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A Scenario Analysis for the Decarbonisation Process in Poland's Road Transport Sector

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Abstract:

Purpose: *This study attempts to identify the progress of the decarbonisation process in the Polish road transport sector. Its main aim is to present potential future scenarios, allowing for the technological, economic, socio-demographic, legal-political environment in three time horizons, i.e., 2025, 2030 and 2035.*
Design/Methodology/Approach: *This study is based on secondary data sources, primarily the literature of the subject and statistical data presented in industrial reports. The methods applied include scenario analysis and the deductive method.*
Findings: *The scenario analysis led to the conclusion that the progress of the decarbonisation in the Polish road transport sector is insufficient to ensure that the targets set by the European Commission are met. To date, however, road transport is the only sector in which greenhouse gas emissions have risen over the past three decades – by a staggering 33%.*
Practical Implications: *The analyses show the variants in which each environmental component impacts the decarbonisation process. Studies of this kind may constitute a clear message for the decision-makers to focus action on selected types of environment which have the greatest positive effect on road transport emission performance.*
Originality/Value: *The situation emerging from the analyses points to the direction and areas on which Poland should put the greatest emphasis. Comprehensive identification of three possible scenario variants and their effect on the progress of decarbonisation in the road transport sector enables us to determine future limitations to achieving the EU's climate policy goals.*

Keywords: *Road transport, scenario analysis, decarbonisation, emission performance.*

JEL Classification: *C53, Q51, R41.*

Paper type: *Research article.*

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1. Introduction

In Poland and worldwide it is increasingly felt that taking action to protect the environment is a necessity (Mihiel, 2020). Decarbonisation of the Polish economy constitutes an enormous challenge. Emissions in Poland are generated mainly in five sectors and areas of the economy: industry, transport, buildings (particularly heating), agriculture and the energy industry. Therefore, taking effective measures in all of these areas to achieve carbon neutrality by 2050 is essential.

Transport makes for 21% of global carbon dioxide emissions. Currently it is the highest-emission sector in many developed countries (COM, 2018). Quick decarbonisation is becoming increasingly urgent, as the chance to halt global warming at a level below 2°C is fast fading. In order to reduce net carbon dioxide emissions to zero by 2050, in the nearest decades Poland would have to decarbonise four times as fast as for the past 30 years (Bajczuk, Bolesta, and Korolec, 2020).

From 2030 to 2050, the changes would have to be even more dynamic. In March 2023, the European Union member states enacted breakthrough regulations, intended to ban the sale of CO2-emitting vehicles by 2035. In win for Germany, the EU agreed to exempt e-fuels from the ban. Despite Poland's opposition, the EU's latest decisions show way for the member states to follow with regard to transportation and climate over the next few years.

Therefore, it is worth analysing the decarbonisation process in the Polish road transport sector, as the conclusions being drawn may prove immensely valuable for institutions responsible for designing Poland's climate policy.

There are many potential scenarios enabling Poland to achieve carbon neutrality by 2050. Subsequent sections of this article present scenario forecasts in line with assumptions, thanks to which it will be possible to predict Poland's progress in terms or road transport decarbonisation in 2025, 2030 and 2035.

2. Literature Review

The EU decarbonisation strategy foresees deep cuts in CO2 in the transport sector (Charalampidis, Karkatsoulis, and Capros, 2019). The increasingly urgent need to cope with global warming, alongside the growing worldwide energy demand, has been leading countries to adopt measures to reduce their greenhouse gas emissions (Prussi, Laveneziana, Testa, and Chiaramonti, 2022).

Decarbonisation issues in transport and aspects of EU climate policy have been analyzed and researched in the past. Very interesting considerations on the effectiveness of urban mobility decarbonisation instruments were made by Polish scientists from Silesia. The presented research results indicate that public transport can be a decarbonisation tool in the new model of mobility, provided that its

competitiveness and efficiency are increased in relation to the passenger car. Measures to improve the competitiveness and efficiency of public transport should be anticipatory, and thus should be treated as a positive incentive as opposed to restrictive measures limiting the availability of passenger cars (Karoń and Tomanek, 2023).

For achieving net-zero emissions by 2050, countries worldwide are committed to setting ambitious carbon reduction targets. In 2022, the officially published report, "Taiwan's Pathway to Net-Zero Emissions in 2050", sets out a comprehensive transition plan based on four fundamental strategies: energy, industrial, lifestyle, and social. The example of this country shows that the simultaneous focus on many areas of socio-economic life in terms of climate policy gives a chance to achieve zero carbon CO2 emissions (Chen, Lee, Wu, and Chen, 2023).

An interesting case study was presented on the example of the Czech Republic, where a baseline scenario (NECP) derived from the National Energy and Climate Plan and three policy scenarios (CPRICE, REF, REG) were assessed. Their results show that achieving a 55% reduction in total GHG emissions by 2030 is realistic even in Czechia (Recka, Maca, and Scasny, 2023).

There were also groups of countries that were subject to a comparative analysis in terms of greenhouse gas emission reduction targets and prospects for their implementation. The Visegrad Group (V4) countries (Czech Republic, Hungary, Poland, and Slovakia) would need to revise their policies and funds allocated for green transformation, which, in turn, might change their projections of the EU climate package targets for 2030. Poland is heavily dependent on fossil fuels, which puts it in the worst situation among the V4 countries. The PEC and the FEC in Poland are growing instead of decreasing, and the share of renewable energy in the energy mix seems impossible to achieve by 2030 (Brożyna, Strielkowski, and Zpevak, 2023).

They were also conducted in China simulates and predicts the trend CO2 emissions in different scenarios, which only confirmed the correctness of choosing the scenario analysis for Poland (Song, Zou, Wang, Zhang, Zhao, and Wang, 2023).

Also note that they exist the short-and long-run causal dynamic interactions between energy consumption, CO2 emissions and economic growth. The example of Greece proved that a continuing degradation of the environment can create negative externalities for the economy by reducing the health of human capital and therefore the long-term productivity (Katrakilidis, Kyritsis, and Patsika, 2014).

3. Material and Methods

Scenario analysis or the scenario method is an approach classified as belonging to the complex heuristic method group applied in forecasting (Kononiuk, 2012). It is

considered a conventional method by many authors, since it involves creating scenarios for forecast events, an approach used for centuries in various forms. Hover, the contemporary scenario method is subject to research requirements related to the analytical approach.

In this context, a scenario is normally defined as "a description of a hypothetical development, built in order to draw attention to cause-and-effect relationships and moments in which a management system intervention is desirable – making a decision to control or regulate the functioning of a given system" (Komorowski, 1988). A scenario is thus a set of variants of a hypothetical development. The variants must be evaluated to determine (assess) the likelihood of each of them.

In scenario analysis, scenarios do not concentrate solely on the investigated system but also on its environment, because the effect of the environment is of key importance for the scenario being evaluated. Thus, the scenario method is often described as one which allows us to apply a comprehensive, systematic approach to forecasting.

The literature of the subject differentiates between four basic groups of scenarios (Gierszewska and Romanowska, 2009):

- possible event scenarios – defining events which may possibly occur in the future and anticipate relevant responses on part of the organisation. Strategic decisions are made taking into account relationships between external (political, economic, social, etc.) and internal factors of the organisation. Tendency and result analysis is a variant of the possible event scenario;
- simulation scenarios – enable a valuation of future strategic choices depending on the impact of the environment on the organisation's situation;
- scenarios of states in environment – evaluate the impact of each process on the organisation, as well as the likelihood of these processes taking place. The evaluation in the analysis is based primarily on the expertise of the scenario's designers and consultants;
- scenarios of processes in environment – an elaborate and detailed analysis of environment scenarios, which focuses on the analysis of processes with a potentially profound impact on the organisation.

This study employs the scenarios of states in environment. Such scenarios are designed in the following variants:

- optimistic – based on factors with the greatest positive impact on the organisation;
- pessimistic – based on factors with the greatest negative impact on the organisation;
- surprise – allowing for factors least likely to occur;

- most likely – based on factors which are most likely to occur, irrespective of their positive or negative effect on the environment.

The surprise variant has been omitted from this study due to the present situation, which in many ways bears resemblance to a surprise scenario. Designing a scenario of states in environment entails the following steps:

- Step 1 – identify the macro environment, competitive environment and factors that have a decisive impact on the organisation.
- Step 2 – construct the scenario, focusing on processes identified in the environment in terms of their influencing force (e.g. from –5 to +5) and direction of influence (regress, stagnation, growth), as well as the likelihood of these factors having impact (0-1).
- Step 3 – order trends according to each scenario (optimistic, pessimistic, most likely).
- Step 4 – perform calculations and present the results graphically; summarise and draw conclusions (determine the most turbulent zone and the extent to which the organisation depends on changes in the environment). Scenarios of states in environment allow us to study the causes of future limitations to formulating strategies.

In accordance with the author's assumptions, scenario analysis was carried out for three time horizons: 2025, 2030 and 2035. These periods were defined in anticipation of further analyses performed with regard to this research issue, albeit with the use of simulation, which will be the subject of the next study.

Table 1. *Scenario analysis – environmental factors*

Factor	Trend	Strength of impact [-5 to +5]	Probability 0-1
Economic environment			
GDP level and growth rate	Growth	+4	0.4
	Stabilisation	-2	0.3
	Regress	-5	0.3
Inflation level	Growth	-5	0.3
	Stabilisation	-3	0.5
	Regress	+4	0.2
Transport companies profit level	Growth	+5	0.4
	Stabilisation	+3	0.4
	Regress	-4	0.2
Level of investment in road infrastructure (charging stations)	Growth	+4	0.2
	Stabilisation	+2	0.4
	Regress	-3	0.4
Poland's transport sector growth rate	Growth	+5	0.2
	Stabilisation	+4	0.6
	Regress	-2	0.2
Growing energy and fuel costs	Growth	-5	0.2

	Stabilisation	-1	0.6
	Regress	4	0.2
Legal-political environment			
Stricter emission norms	Growth	-2	0.3
	Stabilisation	+2	0.4
	Regress	+5	0.2
Taxation on high-emission vehicles	Growth	-4	0.5
	Stabilisation	+3	0.2
	Regress	+5	0.3
Support for the replacement of vehicles with zero-emission ones	Growth	+5	0.3
	Stabilisation	+2	0.3
	Regress	-2	0.4
Schemes and funds aimed at reducing emissions	Growth	+5	0.3
	Stabilisation	+4	0.4
	Regress	-2	0.3
Social and demographic environment			
Decreasing number of employees	Growth	-5	0.5
	Stabilisation	-3	0.3
	Regress	+3	0.2
Low natural growth	Growth	-3	0.4
	Stabilisation	+1	0.4
	Regress	+2	0.2
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3	0.4
	Stabilisation	+2	0.3
	Regress	+3	0.3
Eco-awareness and climate protection commitment	Growth	-3	0.4
	Stabilisation	+2	0.4
	Regress	+5	0.2
Technological environment			
Development of battery technology (electric drive)	Growth	+5	0.4
	Stabilisation	+3	0.5
	Regress	-1	0.1
Development of alternative zero-emission drives	Growth	+5	0.3
	Stabilisation	+3	0.6
	Regress	+1	0.1
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	+5	0.6
	Stabilisation	+2	0.2
	Regress	-3	0.2

Source: *Author's own work.*

This scenario analysis pertains to the economic, legal-political, social, demographic and technological environment. For each of these areas, only the most principal factors (according to the author) which impact the decarbonisation process in the Polish road sector were listed.

4. Scenario Analysis for 2025

Three scenarios were designed for the 2025 horizon: optimistic, pessimistic and realistic (the most likely). They were juxtaposed in Tables 2, 3 and 4. The optimistic variant predicts that the greatest strength of impact will occur in the economic environment. It was estimated at 26 points (maximum positive impact in this area), with the area having an exclusively positive effect. The variant assumes that inflation recedes and energy costs decrease, along with the price of fuel. At the same time, GDP level and growth rate, investment in roads and point components of road infrastructure continue to grow. This enables an increase in transport companies profit levels and the growth rate of the entire sector.

Table 2. *Optimistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***26***
GDP level and growth rate	Growth	4
Inflation level	Regress	4
Transport companies profit level	Growth	5
Level of investment in road infrastructure (charging stations)	Growth	4
Poland's transport sector growth rate	Growth	5
Growing energy and fuel costs	Regress	4
Legal-political environment	***TOTAL***	***20***
Stricter emission norms	Regress	5
Taxation on high-emission vehicles	Regress	5
Support for the replacement of vehicles with zero-emission ones	Growth	5
Schemes and funds aimed at reducing emissions	Growth	5
Social and demographic environment	***TOTAL***	***13***
Decreasing number of employees	Regress	3
Low natural growth	Regress	2
Changes in work and consumption attitudes (reduction, lower involvement)	Regress	3
Eco-awareness and climate protection commitment	Regress	5
Technological environment	***TOTAL***	***15***
Development of battery technology (electric drive)	Growth	5
Development of alternative zero-emission drives	Growth	5
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	5

Source: *Author's own work.*

Changes also take place in the legal environment, where the rate of the introduction of stricter exhaust emission norms becomes slower and taxation on high-emission vehicles is either low or non-existent.

Moreover, numerous forms of support for owners exchanging vehicles for zero-emission ones are available (tax credit, co-financing, etc.) and additional funds are released for emission reduction purposes. Transport companies do not face any issues recruiting staff (drivers), and the demographic situation is more auspicious thanks to improved fertility rate.

Thus, consumption levels in society are growing and environmental protection issues cease to be as vital as today. As for technology, significant advancements have been made and technology for making batteries with better performance and technical specifications is commonly available.

There are many effective forms of alternative, low-emission or zero-emission drives (partly based on today's technology with possible retrofits). Meanwhile, the energy industry is developing, with the use of low- and zero-emission power generation solutions.

Table 3. *Realistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***3***
GDP level and growth rate	Stabilisation	-2
Inflation level	Growth	-5
Transport companies profit level	Growth	5
Level of investment in road infrastructure (charging stations)	Stabilisation	2
Poland's transport sector growth rate	Stabilisation	4
Growing energy and fuel costs	Stabilisation	-1
Legal-political environment	***TOTAL***	***5***
Stricter emission norms	Stabilisation	2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Stabilisation	2
Schemes and funds aimed at reducing emissions	Growth	5
Social and demographic environment	***TOTAL***	***-14***
Decreasing number of employees	Growth	-5
Low natural growth	Growth	-3
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3
Eco-awareness and climate protection commitment	Growth	-3
Technological environment	***TOTAL***	***13***

Development of battery technology (electric drive)	Growth	5
Development of alternative zero-emission drives	Stabilisation	3
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	5

Source: *Author's own work.*

The realistic (likely) variant assumes that the GDP level becomes stable (albeit not necessarily on an elevated level), whereas inflation maintains on a prominent level (rising above expectations). This situation also stabilises investment in road infrastructure: it is not as substantial as expected. This is accompanied by a stabilisation in costs of energy, and, consequently, the cost of fuel. In such conditions, the transport sector also experiences stability (its growth is noticeable yet characterised by relatively low dynamics).

However, by increasing productivity, companies in the sector are able to boost their profits. Exhaust emission norms are not made more stringent (once set, the targets remain in effect). Meanwhile, a tax imposing additional burden on high-emission vehicles (which does not need to be a direct tax – it may take form of additional charges, e.g., for entering a particular zone, etc.) is introduced. No new schemes supporting upgrades to zero-emission vehicles are implemented.

Nevertheless, those which are already in place, obtain addition funding (to include more participants). Problems with finding employees in the transport sector still remain a major obstacle to company growth. The demographic trend does not change: natural growth rate remains low, and the issue appears increasingly severe.

Consumers curb their consumption, both because of the economic situation and for environmental reasons, which grow in significance. Advancements in battery technology lead to new generations of better-performing machines being available. No new alternative zero-emission drives are created. However, more and more effective low- and zero-emission sources are being used in the energy industry.

Table 4. *Pessimistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***-24***
GDP level and growth rate	Regress	-5
Inflation level	Growth	-5
Transport companies profit level	Regress	-4
Level of investment in road infrastructure (charging stations)	Regress	-3
Poland's transport sector growth rate	Regress	-2
Growing energy and fuel costs	Growth	-5
Legal-political environment	***TOTAL***	***-10***

Stricter emission norms	Growth	-2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Regress	-2
Schemes and funds aimed at reducing emissions	Regress	-2
Social and demographic environment	***TOTAL***	***-14***
Decreasing number of employees	Growth	-5
Low natural growth	Growth	-3
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3
Eco-awareness and climate protection commitment	Growth	-3
Technological environment	***TOTAL***	***-3***
Development of battery technology (electric drive)	Regress	-1
Development of alternative zero-emission drives	Regress	1
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Regress	-3

Source: *Author's own work.*

GDP growth rate remains low, contributing to a relative shrinkage in GDP. Inflation is still high and shows some tendencies for further growth. Energy prices continue to rise, which translates into more expensive fuel. In the transport sector, this causes problems with keeping company costs in check, which directly result in limitations to the growth level and growth rate of transport company profits.

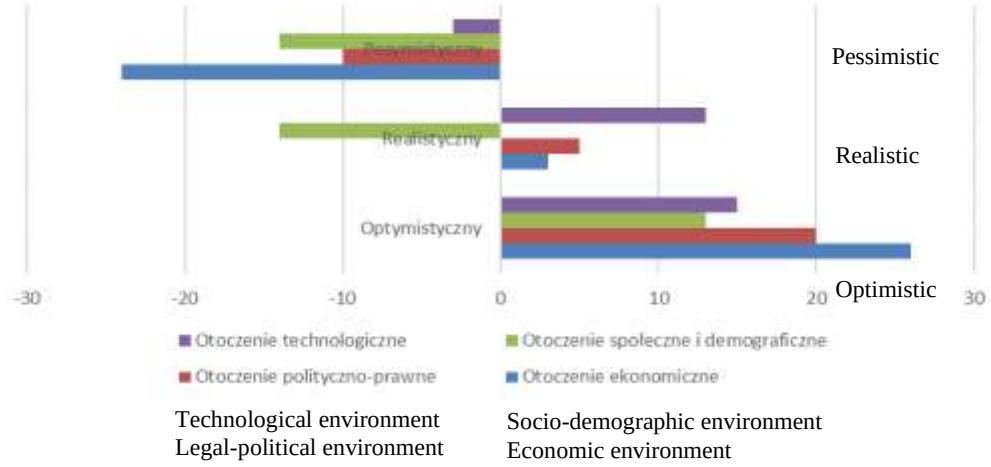
Moreover, this leads to some companies being swept from the market, shrinking the size of the entire sector. Investment in infrastructure is kept to a minimum.

Meanwhile, emission targets are made more stringent. High-emission vehicles are also taxed directly, and the level of such taxation is relatively high. Some schemes supporting upgrades to zero- and low-emission vehicles are withdrawn. This to due to limited financing being available for such incentives. Recruiting employees by transport companies is still an issue, and is becoming more severe. The population crisis continues and deepens, fuelled by low fertility rate.

Consumption is severely curtailed, both due to the overall financial situation and market availability of goods. Eco-awareness is rising to gradually become one of the key determinants of consumer decisions. At the same time, no significant progress in battery technology is made.

Technology fails to offer any novel solutions with regard to lowering emissions of contemporary vehicles or creating alternative zero-emission drives. There is no significant progress in the use of increasingly effective low- and zero-emission sources in the energy industry.

Figure 1. *Comparison of scenarios for 2025*



Source: *Own study.*

A visual presentation of summary results for the strength of impact on the Polish road transport sector decarbonisation process in all scenarios (Figure 1) reveals striking contrasts between the pessimistic and optimistic scenario. This means considerable influence of the environment on the entire process by 2025.

The environment may change very dynamically, which translates into what the process of the changes in the structure of the Polish road transport will look like. In the context of the realistic scenario, the social and demographic environment has the greatest influence, being the source of the strongest negative effect. Basically, the realistic scenario, if it materialises by 2025, appears beneficial from the perspective of short-term decarbonisation of commercial road transport in Poland.

5. Scenario Analysis for 2030

A scenario analysis for 2030 was performed, again based on factors from Table 1. Tables 5-7 list trends with the evaluation of their strength of impact in each area.

Table 5. *Optimistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***24***
GDP level and growth rate	Growth	4
Inflation level	Regress	4
Transport companies profit level	Growth	5
Level of investment in road infrastructure (charging stations)	Stabilisation	2
Poland's transport sector growth rate	Growth	5
Growing energy and fuel costs	Regress	4
Legal-political environment	***TOTAL***	***12***

Stricter emission norms	Stabilisation	2
Taxation on high-emission vehicles	Stabilisation	3
Support for the replacement of vehicles with zero-emission ones	Stabilisation	2
Schemes and funds aimed at reducing emissions	Growth	5
Social and demographic environment	***TOTAL***	***2***
Decreasing number of employees	Stabilisation	-3
Low natural growth	Stabilisation	1
Changes in work and consumption attitudes (reduction, lower involvement)	Stabilisation	2
Eco-awareness and climate protection commitment	Stabilisation	2
Technological environment	***TOTAL***	***15***
Development of battery technology (electric drive)	Growth	5
Development of alternative zero-emission drives	Growth	5
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	5

Source: *Author's own work.*

Per capita GDP and GDP overall growth rate increase. At the same time, inflation falls and stays low. Real energy cost drops, which a concurrent fall in the prices of (already ecological) fuels and power for electric vehicles. Road infrastructure investment level is stable, with the prospect that its current growth rate will be maintained. The transport sector manages to increase its profits and experiences an overall growth. Emission reduction norms stay on a previously set level.

Taxation on high-emission vehicles does not change and remains on the expected level. Schemes promoting vehicle upgrades remain in place in their unchanged form, albeit with increased financial support. Employment issues in the transport sector are mitigated (vacancies are successfully filled). The demographics stabilises, too, and the fertility rate improves, to a certain extent. The tendency to cut back consumption is halted as consumption stabilises. Eco-awareness is still at a considerable level.

However, it is possible to reach a consensus and strike balance between the plans of the environmentalists and capacity for their implementation. Ecology becomes an integral but not a dominant factor in all decisions. Meanwhile, technological development enables more efficient batteries and new, alternative, zero-emission propulsion systems to become more common. At the same time, we see the use of increasingly more effective zero- or low-emission sources in the energy industry (high proportion of these sources in the country's energy mix).

Table 6. *Realistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***10***
GDP level and growth rate	Stabilisation	-2
Inflation level	Regress	4

Transport companies profit level	Stabilisation	3
Level of investment in road infrastructure (charging stations)	Stabilisation	2
Poland's transport sector growth rate	Stabilisation	4
Growing energy and fuel costs	Stabilisation	-1
Legal-political environment	***TOTAL***	***-3***
Stricter emission norms	Growth	-2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Regress	-2
Schemes and funds aimed at reducing emissions	Growth	5
Social and demographic environment	***TOTAL***	***-8***
Decreasing number of employees	Stabilisation	-3
Low natural growth	Stabilisation	1
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3
Eco-awareness and climate protection commitment	Growth	-3
Technological environment	***TOTAL***	***13***
Development of battery technology (electric drive)	Stabilisation	3
Development of alternative zero-emission drives	Growth	5
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	5

Source: *Author's own work.*

Both GDP and its growth rate stabilise, in tandem with the general economic situation. Inflation falls and stays at a low level. Energy and energy carrier prices stabilise, allowing transport companies to stabilise their profits. This promotes overall stability across the transport sector.

Road infrastructure investment level is stable and in line with expectations. Airborne pollutant emission norms become more stringent in the context of climate change. This is accompanied by increased taxation on high-emission vehicles. The number of vehicle upgrade schemes drops as the financing other activities in support of pollutant emission reduction grows.

The method of stimulating the transition to a zero-emission transport sector shifts in favour of fiscal instruments. Employment issues in the transport sector becomes stable (vacancies are successfully filled). The demography issue also stabilises, and the fertility rate improves. Consumption is still being curbed in the light of a more reasonable approach to resource management and the continued rise in eco-awareness.

Technological advancements fail to generate any novel technologies for more optimal batteries. In balance, new types of alternative low- and zero-emission propulsion systems appear. More efficient low- and zero-emission energy sources in

the energy industry are increasingly being applied (an improvement in Poland's energy mix).

Table 7. *Pessimistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***-22***
GDP level and growth rate	Regress	-5
Inflation level	Stabilisation	-3
Transport companies profit level	Regress	-4
Level of investment in road infrastructure (charging stations)	Regress	-3
Poland's transport sector growth rate	Regress	-2
Growing energy and fuel costs	Growth	-5
Legal-political environment	***TOTAL***	***-10***
Stricter emission norms	Growth	-2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Regress	-2
Schemes and funds aimed at reducing emissions	Regress	-2
Social and demographic environment	***TOTAL***	***-14***
Decreasing number of employees	Growth	-5
Low natural growth	Growth	-3
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3
Eco-awareness and climate protection commitment	Growth	-3
Technological environment	***TOTAL***	***-3***
Development of battery technology (electric drive)	Regress	-1
Development of alternative zero-emission drives	Regress	1
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Regress	-3

Source: *Author's own work.*

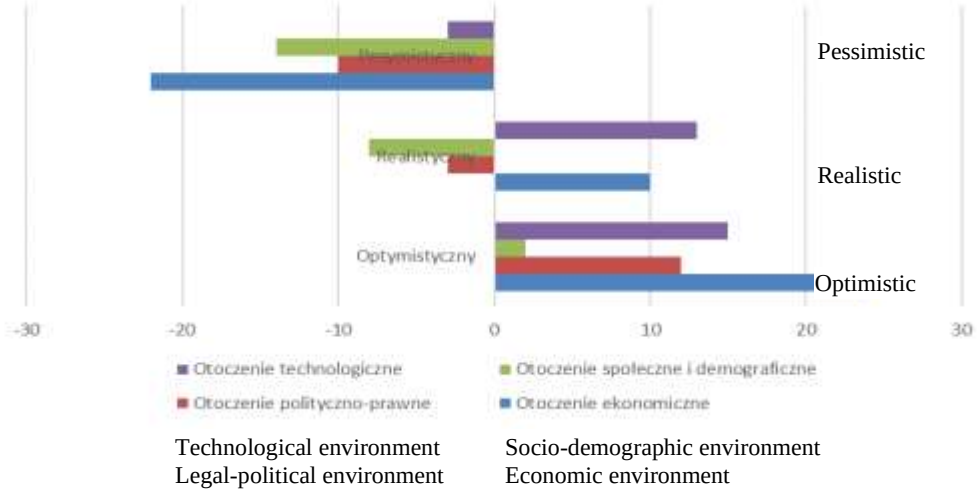
GDP level and growth rate continue to decline. The economy manages to stabilise inflation on a relatively high level. Energy and energy carrier prices are still growing. This leads to a decline in the profits of transport companies and the shrinkage of the transport sector in Poland. Investments in road infrastructures are cut. Emission norms for fuels and pollutants become stricter than anticipated in previous targets.

Additional, new taxes are introduced for high-emission propulsion systems. Some schemes in support of upgrades to zero-emission vehicles are phased out, particularly in connection with difficulties in financing such actions (limited financing). Problems related to the recruitment of staff by the road transport sector remain unsolved. The same can be said of Poland's demographic challenges. Consumption is markedly reduced, and the negative tendency seems to be growing.

Eco-awareness continues to grow and becomes one of the main determinants of decisions made by consumers and governments worldwide. Technological progress fails to offer any ground-breaking or more better-performing technologies pertaining to batteries, alternative propulsion systems or zero-emission solutions for the energy industry.

A visual presentation of summary results for the strength of impact on the Polish road transport sector decarbonisation process in all scenarios (Figure 2) reveals considerable differences between the pessimistic and optimistic scenario, albeit slightly smaller than for the 2025 horizon. Still, it means that in 2030 the environment continues to exert major influence on the entire process. The environment may change rapidly, which markedly translates into what the process of the changes in the structure of the Polish road transport will look like. In the context of the realistic scenario, socio-demographic and legal-political environment have the strongest impact, hence they are the sources of the strongest potential negative effect.

Figure 2. *Comparison of scenarios for 2030*



Technological environment — Socio-demographic environment
Legal-political environment — Economic environment

Source: *Own study.*

Overall, the realistic scenario, should it materialise by 2030, still appears beneficial from the perspective of short-term decarbonisation of commercial road transport in Poland. Nevertheless, there seem to be significant similarities between the realistic and the pessimistic variant.

6. Scenario Analysis for 2035

By referring to Table 1, scenario analysis for 2035 was performed, with several modifications in the strength of impact of each trend. Tables 8-10 list trends with the evaluation of their strength of impact in each area.

Table 8. *Optimistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***24***
GDP level and growth rate	Growth	4
Inflation level	Regress	4
Transport companies profit level	Growth	5
Level of investment in road infrastructure (charging stations)	Stabilisation	2
Poland's transport sector growth rate	Growth	5
Growing energy and fuel costs	Regress	4
Legal-political environment	***TOTAL***	***5***
Stricter emission norms	Stabilisation	2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Stabilisation	2
Schemes and funds aimed at reducing emissions	Growth	5
Social and demographic environment	***TOTAL***	***-1***
Decreasing number of employees	Regress	3
Low natural growth	Growth	-3
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3
Eco-awareness and climate protection commitment	Stabilisation	2
Technological environment	***TOTAL***	***7***
Development of battery technology (electric drive)	Regress	-1
Development of alternative zero-emission drives	Stabilisation	3
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	5

Source: *Author's own work.*

GDP rises together with its overall growth rate. This is accompanied by decreasing inflation, which meets inflation targets. Real energy cost drop, and the same can be said of the prices of (already ecological) fuels and energy required to power electric vehicles. Road infrastructure investment level is stable, with the current upgrade and development rate maintained. The transport sector manages to increase its profits and experiences an overall growth. Emission reduction norms stay on a previously set level.

Taxation on high-emission propulsion systems increases (as expected), new vehicles with high-emission propulsion systems are no longer marketed. Schemes promoting vehicle upgrades remain in place in their unchanged form, albeit with increased financial support. Staff problems in the transport sector have been solved, partly due

to autonomous vehicles using the new road infrastructure. The demographic crisis has been mitigated thanks to improved fertility rate.

The tendency to reduce consumption is still present, though not severe; rather, it is based on consumers' increased eco-awareness, ultimately putting pressure on companies to change their attitude to environmental issues. A generally acceptable consensus has been reached with regard to climate protection and sustainable resource management.

The consensus has become an intrinsic factor influencing each decision. Battery technologies are no longer developed, since they have already achieved a satisfactory level. Progress in the development of new alternative forms of zero-emission propulsion systems stabilises. Innovation levels in technology and solutions for low- and zero-emission sources in the energy industry grows (the proportion of high-emission sources in the energy mix falls rapidly).

Table 9. *Realistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***5***
GDP level and growth rate	Stabilisation	-2
Inflation level	Stabilisation	0
Transport companies profit level	Stabilisation	3
Level of investment in road infrastructure (charging stations)	Regress	-3
Poland's transport sector growth rate	Stabilisation	4
Growing energy and fuel costs	Regress	3
Legal-political environment	***TOTAL***	***0***
Stricter emission norms	Stabilisation	2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Regress	-2
Schemes and funds aimed at reducing emissions	Stabilisation	4
Social and demographic environment	***TOTAL***	***-12***
Decreasing number of employees	Stabilisation	-3
Low natural growth	Growth	-3
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3
Eco-awareness and climate protection commitment	Growth	-3
Technological environment	***TOTAL***	***7***
Development of battery technology (electric drive)	Regress	-1
Development of alternative zero-emission drives	Stabilisation	3
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Growth	5

Source: *Author's own work.*

GDP level and growth rate stabilise (medium level). The same is true for inflation, which is relatively low. There is a reduction in the level of investment in road infrastructures. At the same time, the cost of energy and fuels for road vehicles falls. This is directly followed by a stabilisation of the entire transport sector, as well as the profits of transport companies. Pollutant emission norms are not made stricter (they are in line with targets previously set).

In line with expectations, further restrictions, including tax burdens, are imposed on high-emission vehicles. Support for upgrades to zero-emission vehicles is rolled back (certain schemes are withdrawn). The overall level of financing for pollutant emission reduction schemes stays unchanged. Staffing challenges in the road transport sectors stabilise, with the use of technology and limited growth of the sector being the main reasons. The demographic issue is mitigated due to improved fertility rate. The tendency to cut consumption and manage resources more effectively still holds.

In addition, growing eco-awareness leads to increased public pressure on governments and companies. Battery technologies are no longer developed, as they have already achieved a satisfactory level. Progress in the development of new alternative forms of zero-emission propulsion systems stabilises. Innovation levels in technology and solutions for low- and zero-emission sources in the energy industry grows (the proportion of high-emission sources in the energy mix falls rapidly).

Table 10. *Pessimistic variant*

Factor	Trend	Strength of impact
Economic environment	***TOTAL***	***-23***
GDP level and growth rate	Regress	-5
Inflation level	Growth	-5
Transport companies profit level	Regress	-4
Level of investment in road infrastructure (charging stations)	Regress	-3
Poland's transport sector growth rate	Regress	-2
Growing energy and fuel costs	Growth	-4
Legal-political environment	***TOTAL***	***-10***
Stricter emission norms	Growth	-2
Taxation on high-emission vehicles	Growth	-4
Support for the replacement of vehicles with zero-emission ones	Regress	-2
Schemes and funds aimed at reducing emissions	Regress	-2
Social and demographic environment	***TOTAL***	***-16***
Decreasing number of employees	Growth	-5
Low natural growth	Growth	-3
Changes in work and consumption attitudes (reduction, lower involvement)	Growth	-3

Eco-awareness and climate protection commitment	Growth	-5
Technological environment	***TOTAL***	***-1***
Development of battery technology (electric drive)	Regress	-4
Development of alternative zero-emission drives	Regress	1
Development of low-emission/ zero-emission/ renewable technologies in the energy industry	Stabilisation	2

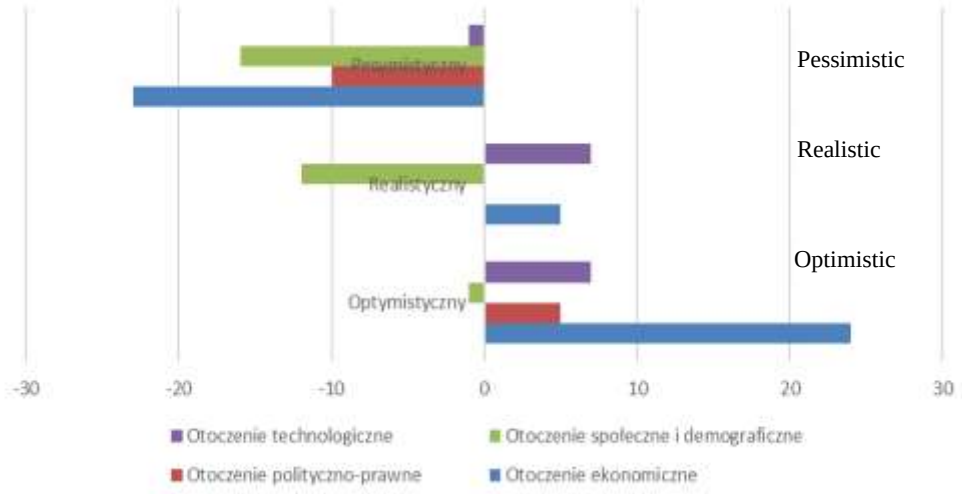
Source: *Author's own work.*

A decline in GDP level and growth rate along with rising inflation as Poland enters another period of economic slump. Energy costs still rise, which translates to a reduction in the profits of transport companies and the entire sector. Emission norms are made stricter (than could be predicted from earlier targets). New, higher (additional) fiscal pressures on high-emission propulsion systems are introduced.

There is a decrease in both the number and funding level of schemes supporting upgrades to zero-emission vehicles. Staffing problems in the transport sector remain unsolved, even with the use of modern technologies. The demographic crisis continues to escalate. The tendency to cut consumption becomes even more radical.

As eco-awareness grows, the public opinion demands both immediate and simultaneous fulfilment of multiple climate targets. In terms of technology, advancements do not allow to manufacture new and more efficient batteries or alternative propulsion systems. Progress in Poland's energy mix improvement through increasing the proportion of zero-emission sources stabilises.

Figure 3. *Comparison of scenarios for 2035*



Technological environment — Socio-demographic environment
Legal-political environment — Economic environment

Source: *Own study.*

A visual presentation of summary results for the strength of impact on the Polish road transport sector decarbonisation process in all scenarios (Figure 3) again displays considerable difference between the pessimistic and optimistic scenario, especially in terms of the economic environment. For two other areas, the gap is smaller than in the analysis for 2030.

This shows that the impact of an environment other than economic one weakens long-term, which results from the assumption that by 2035 the situation in other areas will not have changed or will even have improved. In the long run, the socio-demographic environment constitutes a challenge and the source of negative impact in all variants of the present analysis.

In the realistic scenario, the socio-demographic environment still exerts the greatest influence, which means that it is the source of the strongest potential negative impact, whereas the legal and political environment becomes less significant in terms of its effect. Basically, if the realistic scenario materialises by 2035, it still seems beneficial from the perspective of short-term decarbonisation of commercial road transport in Poland. There is still a great deal of similarity between the realistic and the pessimistic scenario.

7. Conclusions

Transport is a strategic sector of the EU's economy, having direct influence on the lives of all EU citizens, with transport services providing approximately 11 million jobs. At the same time, it is the source of about a quarter of total greenhouse gas emissions in the European Union (COM, 2020). In 2014, emission level in the transport sector started to rise again, so its reduction is a key milestone on the way to meeting the EU's decarbonisation targets (Sergejus Lebedevas, Justas Žaglinskis, Martynas Drazdauskas).

For Poland, achieving carbon neutrality by 2050 will certainly be an enormous challenge. To this end, all sectors of the economy would have to radically lower their emission levels. What is more, negative emission would also need to be ensured to compensate for emissions generated in areas where achieving reduction is particularly problematic (Rabiega, Gorzałczyński, Pyrka, Jeszke, Tobiasz, and Mzyk, 2022).

Vehicles riding on Polish roads almost exclusively include cars with internal combustion engines. There are nearly 30 million vehicles per 38 million inhabitants, which makes Poland one of the most heavily motorised countries in Europe.

Therefore, car owners would have to be provided with inexpensive, second-hand alternative solutions. Technologies which would enable cutting emissions generated by transportation and replace currently used engine-powered vehicles mostly include electric cars, as well as hydrogen trucks and buses (Wang, Jia, Li, Zhang, and

Zhang, 2021). They should be supplemented by alternatives to the conventional model of passenger transport. e.g. car pooling and the use of electric scooters in cities.

Scenario analyses presented in this study allow us to conclude that Poland's road transport decarbonisation efforts are too slow and should be stepped up in the years to come. In addition, taking into account the current structure of means of transport in Poland in terms of emission performance (Pyra, 2023), the outlook is far from optimistic.

The analysed periods are characterised by a strong impact of each type of environment, which can be either positive or negative. Particularly noteworthy is the realistic variant, which reveals the following patterns:

- in 2025, the socio-demographic environment is the source of the most negative impact, while the technological environment supports road transport decarbonisation efforts;
- in 2030, the socio-demographic environment remains the source of the most negative impact, while both the technological and economic environment support road transport decarbonisation efforts;
- in 2035, the socio-demographic environment is the source of the most negative impact, with the technological environment supporting the road transport decarbonisation process.

Finally, it appears reasonable to claim that if the pessimistic scenario should materialise, reaching carbon neutrality in Poland by 2050 (which requires a complete elimination of transport-generated emissions) will be jeopardized. In the realistic and the optimistic scenario, the outlook is much more auspicious, although demands appropriate focus on relevant areas of each environment.

The technological environment, e.g., a more widespread use of electrical vehicles, clearly becomes a priority. Already by 2037, all passenger vehicles must be electric for Poland to remain on track with its decarbonisation project (Engel, Purta, Speelman, Szarek, van der Pluijm, 2020).

The process of decarbonising road transport and, more broadly, the entire Polish economy by 2050 is a truly colossal endeavour. Challenging as it may seem, estimates imply that the project is perfectly feasible and realistic on one condition: a complete commitment on part of the public sector, business and the entire society.

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