THE IMPACT OF EMISSIONS REGULATIONS ON THE AUTOMOTIVE INDUSTRY

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Abstract

The automotive industry is increasingly affected by stricter emission regulations introduced by the European Union in response to growing demands for sustainability and emission reduction in transport. These regulatory measures also have a significant impact on the strategies of automotive companies, but their comprehensive impact on the performance of European manufacturers has not yet been sufficiently analysed. The aim of this paper is to assess the economic impact of emission regulations on the automotive industry in the European Union and to identify how they affect European car manufacturers. Statistical methods, in particular correlation and regression analysis, are used to analyse the impact on the Volkswagen Group and its competitors, focusing on the relationship between emissions trends and selected variables. The results show that the current pace of electrification is not sufficient to meet the set emission targets and also point to the insufficient preparedness of the energy infrastructure. Based on these findings, recommendations are proposed in the area of corporate strategy for a specific car manufacturer and in the area of the regulatory framework, which reflect the economic and technological challenges associated with the transition to low-emission mobility.

Key words: emissions regulations, automotive industry, electromobility

JEL Code: L62, Q58, M21

Introduction

The European Union has long emphasized sustainable development, the fight against climate change, and green policies aimed at achieving climate neutrality by 2050. One of the key tools for achieving these goals is emissions regulation, which has a significant impact on the automotive industry, one of the important sectors of the European economy and a major producer of greenhouse gas emissions. According to available data, approximately a quarter of total emissions in the EU in 2022 were generated by transport, with emissions from road

transport 18 % higher than in 1990, despite efforts to reduce them. Reducing emissions in transport is also closely linked to the need to develop energy infrastructure capable of supplying environmentally friendly electricity, which requires linking the issue of electromobility with the energy sector. As a result of climate change and stricter emission standards, the European automotive industry is undergoing a fundamental transformation, the main direction of which is the transition from internal combustion engine vehicles (ICEV) to electric vehicles (BEV). The changes concern not only the propulsion of vehicles themselves, but also production and operational aspects. The gradual tightening of standards is forcing manufacturers to invest heavily in the development of alternative powertrains and low-emission technologies. Emission regulations thus not only affect the environmental performance of vehicles, but also have a significant impact on the performance of the automotive sector, its competitiveness, and its interaction with other industries. Given the extensive interdependence of the automotive industry with other sectors, it is difficult to accurately estimate the sector's impact on the European economy. It also remains to be seen how European manufacturers will fare in a market influenced by carbon neutrality targets and new competition.

1 Literature review

The environmental impacts of road transport are related to transportation, which accounts for 14% of global CO_2 emissions, making it one of the sectors with the greatest negative environmental impacts after energy, agriculture, and manufacturing. Approximately half of these emissions come from road transport. (Hannappel, 2017) Automobile transport is a significant source of pollution in many respects. Gradually, increasingly stringent emission regulations are being introduced with the aim of reducing the environmental burden associated with vehicle operation. However, as Li and Nam (2022) mention, the adoption of these regulations is not only conditional on reducing the burden on the environment.

To meet the 2030 emission targets, the share of electric cars sold will need to reach 27% to 41%. It will not be possible to achieve the set average emissions in the future by) simply increasing the efficiency of combustion engines. (Fritz et al., 2019) Emission regulations in the EU automotive industry have mixed effects. On the one hand, they stimulate technological progress, increase the competitiveness of manufacturers in international markets, and promote the reduction of greenhouse gas emissions (Li & Nam, 2022; Theilen & Tomori, 2023), but on the other hand, they lead to changes in market

behaviour. These include, for example, a preference for heavier vehicles (Pardi, 2021), attempts to circumvent regulations (Reynaert, 2020), and the deepening of regional inequalities within the supply chain (Szabó & Newell, 2024). Campos-Romero et al. (2024) also report that higher emissions are linked to the uneven distribution of roles between EU regions in production processes.

The regulatory system, based on average vehicle weight and laboratory emissions tests in accordance with EU regulations, has been criticized for its ineffectiveness in real-world driving conditions (Degraeuwe & Weiss, 2017), its impact on pricing (Čižinská & Chládková, 2021), and its socioeconomic impacts, such as rising car prices (Sharif et al., 2019) or potential risks related to employment (Szabó & Newell, 2024). Ecology in the automotive industry is highly complex and dependent on the specific conditions of individual countries. (Adamczyk et al., 2023; Qiao et al., 2017) Vehicle operation itself is not the only factor contributing to pollution; processes preceding production, such as the extraction and processing of raw materials, as well as the subsequent disposal of the vehicle at the end of its life, must also be taken into account. In the production phase, the amount of energy consumed causes the most damage, while the final life phase of a car is problematic due to possible soil contamination. (Staniszewska et al., 2020) Current literature points to a number of problems associated with the ineffectiveness of emission regulations, but there is a lack of proposals for alternative approaches and analysis of the specific impacts on individual car manufacturers.

2 Methodology

The aim of this paper is to analyse the impact of EU emissions regulations on the economic performance of passenger car manufacturers, specifically using the example of the Volkswagen Group. Based on the results, recommendations are proposed for regulators and for the automotive group itself with the aim of improving competitiveness and the ability to meet emission targets. The study focuses on assessing the impact of emission regulations on changes in the company's market position, the impact on the performance and saleability of cars, and the realistic setting of emission limits for the future.

Correlation and regression analysis were used to evaluate the relationships between emission regulations and economic indicators. Correlation analysis was performed using Pearson's correlation coefficient to identify linear dependencies between the following pairs of variables:

- average CO_2 emissions/km and the market share of electric cars,
- average CO_2 emissions/km and the average price of a new car,

- average CO_2 emissions/km and the number of cars sold

Statistical significance was tested using a t-test, with the null hypothesis H_0 (H_0: r = 0) (no linear dependence) being tested against the alternative hypothesis H_A (H_A: r ≠ 0). To reject H_0, the following must apply at a significance level of α = 0.05. In the case of statistically significant correlations, linear regression was then performed to identify trends in time series and predict the development of dependent variables. Regression models were tested at a 95 % confidence level. The statistical significance of individual coefficients was assessed using a t-test (based on p-values) and the overall quality of the model using an F-test. For the purposes of mutual comparison between companies and with the overall market, the data was converted to basic indices, where 100 % corresponds to the average value for the period 2015-2023.

Secondary quantitative data drawn from the annual reports of car manufacturers, the annual reports published by the European Automobile Manufacturers' Association (ACEA), the Statista portal, and relevant EU regulations are used to process the analyses. The data collection is limited to the period between 2015 and 2023, with 2015 chosen as the starting point due to the introduction of the 130 g CO_2/km limit. The calculations were performed using the Data Analysis tool in MS Excel. Benchmarking is used to assess the position of the Volkswagen Group and to compare it with its competitors (Stellantis, BMW Group, Mercedes-Benz), focusing on compliance with emission limits. The selection was made based on production volume in 2023 and a share of the European market exceeding 5 %. However, due to limited data availability, it is not possible to perform all analyses for the entire comparison sample.

3 Analysis results

The results were obtained based on correlation and regression analysis of selected variables listed in the methodology section. Due to data availability and the meaningfulness of the analysis, data for the company itself and the entire market were not analysed for all pairs of variables, but only for one of these variants. To determine the statistical significance of the correlation coefficients, Student's t-distribution with seven degrees of freedom was used, in this case n = 9, years 2015-2023. The significance level was set to the standard α = 0.05, which corresponds to the critical value $t_{crit} = 2.365$. Since the degrees of freedom and significance level were the same for all tests, this value applies to all pairs of variables. Pairs of variables for which the null hypothesis was rejected and which correlate significantly with

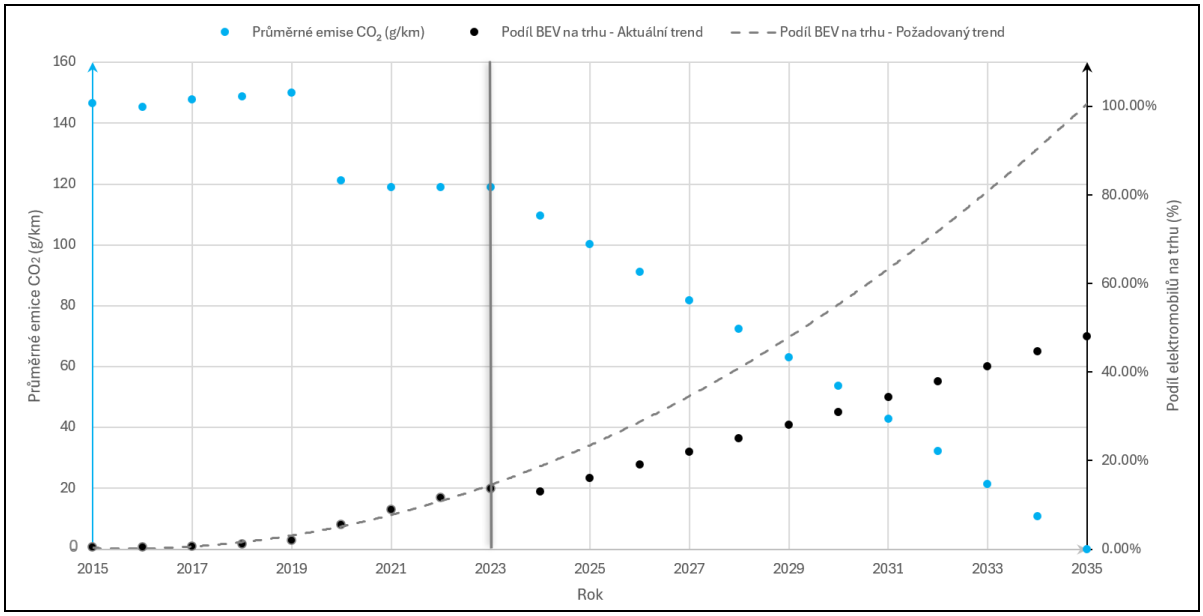
each other are also identified. The analysis then focuses on these variables and compares their characteristics with the competition. The results of the analysis for the identified correlating pairs of variables are then processed and presented: average CO_2 emissions/km and the market share of electric cars, average CO_2 emissions/km and the average price of a new car, average CO_2 emissions/km and the number of cars sold. The output of the regression analysis is always a linear function in the form $y = k_1x + k_2$ compiled according to the methodology described above.

Relationship between average CO_2 emissions and the market share of electric vehicles

Correlation analysis showed a strong statistically significant relationship between CO_2 emissions and the market share of BEVs within the EU. Although equivalent data is not available for all car manufacturers, it can be assumed with a high degree of probability that the trends for individual manufacturers will correspond to the aggregate trend for the market as a whole. This is because the emission targets are binding for all manufacturers, and they will have to comply with them in order to avoid penalties. Emissions values are not only influenced by the market share of BEVs, but also by the share of hybrid vehicles and modifications to combustion engines. However, due to design limitations, these technologies have limited potential for further reducing emissions. In the future, it will therefore be necessary to address emissions reduction primarily through a higher share of electric vehicles on offer.

The market share of electric vehicles was set as a dependent variable in the model, i.e., as a function of CO_2 emissions in g/km. The results of the regression model can therefore be interpreted in terms of the necessary market share of electric vehicles required to achieve a certain level of emissions. Two values were selected for the prediction of development in accordance with European legislation: 2030, when CO_2 emissions should be 55 % lower than in 2021, and 2035, when emissions from newly registered vehicles should reach zero. It is assumed that all manufacturers will strive to meet these targets evenly, rather than in leaps and bounds, even though in some cases it might be strategically advantageous to comply with the regulations at the last minute. However, this will not be technically and productionally feasible within a single year. For this reason, the model (Fig 1) chose a scenario of a linear decline in emissions between 2023-2030 and then 2030-2035.

Fig. 1 *Development of emissions and market share of electric vehicles in the EU*



Source Own processing based on data from the European Environment Agency and ACEA. (ACEA, 2024a; European Environment Agency, 2024c)

Based on historical data, a regression analysis was performed to identify the relationship between emissions and the market share of electric vehicles, where the linear equation has the form: $y = 0{,}481 - 0{,}0032 * x$. This relationship is statistically significant at the 5 % significance level. In the graph, the predicted values based on this relationship are shown by the black line, and it is clear that, assuming the current trend continues, this relationship will have to change when zero emissions are achieved, as the market share of BEVs is only 48 %. This is not technically feasible unless we consider the presence of other alternative powertrains or significant technological changes. The result of this analysis indicates that the reduction in emissions to date has been achieved mainly through the efficiency improvements of ICEVs and other transitional CO_2 reduction methods, rather than a significant increase in the share of electric vehicles. In addition to the current trend line, the graph also shows a grey line representing the desired development that would lead to the target of a 100% share of zero-emission vehicles by 2035. This trend was modelled as nonlinear to reflect aspects of the slowing effectiveness of transitional measures. The results of the model show that in order to achieve a 100 % share of electric cars on the market in 2035, their average year-on-year growth would have to be approximately 7.2 percentage points), which, given the current growth rate (2-3 percentage points per year) and other external factors (limited availability and capacity of charging infrastructure, consumer

demand trends, high purchase costs of electric cars), appears to be an ambitious goal. It can be said that achieving emission targets requires not only technological progress, massive investment in infrastructure and production, and a change in consumer preferences, but also support from governments and regulators.

Relationship between average CO_2 emissions and average price

The results of the regression analysis presented in Table 1 show a strong negative correlation between average CO_2 emissions and car prices at the market level (r = -0.95), with the model found to be statistically significant. In the analysis, emissions were set as the independent variable and car prices as the dependent variable, which allows the results to be interpreted in terms of a possible increase in prices following a reduction in emissions. This relationship assumes that reducing emissions is associated with higher costs for technology, materials, development, etc., which may subsequently be reflected in the final price of the car. Although the price is also influenced by other factors, this analysis can provide insight into how effectively individual companies are investing in emission reductions.

Tab 1 *Relationship between average CO_2 emissions (g/km) and average car price*

	total market	VW Group	Mercedes-Benz	Stellantis	BMW Group
correlation coefficient	-0.95	-0.87	-0.81	-0.81	-0.87
k_2	42 414	84 635	146 903	33 250	88 585
k_1	-109	-369	-485	-98	-298
P-value model	0.0001	0.0025	0.0087	0.0081	0.0023
P-value k_2	6E-08	0.0001	0.0001	4E-05	2E-05
P-value k_1	0.0001	0.0025	0.0087	0.0081	0.0023

Source Own processing based on data from annual reports, the European Environment Agency, and the Statista database. (BMW Group, 2024; European Environment Agency, 2024c; FCA, 2016; Mercedes-Benz Group, 2024; Statista, 2025; Stellantis, 2024; Volkswagen Group, 2024a)

The coefficient k_1, which indicates the change in the price of a car when emissions fall by 1 g CO_2/km, reaches a value of -109 €/g/km for the market as a whole. This relationship shows that a reduction in emissions of 10 g CO_2/km is associated with an average increase in the price of a car of 1,090 euros. This development probably reflects the rising costs associated with the implementation of low-emission technologies, but other factors such as inflation must also be taken into account. For all manufacturers examined, the null hypothesis was rejected at a 5 % significance level, indicating the existence of a statistically significant

relationship between emissions and prices. However, differences in the values of the coefficient k_1 were identified between individual car manufacturers. The results show that mainly premium manufacturers such as the BMW Group (k_1 = -298 €/g/km), VW Group (k_1 = -369 €/g/km), and Mercedes-Benz (k_1 = -485 €/g/km) show a higher price increase when reducing emissions compared to Stellantis (k_1 = -98 €/g/km), which is closer to the market average. This may be related to different manufacturer strategies, such as the use of more expensive technologies or a higher degree of cost transfer to the end customer. Overall, it can be said that at the market level, a strong relationship between emissions reductions and car price increases was demonstrated for all manufacturers. In the case of the VW Group, prices were found to have increased more than threefold compared to the market average, but the value is still comparable to other manufacturers surveyed. This suggests that the way in which costs are passed on with the reduction of emissions varies between manufacturers.

Relationship between average CO_2 emissions and number of cars sold

Whether reducing emissions affects the size of the EU car market is shown by the results of a regression analysis that examined the relationship between the number of cars sold and average CO_2 emissions (g/km) (Table 2).

Tab 2 *Relationship between average CO_2 emissions (g/km) and number of cars sold*

	total market	VW Group	Mercedes-Benz	BMW Group
correlation coefficient	0.69	0.95	0.81	0.59
k_2	4 748 177	-1 438 588	13 928	700 617
k_1	49 316	33 168	5 753	2 208
P-value (model)	0.0387	0.000002	0.0088	0.0925
P-value k_2	0.1076	0.0427	0.9533	0.0031
P-value k_1	0.0387	0.0001	0.0088	0.0925

Source Own processing based on data from annual reports, the European Environment Agency, ACEA, and the Statista database. (ACEA, 2024a; BMW Group, 2024; European Environment Agency, 2024c; FCA, 2016; Mercedes-Benz Group, 2024; Statista, 2025; Stellantis, 2024; Volkswagen Group, 2024a)

The results confirm a positive correlation (r = 0.69), suggesting that the decline in CO_2 emissions is linked to the decline in the size of the European car market. According to the results of the regression analysis, a reduction in emissions of 1g CO_2/km corresponds to a decline in annual sales in the EU car market of approximately 49,316 cars. This situation may have been influenced by the crisis in 2020, which coincided with a period of significant

emissions reductions. At the level of individual car manufacturers, a statistically significant correlation between emissions and the number of vehicles sold was confirmed for the VW Group and Mercedes-Benz. Taking into account the k_1, coefficients, sales volume, and CO_2 emissions from 2023, the identified correlations can be used to estimate the decline in sales by 2035, when CO_2 emissions are to be zero. If the relationships shown in the table were to hold true, the entire automotive market would decline by 46% by 2035 compared to 2023, Mercedes-Benz sales would decline by 95 %, and VW Group sales would be zero. It can therefore be concluded that the strength of the identified relationships cannot be considered valid in the long term, but it can be stated that reducing car emissions causes their prices to rise. These estimates are not realistic predictions, but rather evidence that the relationship between emissions and market size is not linearly sustainable in the long term.

Conclusion

The analysis revealed several key relationships between emissions regulations and economic aspects of the automotive industry, particularly in the context of the VW Group. The most striking finding is the strong negative correlation between average CO_2 emissions and the share of electric vehicles. This confirms that the current growth rate of BEVs would need to more than double to achieve the 100% target in 2035. Furthermore, it was identified that CO_2 emission reductions are associated with an increase in car prices. This relationship was more pronounced for the VW Group than the market average, indicating higher costs passed on to consumers or the use of more expensive technologies. A positive correlation between emissions and market size was also confirmed, i.e., historically, reducing emissions has been associated with a decline in the number of vehicles sold on the European market, suggesting that the transition to low-emission mobility is linked to a decline in the size of the automotive market.

Based on these findings, several recommendations can be formulated for the Volkswagen Group in the following areas: changes in portfolio and pricing strategy, development of in-house battery production capacities, and diversification of the business model. The analysis found that reducing emissions has so far been associated with higher car prices and that demand for VW Group vehicles is more sensitive to price changes than that for other competitors. This should be taken into account when developing a pricing strategy for electric cars in the higher price segment. There is room for improvement, particularly for the Audi brand, especially in expanding the range of electrified models in the premium segment.

Another shortcoming of the VW Group in the context of the transition to electromobility is the absence of affordable smaller models, which have gradually disappeared from the brands' portfolios as a result of EU emissions regulations. Given the need to expand electromobility into lower segments and markets with lower purchasing power, it is necessary to offer smaller models with a lower base price. Overall, the VW Group should also increase the share of hybrid cars in its sales. Such a strategy has been identified as successful among competitors. At the same time, however, it can be said that, compared to its competitors, the VW Group is responding successfully to emissions regulations, as its market share is increasing with the growth of electromobility. Another area is the development of its own battery production capacities, which is important given its dependence on Chinese manufacturers and the strategic importance of this component. It is necessary to focus on building its own battery production plants in Europe. The VW Group should strive for vertical integration of the supply chain. It would therefore be advisable to also consider partnerships and acquisitions in the field of metal mining and processing. Controlling the entire production process would reduce the company's dependence on external suppliers, lower production costs, and improve control over the quality and parameters of batteries. Last but not least, it is also important to focus on diversifying the business model. Given the Volkswagen Group's high dependence on the Chinese market, it would be advisable to strengthen its position in other markets and also focus on expanding its portfolio of services in the area of shared mobility or energy infrastructure.

From the perspective of regulatory measures, the analysis leans towards a more comprehensive approach on the part of regulators. This mainly involves the introduction of a fleet renewal program, the regulation of supply chain localization, and a review of the timetable for the transition to electromobility. Due to the high average age of passenger cars in the EU (12.3 years), electric cars account for only 1.2 % of the total fleet. However, support for the sale of new electric cars alone is not enough. It will be necessary to introduce a Europe-wide program to support the replacement of older vehicles with new low-emission ones. A minimum localization rule for the production chain should be introduced for the EU, which would apply to all car manufacturers. Among other things, these rules would stimulate the development of subcontracting companies, which would strengthen European industry and could reduce dependence on imports. At the same time, this regulation could also include requirements for a minimum share of recycled materials or standards for the environmental

impact of production itself. The analysis also showed that the current timetable for the transition to electromobility by 2035 carries significant risks. The planned rapid growth in the market share of electric cars could have negative impacts on car manufacturers, consumers, and infrastructure. A suitable solution could be, for example, the introduction of a transition period during which other low-emission powertrains, such as hybrids and plug-in hybrids, would also be allowed.

Given the aim of the study, which is to examine how EU emissions regulations affect European car manufacturers, it can be said that emissions regulations are a highly complex issue that affects not only car manufacturers themselves, but also a number of other companies, industries, and millions of employees across Europe. The regulations thus have profound economic, technological, and social consequences that are not currently fully taken into account in their development. The analysis showed that the transition to low-emission mobility is associated with a number of challenges, such as rising car prices, the risk of a decline in market size, dependence on imports of key components, and slow fleet renewal. The size of the EU car market is expected to remain constant, at the average number of cars sold between 2015 and 2023. The market share of electric cars will gradually increase according to the required scenario, and the average age of the vehicle fleet will remain at the 2023 level. Tightening environmental standards for new cars and promoting electromobility will not be sufficient to achieve environmental goals, and fleet renewal will have to be seen as a complex process in which the technical modernization of vehicles, their total number, and the way they are used in society must be addressed simultaneously. The emphasis should be placed not only on replacing older vehicles with newer ones with lower emissions, but also on reducing car use overall. At the same time, it is necessary to take into account the risk of deliberately extending the life of cars in a situation of rising prices and declining availability of cars with combustion engines. In the long term, it is therefore necessary to move away from a narrowly defined concept of sustainability in transport through electrification and focus on a broader transformation of the overall mobility system.

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