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A Formalised Method for Analysing the Relationship between the Economy and Transport: The Case of the European Union and Poland

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Abstract:

Purpose: *The purpose of this study is to analyse and assess the relationship between economic development and transport development in the European Union and Poland.*
Design/Methodology/Approach: *The study was conducted using formalised methods and expert analyses, drawing on the relevant literature as well as the authors' theoretical and practical experience. The issue is addressed comprehensively, as analysing transport-related problems in isolation from the economy would be methodologically inadequate.*
Findings: *The study is based on formalised methods, expert analyses, a literature review, and the authors' theoretical and practical expertise. It examines and presents the relationship between the economy and transport development over a nearly 20-year period in the European Union and Poland, and assesses its validity.*
Practical implications: *The study's theoretical contribution lies in the development of a formalised research method, while its practical value consists in its applicability by EU and national authorities in the design of transport development strategies.*
Originality/value: *This study offers a comprehensive and methodologically rigorous analysis of the research problem over a 19-year time horizon, applying formalised methods (including a six-degree polynomial and exponential function), structuring the empirical material and generating substantive conclusions.*

Keywords: *Mathematical methods, economic development, transport development.*

JEL codes: *C10, O00.*

Type of paper: *Research article.*

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1. Introduction

This article presents the results of long-term research into the relationship between the economy and transport, using formalised methods applied to the case of the European Union and Poland over a nearly 20-year period. The research period is limited to 2019 to prevent COVID-19 restrictions from distorting the results. Following 2019, key economic and transport indicators underwent significant changes, reflecting the pandemic's impact on both domains.

The methods used (i.e., the 6th-degree polynomial and exponential functions) allow the analysis of the relationship between economic development and transport development throughout the research period.

2. Transport and the Economy: A Global Review

The importance of the transport sector for the global economy has been discussed by Maciej Mindur in several publications (Mindur, 2006, pp. 47–99; Mindur, 2007, pp. 115–134; Mindur, 2009, pp. 37–40; Mindur, 2010; Mindur, 2013, pp. 219–228). Transport encompasses activities that reflect the relationship between the economy and its needs, as well as the often negative impact of transport on the environment (Sitarz, 2024, pp. 1–14).

At the same time, transport shapes infrastructure development (Mindur, 2010) and, consequently, also influences economic development. Already in the 1970s, environmental pollution became an obstacle to further development in Europe, and it was particularly severe in the Ruhr area of the Federal Republic of Germany. Since then, some of the most environmentally damaging industries have been relocated abroad, while in other cases environmentally-friendly solutions have been implemented, such as smokestacks equipped with filters or wastewater treatment plants.

Therefore, environmental degradation caused by industrial activities in Europe has been significantly reduced; however, the problem has not been definitively resolved. Pollution caused by transport is significant enough that it has become a global problem. One major consequence is global warming, which leads to the melting of ice in the Arctic and Antarctic regions and increases poverty in many African regions, contributing to the expansion of famine-affected areas.

Transport does not play a predominant role in causing this damage; however, it would be inaccurate to deny its contribution. However, traffic-related air pollution already poses a threat to the sustainable development of some metropolitan areas, such as Beijing – where traffic restrictions have recently been introduced – and Poland, which is among the most heavily polluted countries in Europe. The increase in road traffic and the number of road users also influence transport development.

Despite less advanced technology, travel within metropolitan areas (e.g., from the outskirts of London to the city centre) in early 20th century took as much time, or even less time than it does today (Mindur, 2010).

However, global transport activity (based on traffic growth in the United States, the European Union, and China, as well as the stabilised level of transport work in Japan) shows an upward trend, similar to that of the global economy. This provides evidence of a close relationship between the economy and transport.

Transport is a key economic sector in every economy, a major driver of technological and economic progress, and essential for production (Kadlubek *et al.,* 2022a; 2022b). Ensuring transport capacity that meets the needs of the economy requires an efficient freight transport system. This subsystem should be systematically developed through the use of modern transport and transshipment technologies, telematics and IT systems, management methods etc. Logistics centres and the widespread adoption of logistics solutions play a significant role in rationalising freight transport.

The most important requirement for efficient transport services is aligning transport activities with the structure and characteristics of the economy and the nature of production. For example, the modern system of the US economy and the need to meet its transport requirements have made the US transport system one of the most advanced, as well as environmentally and socially friendly.

In general, the US transport system is dominated by road transport, while rail transport is among the most environmentally friendly modes. According to the studies, intermodal transport and the widespread use of containers have the highest share in the US transport system. On the other hand, the development of the Russian economy, based mainly on the extraction and export of hydrocarbons, has led to pipeline transport becoming the most important transport mode.

China's economic growth, based mainly on industrial exports, has contributed to the rapid expansion of container shipping. This is evidenced by the fact that among the fifteen largest container ports in the world, eight (including four of the top five in terms of container throughput) are located in China (World Shipping Council).

China's domestic transport is dominated by inland water transport, which is due to favourable geographical conditions and to the expansion and improvement of waterways as a result of government initiatives supported financially by the World Bank (The World Bank).

Transport is involved in all areas of the economy. For example, transportation issues are part of economic policy, land-use planning, social policy, local government and regional policy, as well as of budgetary and fiscal policy. This confirms the thesis of strong interdependencies between the economy and transport (Mindur, 2004).

The negative effects of economic activity include, among others, an excessive increase in transport intensity, which should be rationalised, i.e., reduced (Rydzkowki and Wojewódzka-Król, 2010).

Transport intensity in the national economy is determined by the sum of material consumption, energy consumption, and labour input in transport. Overall, transport intensity refers to the level of transport activity resulting from the pursuit of other social and economic activities. The level of transport activity should be understood as the engagement of human labour and capital in transport services across all sectors of the national economy, including meeting the individual mobility needs of the population in modern societies (Rydzkowki and Wojewódzka-Król, 2010).

In general, transport intensity in the national economy can be defined as the ratio of transport-related costs to the effects generated in social and economic activities supported by transport. The productive role of transport activities lies in transferring the value added of transport services to the transported goods, thereby increasing their total value. Therefore, an increase in transport intensity leads to higher unit values (or unit prices) of transported goods and to higher unit production costs, which ultimately contributes to price increases (Rydzkowki, Wojewódzka-Król, 2010).

3. Assessment of Relationships between the Economy and Transport in the EU Using the 6th-Degree Polynomial and Exponential functions

The following metrics can be used to study transport intensity in the national economy:

- tonnes transported per unit of GDP and national income,
- tonne-kilometres of transport activity per unit of GDP and national income,
- values of transport and others services of basic transport activities per unit of GDP and national income (Kuziemkowski, 1981).

The numerator of these metrics represents the overall costs of transport activities, while the denominator represents the aggregate output of social and economic activities. The costs incurred by transport activities are indirectly reflected in the volume of good transported (in tonnes) and the level of transport activity (in tonne-kilometres). The result of social and economic activities are gross domestic product (GDP) and national income (Rydzkowki and Wojewódzka-Król, 2010).

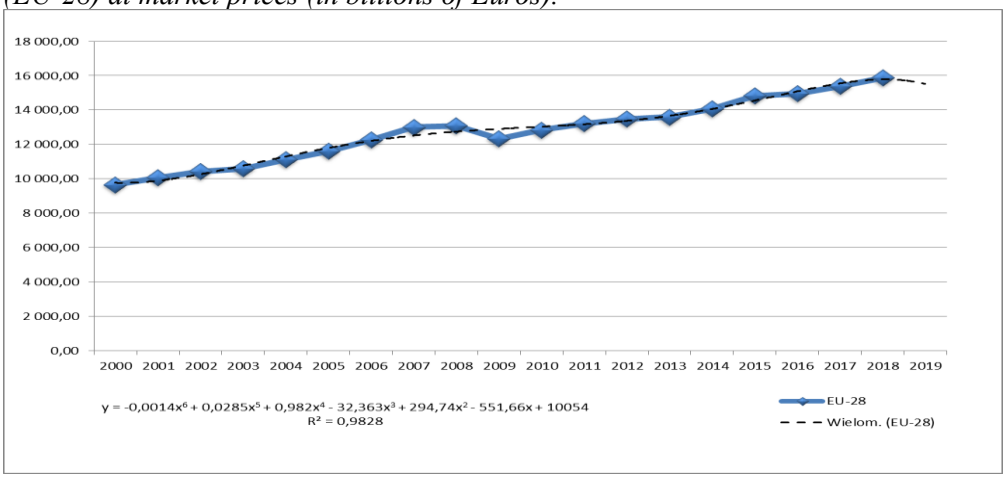
The studies show social and economic activity measured by gross domestic product (GDP) in Euros (Figure 1) and transport activity measured by tonne-kilometres across all transport modes (Figure 2).

The value of the variable for 2018 was extrapolated using a 6th-degree polynomial trend line. This extrapolation was performed in Microsoft Excel by forecasting one

period ahead. The extrapolated values were calculated using the LINEST function (REGLINP in Polish Excel) where the y-range and x-range are selected to obtain the coefficients of the 6th-degree polynomial trend line, which is then used for extrapolation.

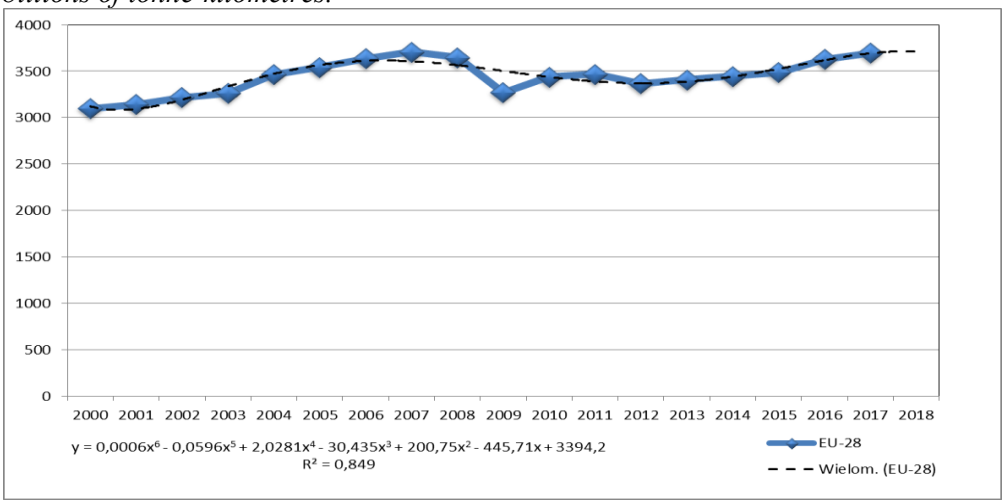
Figures 3 and 4 show the exponential and non-linear polynomial curves, respectively, illustrating the development of transport intensity in the national economies of the European Union (EU-28) over time.

Figure 1. *Development of the European Union's gross domestic product (GDP) (EU-28) at market prices (in billions of Euros).*



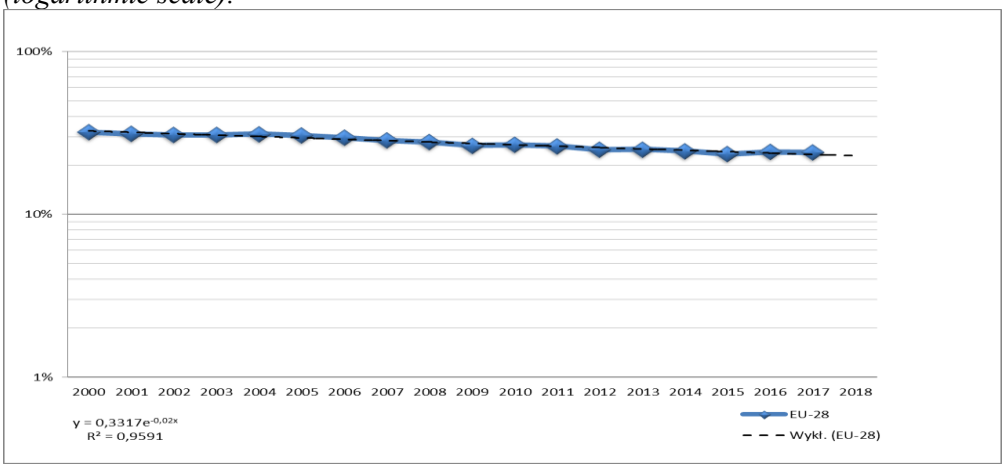
Source: *Authors' own analysis based on: Mindur, 2010 (chapter 7) and European Statistical Office (Eurostat), GDP and main aggregates – selected international annual. Retrieved from: https://ec.europa.eu/eurostat/web/products-datasets/-/naida_10_gdp.*

Figure 2. *Evolution of freight transport activity in the European Union (EU-28) in billions of tonne-kilometres.*



Source: *Authors' own analysis, based on: Mindur, 2010 (chapter 7); Central Statistical Office of Poland (GUS); Eurostat (European Statistical Office); OECD Statistics; DG MOVE (2017) – Performance of freight transport (tkm), Statistical Pocketbook; and World Bank, World Development Indicators. Retrieved from: https://stat.gov.pl/statystykamiedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/transport-i-lacznosc/; https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=ttr00005&plugin=1; https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1142.pdf; https://stats.oecd.org/#; https://www.eea.europa.eu/data-and-maps/indicators/freight-transport-demand-version-2/assessment-7; http://worldbank.org.*

Figure 3. *Transport intensity of the European Union's national economies (EU-28) (logarithmic scale).*

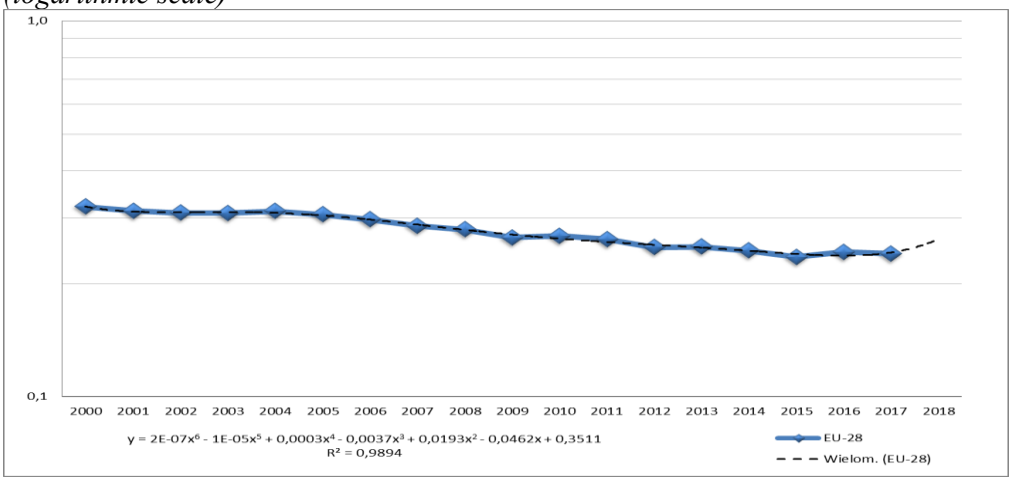


Source: *Authors' own analysis based on: Mindur, 2010 (chapter 7); Central Statistical Office of Poland (GUS); Eurostat (European Statistical Office); OECD Statistics; DG MOVE (2017), Performance of freight transport (tkm), Statistical Pocketbook; and World Bank, World Development Indicators. Retrieved from: https://stat.gov.pl/statystykamiedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/transport-i-lacznosc/; https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=ttr00005&plugin=1; https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1142.pdf; https://stats.oecd.org/#; https://www.eea.europa.eu/data-and-maps/indicators/freight-transport-demand-version-2/assessment-7; http://worldbank.org.*

The analysis of both the exponential and polynomial trend curves allows the following conclusions to be drawn:

- transport intensity in the European Union (EU-28) remained relatively stable from 2000 to 2005, whereas a decline in transport intensity is observed from 2006 to 2018;
- the coefficients of determination (R^2) for the exponential and polynomial trend curves were relatively high, amounting to 0.9591 and 0.9894, respectively.

Figure 4. *Transport intensity of the European Union's national economies (EU-28) (logarithmic scale)*



Source: *Authors' own analysis based on: Mindur, 2010 (chapter 7); Central Statistical Office of Poland (GUS); Eurostat (European Statistical Office); OECD Statistics; DG MOVE (2017), Performance of freight transport (tkm), Statistical Pocketbook; and World Bank, World Development Indicators. Retrieved from: https://stat.gov.pl/statystykamiedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/transport-i-lacznosc/; https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=ttr00005&plugin=1; https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1142.pdf; https://stats.oecd.org/#; https://www.eea.europa.eu/data-and-maps/indicators/freight-transport-demand-version-2/assessment-7; http://worldbank.org.*

In 2000–2018 the European Union's (EU-28) gross domestic product (GDP) grew strongly, except in 2009, when it fell to the level of 2006. This decline resulted from the global economic crisis that began in the United States in September 2008 following the collapse of Lehman Brothers.

The period studied show a dynamic increase in freight transport volume; however, 2009 is characterised by a significant decline to a level similar to that of 2003.

Transport intensity in the studied period exhibits a downward trend. This may indicate that global economic growth requires less transport input due to the structural changes in the global economy, namely the increasing share of the service sector and the introduction of new technologies (Mindur, 2010).

A decrease in transport intensity in developed countries may be caused by the following factors (Liberadzki, Mindur, 2006):

- rationalisation of production activities, including the reduction of transport needs;

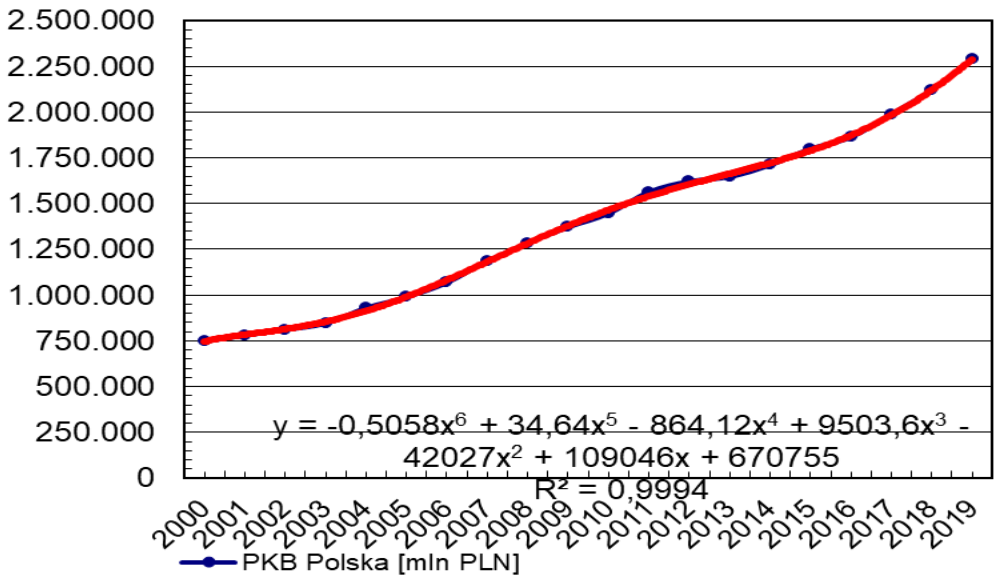
- structural changes in the economy, such as the growth of the service sector and improvements in logistics systems, which shift production from a "storage-based" model to a "just-in-time" or "smooth" economy, where logistics and transport processes begin in the final production phase;
- increased efficiency in the use of transport systems, reflected in a fundamental change in service users' expectations regarding quality, particularly in terms of the full range of transport and logistics services, on-time delivery, shipment size, delivery at precisely defined times, price, and flexibility. Service providers (e.g., transport, logistics, shipping companies) must adapt to these new expectations.

The decrease in transport intensity in the European Union's (EU-28) should be regarded as positive, since it contributes to reducing production and service costs.

4. Assessment of the Relationship between the Economy and Transport Development in Poland

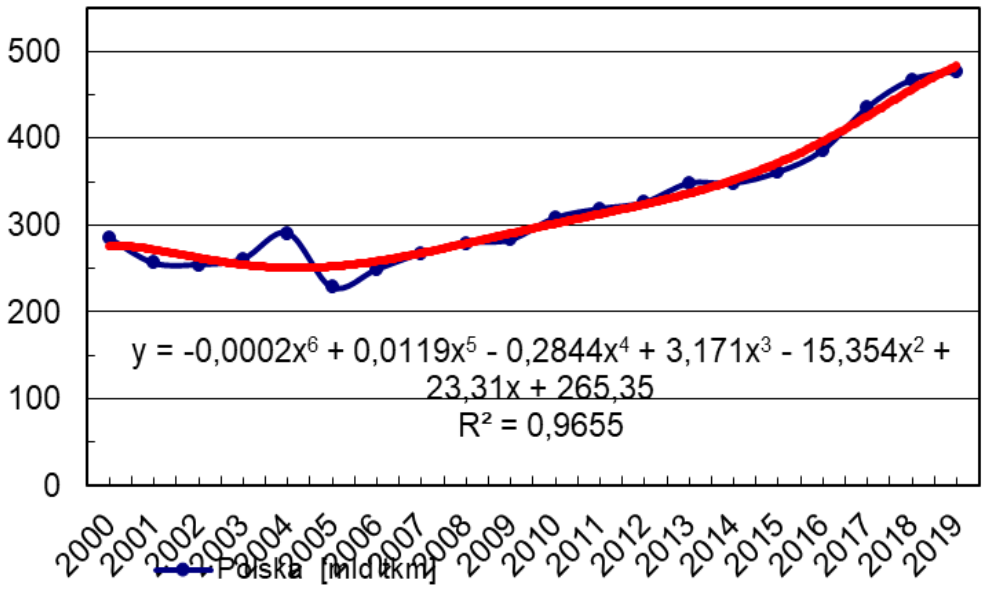
Using the same criteria and formalised methods as for the EU-28, the 6th-degree polynomial trend curves for gross domestic product (GDP) in millions of PLN and passenger transport in billions of passenger-kilometres for the Polish economy are shown in Figures 5–7 for 2000–2019.

Figure 5. *Evolution of Poland's gross domestic product (GDP) at market prices for 2000–2019.*



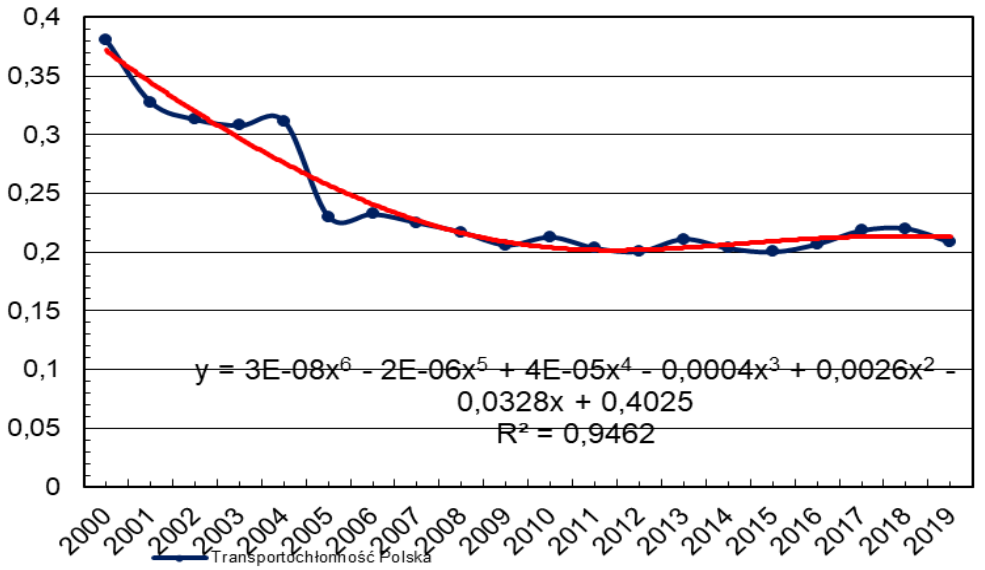
Source: *Authors' own analysis based on data from the Central Statistical Office of Poland (GUS). Retrieved from: https://stat.gov.pl/statystykamiedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/transport-i-lacznosc/.*

Figure 6. *Evolution of Poland's freight transport volume for 2000–2019.*



Source: *Authors' own analysis based on data from the Central Statistical Office of Poland (GUS). Retrieved from: https://stat.gov.pl/statystykamiedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/transport-i-lacznosc/.*

Figure 7. *Transport intensity in Poland (logarithmic scale) for 2000–2019.*



Source: *Authors' own analysis based on data from the Central Statistical Office of Poland (GUS. Retrieved from: https://stat.gov.pl/statystykamiedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/transport-i-lacznosc/.*

The goodness of fit to the regression models presented in the charts for both Poland's gross domestic product (GDP) and transport volume is very high. The coefficients of determination (R^2) are 0.9994 and 0.9655, respectively. The reliability, expressed by the coefficient of determination (R^2) for the GDP trend curve, is very close to 1, indicating an excellent fit.

Just the reliability of the transport volume curve is similarly high, although slightly lower than that of the GDP curve. The coefficient of determination (R^2) for the transport intensity curve using a 6th-degree polynomial function was 0.9462, indicating a high fit close to 1. The coefficient of determination (R^2) for the exponential trend curve of transport intensity is considerably lower ($R^2 = 0.6501$. Therefore, this curve will not be used in further analysis.

The trend shown in Figure 5 indicates that Poland's gross domestic product exhibited moderate growth in 2000–2006. In contrast, from 2007 to 2019, following Poland's accession to the European Union, the data indicate robust growth. For Polish transport volume (Figure 6), the curve for 2000-2006 is irregular and exhibits a downward trend. By contrast, robust growth is observed from 2007 to 2019.

Analysis of the curves in Figure 7, which show the regression lines for transport intensity in Poland, indicates a significant decline in transport intensity in 2000–2009, whereas in 2010–2019 the trend is close to linear with a modest upward slope. Overall, in the period 2000–2019, Polish transport intensity – similarly to that observed in the European Union – exhibits a downward trend. This reflects technological progress and innovation in the Polish economy.

However, transport intensity in Poland still remains relatively high, as the transport volume curve continues to exhibit increasing trend. This indicates that, for the economy to function efficiently, transport activities must be maintained at an adequate level.

These findings underscore the importance of implementing optimal transport technologies that are environmentally and socially friendly, as well as the need for the further development of intermodal transport in Poland.

5. Summary

The following conclusions can be drawn from the studies synthetically presented in the article:

1. There are close relationships and interdependencies between economic development and transport development.
2. Transport encompasses activities in which mutual relationships between the economy and its requirements occur, while at the same time transport exerts

impacts on the environment that are not always positive, particularly in terms of safety and ecological outcomes.

3. Economic development requires an efficient transport system that is adapted to the structure and specificity of the economy concerned.
4. Transport is an important production sector in every economy, a key factor of technical and economic progress, and a fundamental instrument supporting production processes.
5. Ensuring transport capacity adequate to the needs of the national economy requires an efficient freight transport system supported by modern transport and transshipment technologies, telematic and IT systems, and advanced management methods.
6. An excessive increase in transport intensity[4] undermines economic competitiveness and therefore should be subject to rationalisation measures. The formalised methods for analysing transport intensity presented in this article play an important cognitive role and constitute a useful analytical tool for supporting policy-making and planning in this area.

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[4]*Transport intensity in the national economy is defined as the ratio of costs incurred by transport activities to the outcomes of social and economic activities supported by transport.*

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