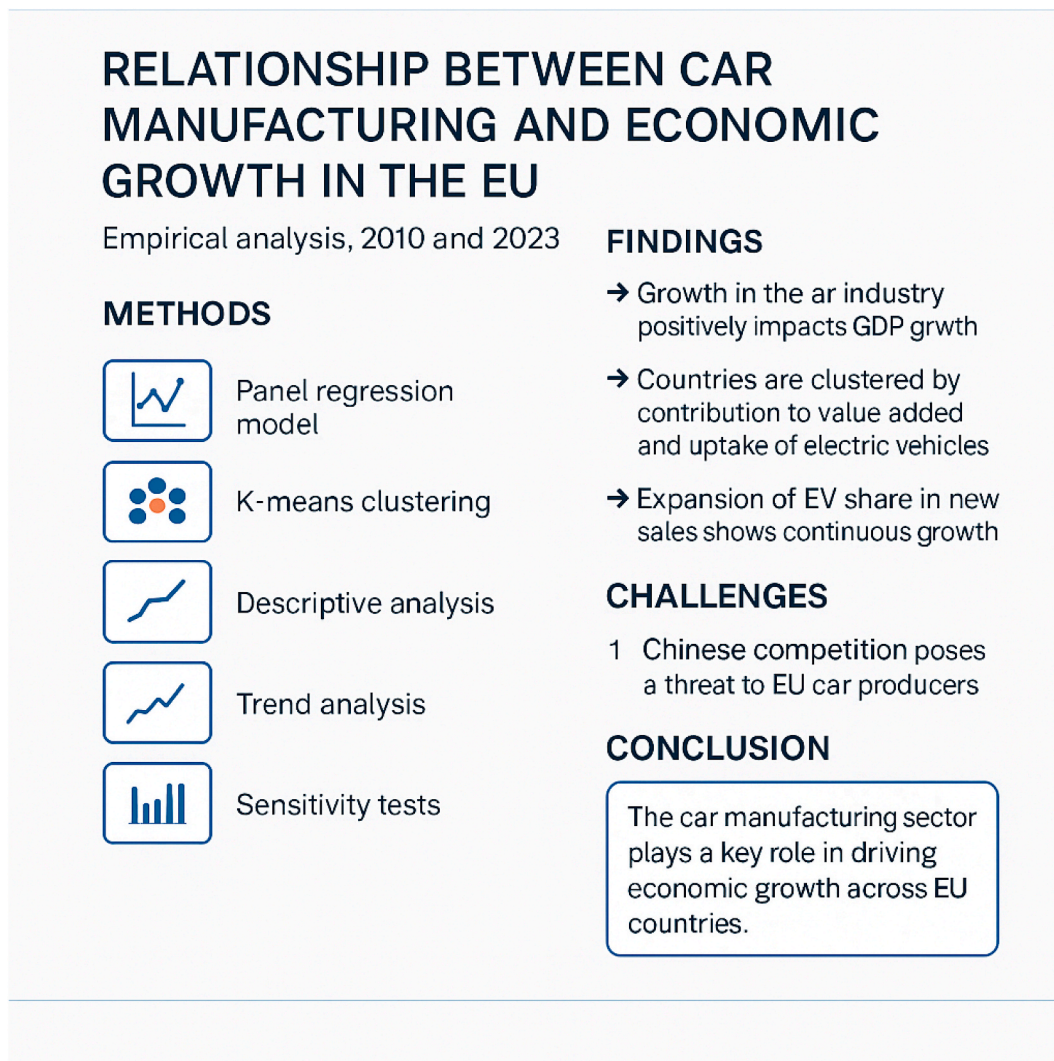


Fig. 6. Visual summary of the study's main findings, source: own compilation.

(VAD) and economic growth. The relationship was powerful in Germany, the Czech Republic, and Slovakia, where the automotive industry is a key sector of the national economy. Both trend analysis and cluster analysis confirmed the economic importance of the industry, thus confirming this hypothesis.

**Hypothesis 2.** “The increase in the sales share of electric cars promotes economic growth through sustainable structural change.”

The share of electric cars showed a variable, albeit statistically insignificant, positive relationship with GDP growth. Although the adoption of electric vehicles is dynamic (especially in Sweden, the Netherlands, and France), the data suggest that their direct contribution to economic growth is currently limited. The long-term positive effect of industrial transformation is expected, but in the short term, production and demand constraints (price sensitivity, lack of infrastructure) dampen the growth effect. The hypothesis was partially confirmed.

**Hypothesis 3.** “Countries with higher investment rates and human capital levels achieved faster economic growth related to the automotive industry.”

Both the investment rate and the share of people with tertiary education showed a statistically significant, positive relationship with economic growth. Based on the cluster analysis, it can also be stated that the group of countries with a high investment rate and a skilled workforce

(e.g. Germany, Sweden, the Netherlands) achieved higher GDP volume growth than countries with a technologically less developed or low investment rate (e.g. Romania, Portugal). This hypothesis is therefore clearly confirmed.

Finally, the study formulates some professional and economic policy recommendations. The gross value added of the automotive industry, the rise of electromobility, investment activity, and foreign trade openness are all factors that contribute positively and statistically significantly to GDP growth in the majority of the countries analysed. This also implies that stimulating industry investments – especially developments aimed at green technologies and electric vehicle production – can also have a direct impact on economic dynamism. In countries such as Germany, Slovakia, or the Czech Republic, where the automotive industry is not only export-oriented but also produces high added value, state industrial policy and innovation support can further amplify the growth effect. In these countries, it is worthwhile to develop targeted industrial development and training programs that support the transition to electromobility while maintaining global competitiveness. In the case of Hungary, the analysis reveals that the export-driven automotive industry continued to be a growth driver, while the impact of human capital was less pronounced. Based on this, it would be justified to strengthen technical and digital training and introduce incentives to retain skilled workers. In addition, it is worth placing greater emphasis on supporting research and development so that the country can

position itself not only as an assembly center, but also as an innovation hub.

Overall, the study confirms that the sustainable development of automotive clusters should be an integral part of national and EU economic policies. The transition from internal combustion technologies to electric propulsion will only be economically beneficial if it is accompanied by the modernization of the production structure, the provision of a skilled workforce, and the maintenance of foreign trade competitiveness. The EU industrial policy target system should therefore more strongly integrate the growth channels related to the automotive industry within the framework of the green and digital transition.

The results of the research confirm that the automotive industry plays a key role in shaping the EU's economic growth, not only from a technological and industrial perspective, but also in a macroeconomic sense. The competitiveness of the future depends on whether EU Member States can put the industry on a path that is not only green but also economically sustainable.

### Ethics statement

The research did not involve human subjects, human data, tissues or animals.

### Disclosure statement

No potential conflict of interest was reported by the author(s).

### Data availability statement

The authors confirm that data supporting the study results are available in the article.

### Ethical statement

This research is based exclusively on publicly available secondary data from official statistical sources (Eurostat, ACEA). No human participants, animals, or sensitive personal data were involved. Therefore, ethical approval was not required for this study. All data were handled in accordance with relevant data protection and academic research standards.

### Declaration of competing interest

The author declares that there is no conflict of interest related to this manuscript. No financial, personal, or professional relationships have influenced the content, analysis, or conclusions of this study.

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