Simulation the Impact of Eco Expenditure on the Effectiveness of Eco Projects: the Railways of Ukraine Case

Nestor Shpak[a], Liana Maznyk[b], Zoriana Dvulit[a], Oksana Mykytiuk[c] and Tatiana Melnyk[d]

[a] *Lviv Polytechnic National University, Bandera str. 12, Lviv, 79000, Ukraine*
[b] *National University of Food Technologies, Volodymyrska Str. 68, Kyiv, 01601, Ukraine*
[c] *Taras Shevchenko National University of Kyiv, Volodymyrska Str. 64/13, Kyiv, 01601, Ukraine*
[d] *Joint Stock Company "Ukrzaliznytsia", Jerzy Giedroyc, 5, Kyiv, 03150, Ukraine*

Abstract

A system of indicators of the structure and dynamics of operational freight turnover, which includes environmental protection expenditure, carbon dioxide (CO_2) emissions from railway transport enterprises was created. A multilevel hierarchical model of the relationship between: operational turnover and the amount of CO_2 emissions by the relevant sources of pollution in terms of their volume and structure (the first level); environmental expenditure and the amount of CO_2 emissions (the second level), was developed. The results of the study confirmed that largely the reduction of such harmful emissions is due to the size and structure of expenditure for environmental projects. The novelty of the article is the development of methodological approaches to test the hypothesis that with increasing environmental expenditure for environmental protection, CO_2 emissions from rolling stock and stationary sources of pollution of the six railways of Ukraine are reduced.

Keywords 1

Expenditure, Environmental protection, Ukrainian railways, Simulation

1. Relevance

Railway transport companies rank second in the ranking of major air pollutants in the transport industry. Diesel locomotives have the most detrimental effect on the environment, compared to other elements of the rolling stock of the inventory of railway transport enterprises, polluting the air by burning diesel fuel, the consumption of which drives the diesel traction. Reducing this negative impact is one of the most important tasks of railway companies. The officially declared goal of JSC Ukrzaliznytsia is, among others, to meet the needs for safe and high-quality rail transportation, sustainable development of the railway transport. In recent years though, the company made some decisions not focused on those strategic aims. In particular, on February 23, 2018, an agreement was signed on the purchase of locomotives of the American conglomerate General Electric. At that time, this decision was based on future stability and quality of supply, ensuring the output of products for export. But soon (October 29, 2020) the head of JSC "Ukrzaliznytsia" officially declared that he sees no need for further purchase of General Electric locomotives and noted that it will be more profitable to switch to electric locomotives, as it is much more efficient from an economic and environmental point of view. Thus, the lack of a strategic vision for the impact of the type of traction on the environment of the main pollutants does not allow: to optimize the size and structure of environmental expenditure in different areas in their distribution among railway enterprises; to make appropriate decisions regarding the expediency of purchasing a railway fleet according to the types of

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EMAIL: nestor.o.shpak@lpnu.ua (N. Shpak); solieri@i.ua (L. Maznyk); zoriana.p.dvulit@lpnu.ua (Z. Dvulit); mykytiuk@knu.ua (O. Mykytiuk); avgust26@ukr.net (T. Melnyk)
ORCID: 0000-0003-0620-2458 (N. Shpak); 0000-0002-5387-7442 (L. Maznyk); 0000-0002-2157-1422 (Z. Dvulit); 0000-0002-8657-7278 (O. Mykytiuk); 0000-0003-2216-0606 (T. Melnyk)

traction on which passengers and cargo are transported. In the context of our study, the type of traction is a crucial factor influencing the environment, environmental projects and expenditure etc.

2. Literature review

Theoretical analysis of literature sources on the research topic concerned the impact of railways on the environment and international experience in conducting and implementing environmental projects in various fields. In particular, an estimate of CO_2 emissions from railway maintenance was carried out. The results of the study [1] allow engineers, construction managers to critically plan strategic maintenance of railways.

The issue of environmental impact of the transport sector, including rail transport, due to significant amounts of CO_2 emissions is presented in [2-6], in particular in the area of tax collection [7]. In [8] the increase of pollutant emissions due to the development of infrastructure and global transport needs is substantiated. This is also reflected in the study [9] on air pollution due to emissions of airborne particles from stationary and mobile sources.

In particular, in [10] the impact of the Prydniprovska regional railway of JSC «Ukrzaliznytsia” on the environment was analyzed. The study [11] is devoted to prospects of electrification of railways. According to [12], an important task in assessing the impact of transport on the environment is to better understand the effects of CO_2 emissions, in order to develop optimal routes to achieve long-term greenhouse gas reductions from transport. The impact of various factors, including personnel on the level of environmental safety and safety in general in railway transport, was considered in [13].

Despite the significant relevance of the research topic, insufficient attention is still paid to the analysis and evaluation of the relationship between environmental expenditure and CO_2 emissions by transport companies as one of the largest polluters.

3. Research methodology

A multilevel hierarchical model is proposes, which at the first level estimates the relationship between operational turnover and the amount of CO_2 emissions by the relevant sources of pollution in terms of their volume and structure. The second level of simulation focuses on the structure and closeness of the relationship between environmental expenditure and the amount of carbon dioxide emissions as the most harmful pollutant. At the third level, the share of variation in emissions due to transportation is compared with the share of variation in emissions due to the cost of environmental projects. The hierarchy of the model also provides for the structuring of the object of study: the first level of the hierarchy – six railways of JSC "Ukrzaliznytsia", the second level – JSC "Ukrzaliznytsia". The system of selected indicators provided for the inclusion of relevant statistical reports submitted to state statistics bodies and internal statistical reporting of the railways of Ukraine for 2007-2019.

4. Research results

The application of the proposed hierarchical methodology involves conducting a priori analysis of the dynamics of volume and quality indicators of six railways of Ukraine and JSC "Ukrzaliznytsia" in general. According to [14], the indicators of specific volumes of electric traction in total turnover in 2007-2019 show the variation of its fluctuations in the range from 84.2% in 2007 to 91.2% in 2014. In 2015, the share of electric traction decreased to 89.7%, and since 2016 there has been a tendency to its reduction from 88.55% (2016) to 86.49 in 2019. The operational length of electrified sections during the study period increased from 9670.6 km in 2007 to 10267.5 km in 2013, and decreased to 9999.6 km in 2015. The downward trend was observed in 2019 (up to 9319 km). 2019 was a difficult year in terms of both the results of transportation work and environmental protection activities. In the context of Ukraine's international obligations, including JSC "Ukrzaliznytsia", such dynamics is unacceptable and makes it difficult to meet the relevant requirements.

In pursuance of Ukraine’s obligations under international treaties [15] and the requirements of the United Nations Framework Convention on Climate Change [16], the Law of Ukraine "On Principles for Monitoring, Reporting and Verification of Greenhouse Gas Emissions" [17] was adopted and put into action on 01.01.2021. It applies to relations arising in the field of monitoring, reporting and verification of greenhouse gas emissions from installations located in Ukraine. Emissions of pollutants and greenhouse gases into the atmosphere by railway transport enterprises are defined as the total amount of air pollution from stationary and mobile sources of pollution. The source of greenhouse gas emissions is: a separate part of the installation from which the emissions are made, or a process within the installation that leads to emissions.

Annual data on the amount of environmental expenditure for each of the railways of Ukraine (regional branches of JSC "Ukrzaliznytsia": "Lvivska Railway", "Odeska Railway", "Prydniprovska Railway", "Pivdenno-Zakhidna Railway", "Pivdenna Railway", "Donetska Railway") in 2007-2019 was used. CO2 emissions from the railway transport enterprises come from stationary sources of pollution and rolling stock. The emissions from stationary sources are recorded for each railway and submitted in the form of annual reports.

According to regulations [18, 19], the input data for determining the amount of pollutant emissions into the air from the rolling stock are: fuel consumption for locomotive engines and specific emissions of pollutants and greenhouse gases per unit of diesel fuel used by diesel locomotives. The calculation of emissions of pollutants and greenhouse gases from railway transport is based on the initial data of enterprises on fuel consumption for the operation of locomotive engines. In order to calculate the emissions of pollutants and greenhouse gases from railway transport, the volumes of fuel consumed by railway rolling stock were determined. In the research the data on the volumes of fuel consumption for the operation of railway transport engines, submitted in the forms of the state statistical observation report №4-mtp [20], was processed. Selection of reports and indicators in them on railway transport from the total set of reports submitted by enterprises, organizations, institutions, was performed according to the following criteria for railway transport: codes of economic activity 60.10.1, 60.10.2, 63.21.1, section "Final consumption energy materials and petroleum products", column 5 ("for transport activities"), line 300 (gasoil (diesel fuel)).

The dynamics of diesel fuel consumption by Ukrainian railways is different. On six railways there was a general decrease in fuel consumption by diesel locomotives during the studied period. However, such a structure is not typical for all six railways. Consumption of diesel fuel in 2019 compared to 2007 had a downward trend for each of them, while their structure was not steady downward. The dynamics and structure of railway consumption changed in different ways: in some the share increased, in others, on the contrary, decreased.

In general, the consumption of diesel fuel by the railways of Ukraine has a declining trend. Moreover, the peculiarities of the dynamics of diesel fuel consumption on all railways are nonlinear dynamic dependences, which can be explained by significant structural changes in diesel fuel consumption by these railways in 2007-2019. The analysis of structural changes indicates changes on all six railways. They show a non-linear trend in the dynamics of fuel consumption. This non-linear dynamics is related to the behavior of Ukrzaliznytsia as a complex system, which can be seen through changes in its structure.

The dynamics of the structure of the total operational turnover of the Ukrainian railways in 2007-2019 was characterized by significant fluctuations. Thus, the share of Odeska, Pivdenno-Zakhidna railway and Lvivska railways increased rapidly in 2015-2019 (with slight fluctuations over the years), in 2013-2019 the share of Donetsk railway decreased sharply. The share of Prydniprovska Railway is quite unstable, the largest decline occurred in 2015 with a gradual slow growth until 2019 (Fig. 1). The general trend for JSC "Ukrzaliznytsia" is decline of the total operational turnover (Fig. 2). Forecasting the dynamics of the studied indicator is recommended using a linear trend. The existing trends for individual railways, presented in Fig. 2, are mainly declining by various forms of dependence.

The share of emissions of the Donetska Railway in their total volume since 2013 has been rapidly declining. This can be explained by the corresponding reduction in traffic. The share of emissions of the Pivdenna Railway in 2007-2013 is also rapidly declining and shows a weak upward trend in 2015-2019. At the same time, the shares of emissions of Lvivska and Pivdenno-Zakhidna Railways are growing.

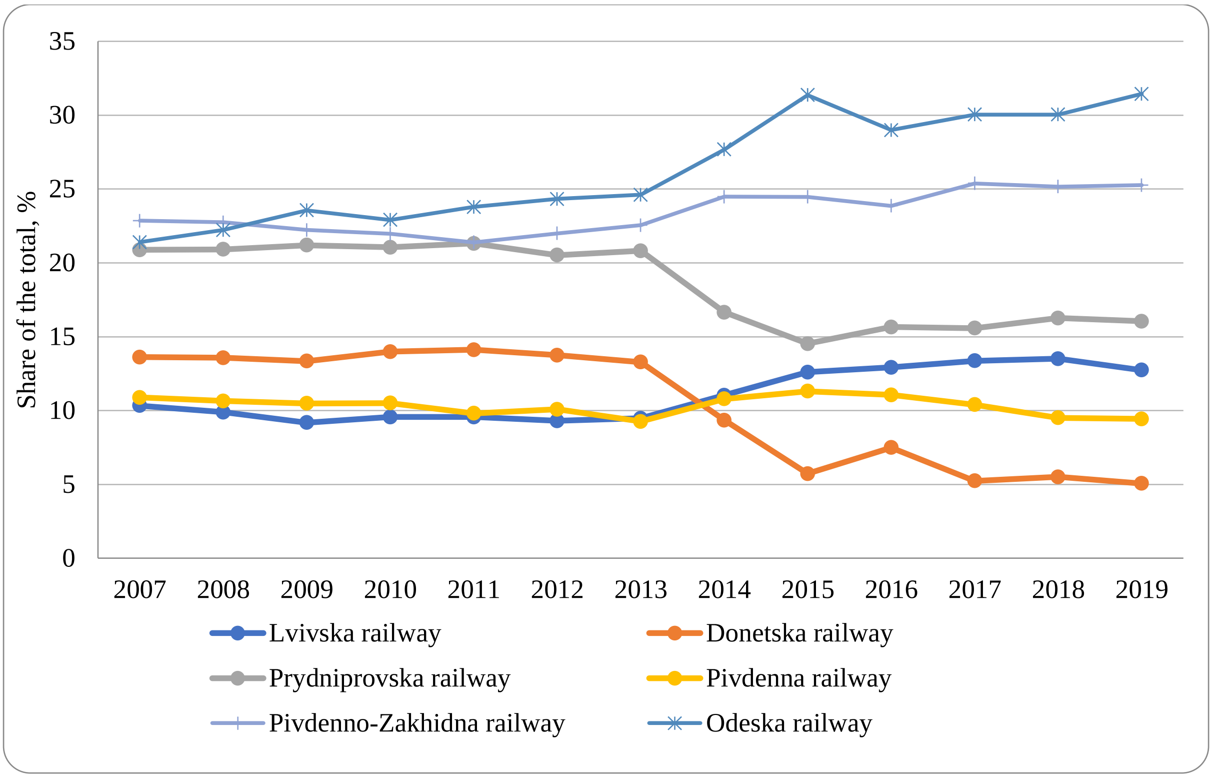

Figure 1: Dynamics of the structure of the total operational turnover of JSC "Ukrzaliznytsia" in 2007-2019 by railways

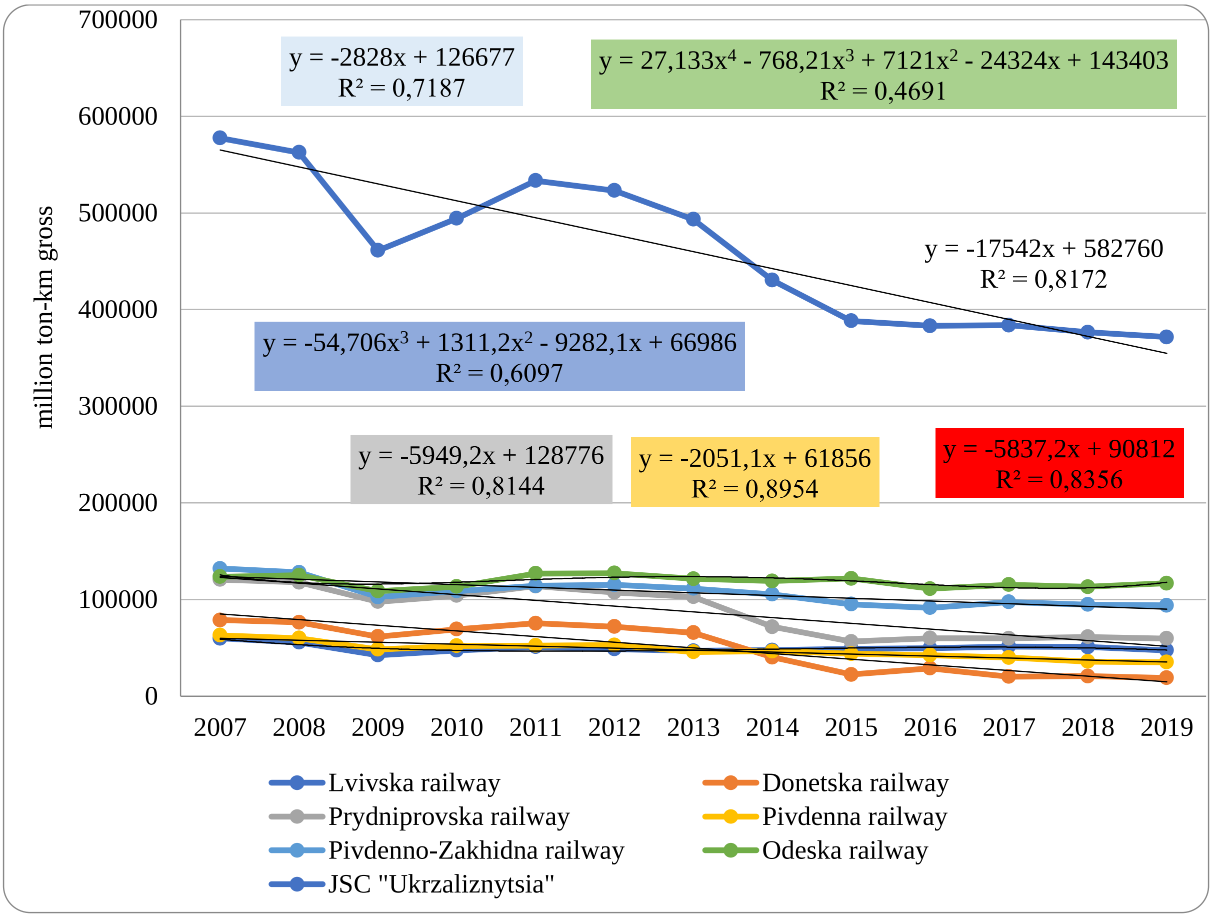

Figure 2: Dynamics of the total operational turnover of JSC "Ukrzaliznytsia" in 2007-2019 by railways

The corresponding indicators for the Prydniprovska and Odeska Railways have slight fluctuations over time with a manor increase in the share. The structure of pollution of rolling stock and stationary sources is also unstable. Thus, the share of pollution by rolling stock was the highest for the Southern Railway in 2007 (99.79%) and the lowest for the Donetska Railway in 2009 (65.39%).

The largest "polluter" was the Odeska Railway in 2017 (21.63% of all emissions from the railways of Ukraine), the smallest – the Prydniprovska one (11.52%) in 2014. The total change in emissions from the railways decreased by almost 42%, which is significantly ahead reduction of traffic volumes, which decreased in 2019 compared to 2007 by less than 36% (Fig. 3 and Fig. 4).

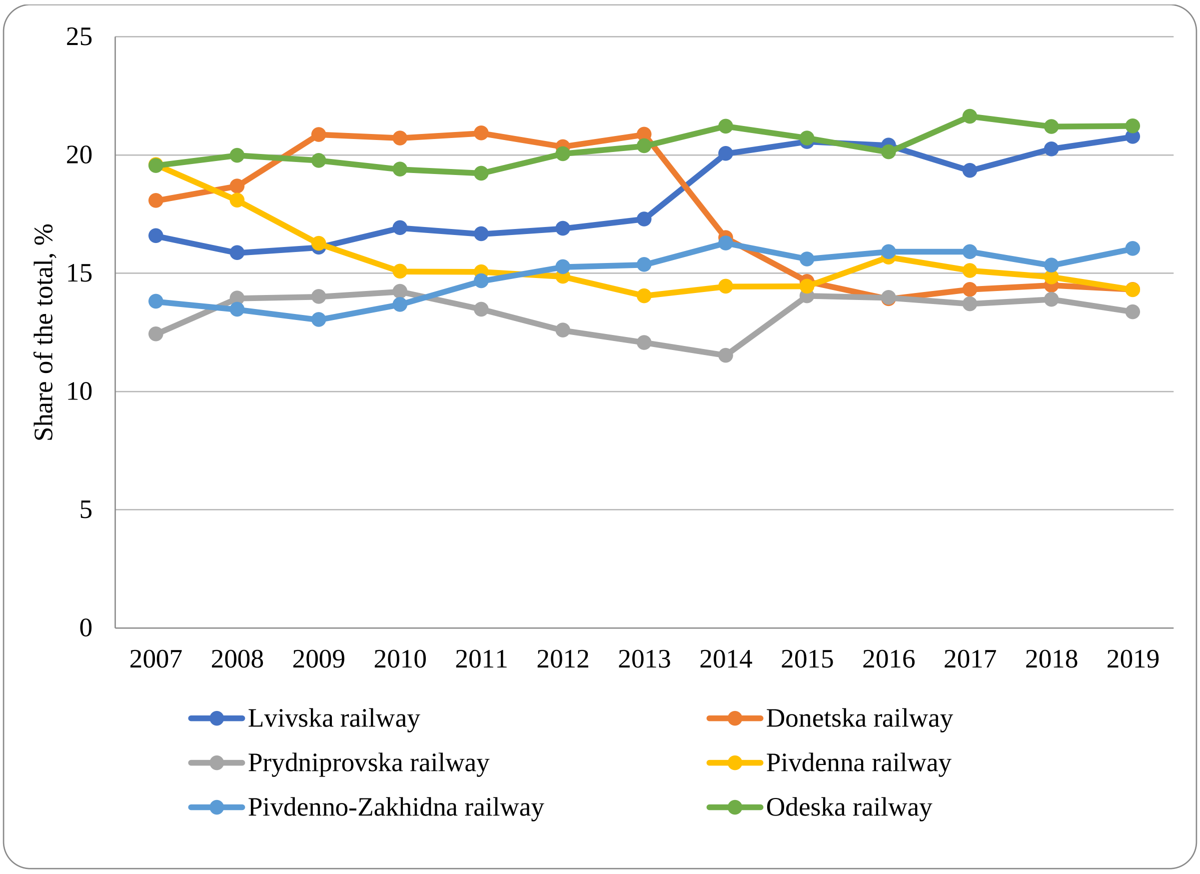

Figure 3: Dynamics of the structure of emissions of JSC "Ukrzaliznytsia" in 2007-2019 by the railways

In the studied period, the structure of environmental protection expenditure for the railways of Ukraine is characterized by significant changes. The lowest share of total expenditures in 2009 (2.36%) falls on the Pivdenna Railway, which, however, in 2011 became the leader in this indicator (52.25%). Significant fluctuations of the respective shares are also characteristic of the Odeska Railway – from 4.92% (2012) to 37.89% (2009).

The dynamics of environmental protection expenditures in absolute terms is also unstable. More than a fourfold increase in this indicator was observed in 2012 compared to 2007 and a decrease of almost 15% in 2015. Later, this indicator began to increase gradually to 11.34% in 2019 compared to 2007 (Fig. 5 and Fig. 6).

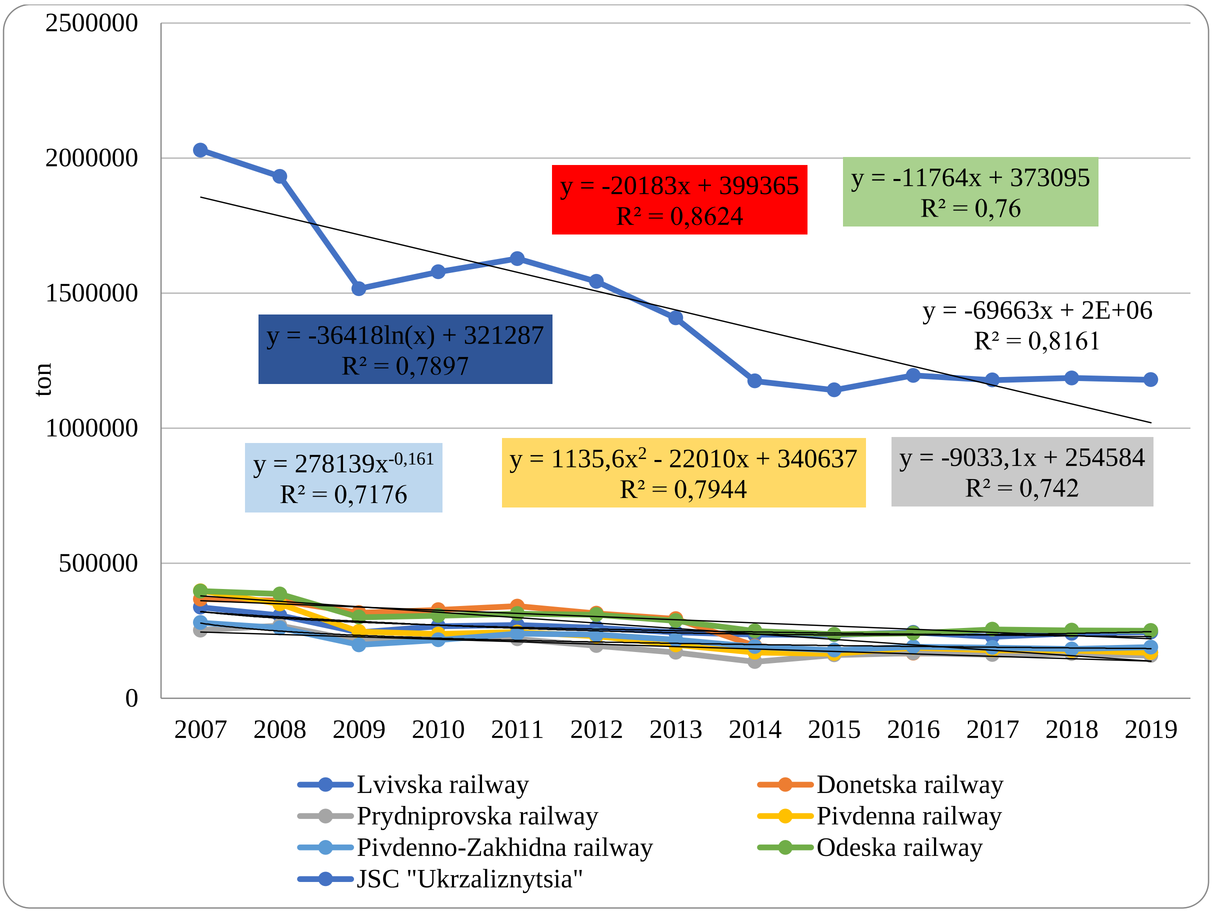

Figure 4: Dynamics of emissions of JSC "Ukrzaliznytsia" in 2007-2019 by the railways

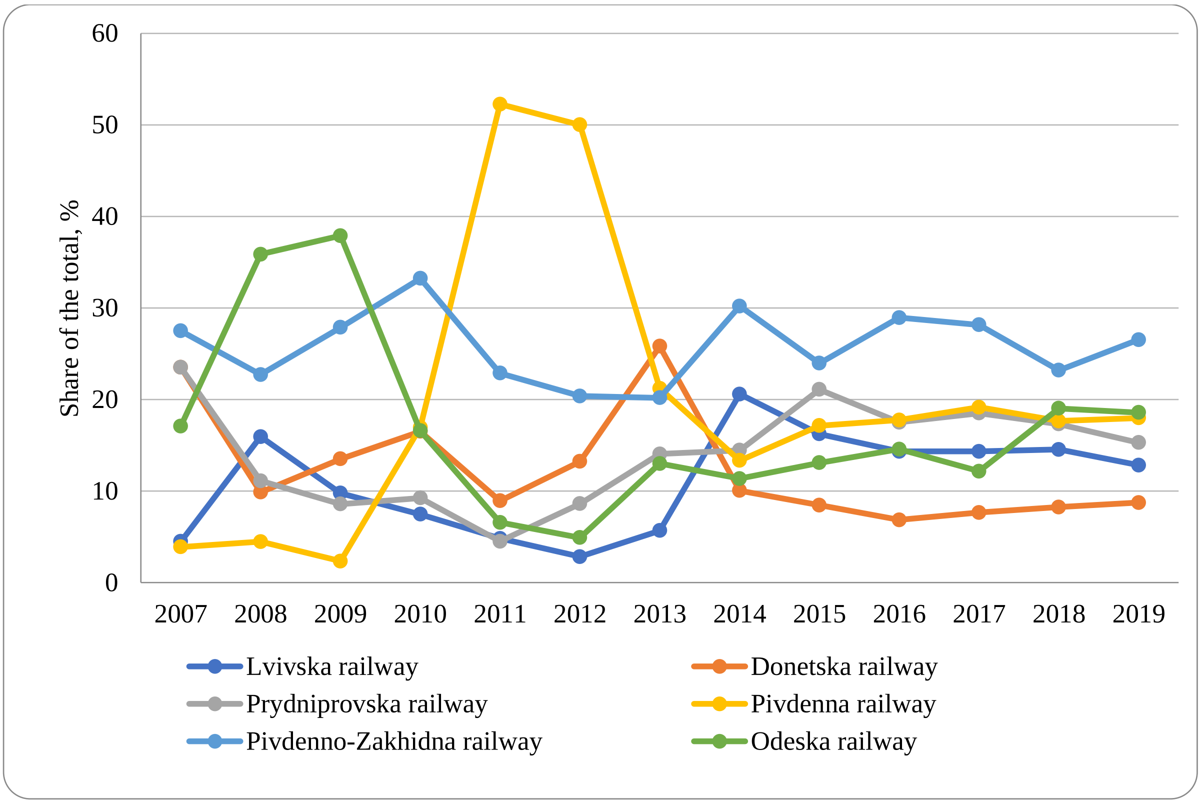

Figure 5: Dynamics of the structure of environmental protection expenditure of the Ukrainian railways in 2007-2019

The results of the correlation-regression analysis of the dependence of emissions by Ukrainian railways on the dynamics of operational turnover (the first level of the model hierarchy after a priori analysis) showed a direct relationship between these indicators. In particular, the variation in emissions growth at the Lvivska Railway by 58% can be explained by changes in freight turnover (the variation in the share of this indicator by almost 86.7% is due to the share in freight turnover). For the Donetska Railway, it is 96.2% (for the share of 88.8%). The variation of emissions growth on the Prydniprovska Railway by more than 70% can be explained by changes in freight turnover (but the variation of the share of this indicator almost does not depend on the corresponding share in the structure of freight turnover).

The variation of emissions on the Pivdenna Railway is almost 80%, which can be explained by changes in the dynamics of freight turnover, but the structural indicators are not clear, as well as for the Prydniprovska Railway. The greatest dependence is observed for the Pivdenno-Zakhidna Railway (more than 93.2% of the variation; while for structural indicators a close connection exists).

The exception to all railways is Odeska, because no connection between emissions variation and freight turnover in absolute terms, although the corresponding structural indicators are 67.6% dependent. In general, the coefficient of determination of 88.5% is indicative for JSC "Ukrzaliznytsia". The adequacy of the applied models is confirmed by the relevant statistical criteria, the probability is 0.95 (Fig. 6-19).

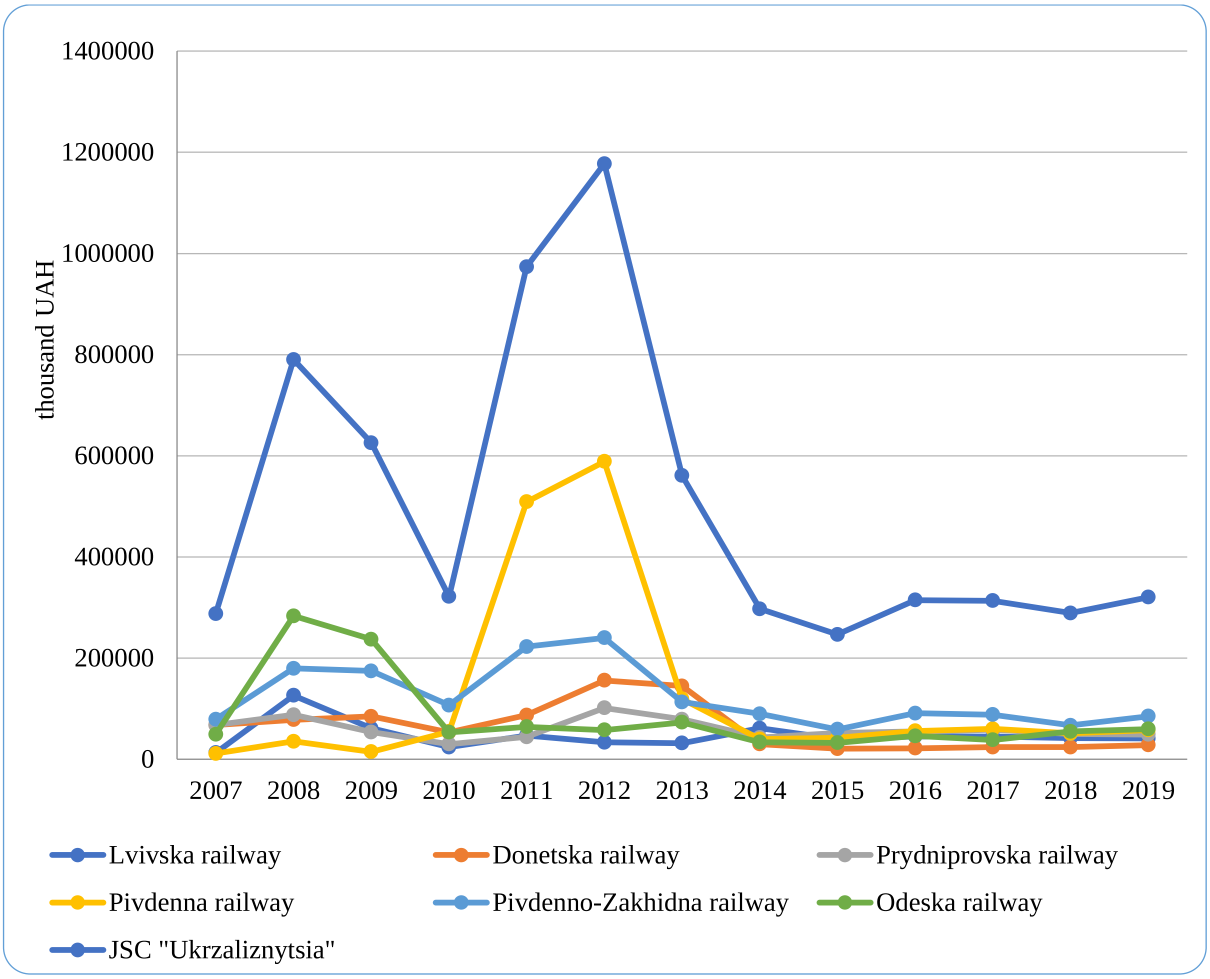

Figure 6: Dynamics of environmental protection expenditure of the Ukrainian railways in 2007-2019

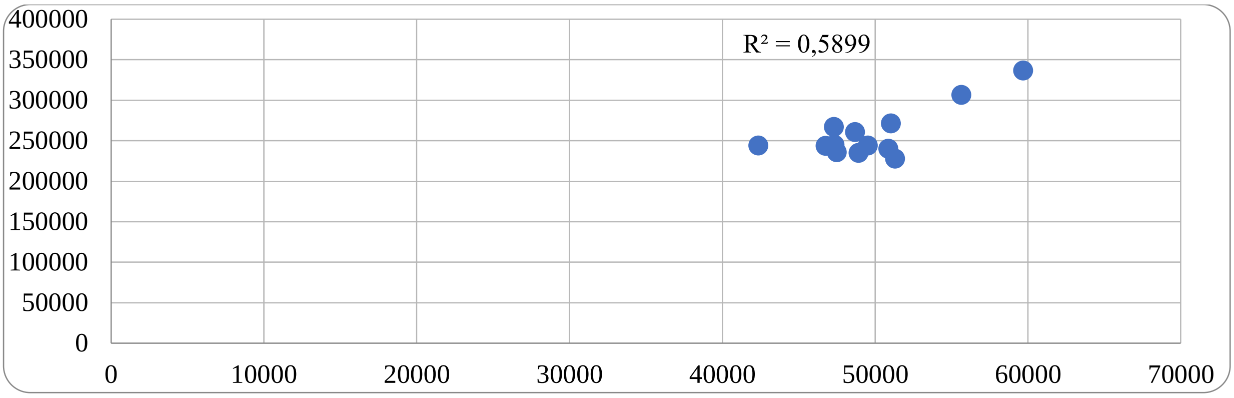

Figure 7: Dependence of emissions of Lvivska Railway on the dynamics of operational freight turnover in 2007-2019

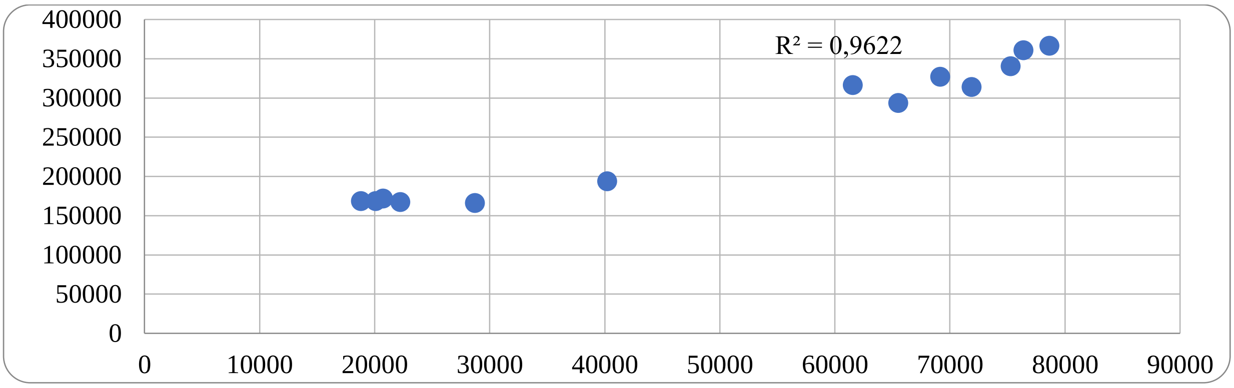

Figure 8: Dependence of emissions of Donetska Railway on the dynamics of operational freight turnover in 2007-2019

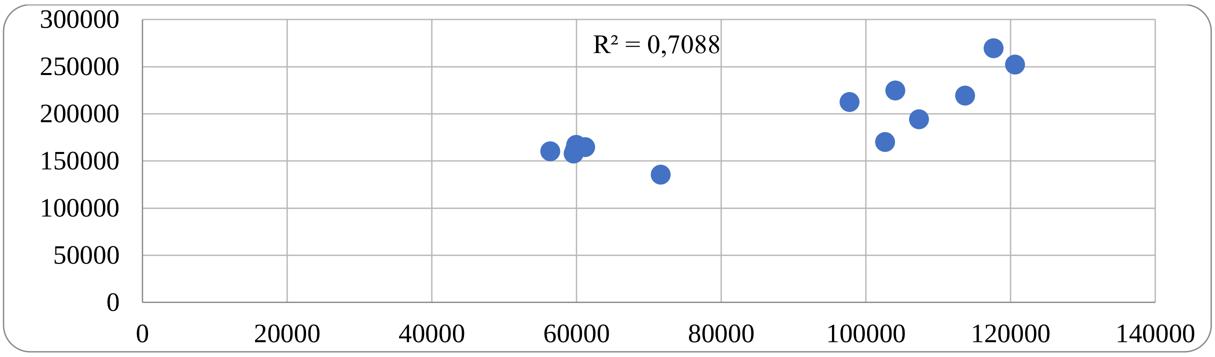

Figure 9: Dependence of emissions of Prydniprovska Railway on the dynamics of operational freight turnover in 2007-2019

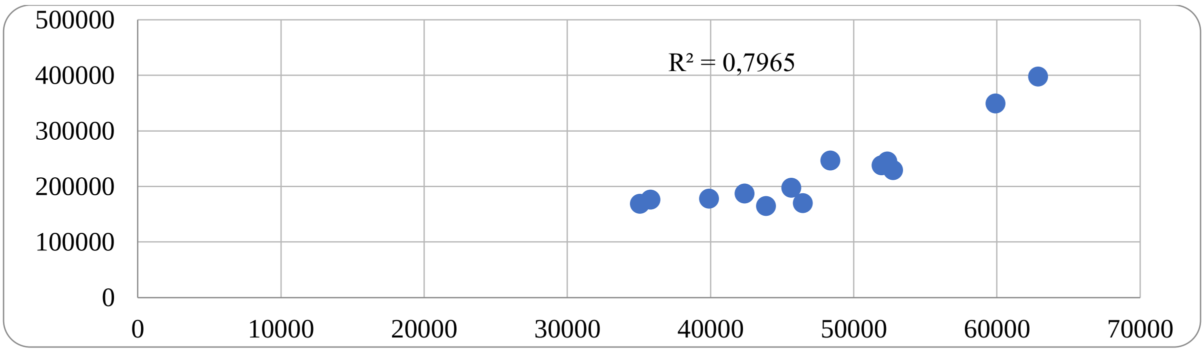

Figure 10: Dependence of emissions of Pivdenna Railway on the dynamics of operational freight turnover in 2007-2019

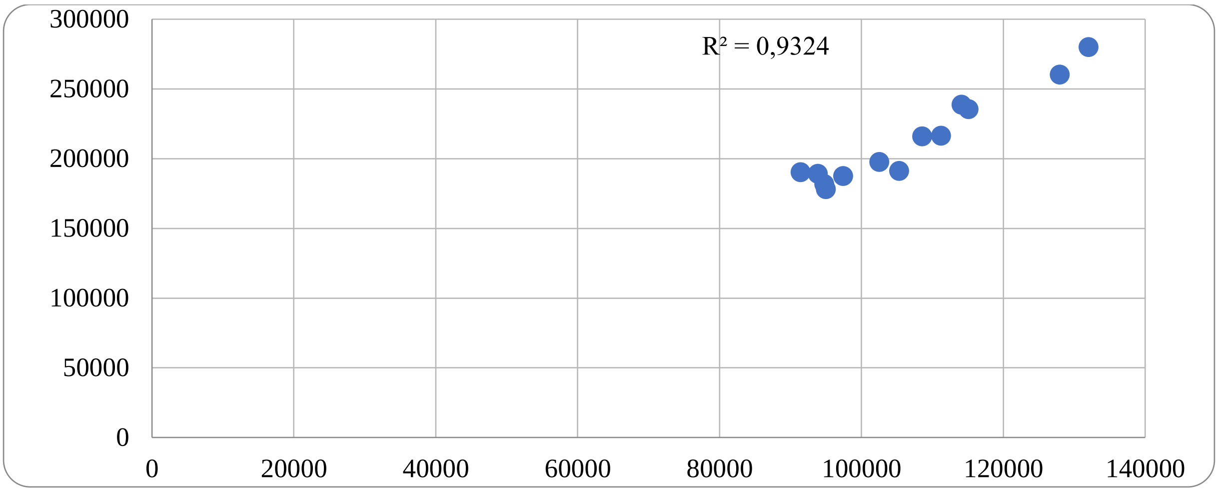

Figure 11: Dependence of emissions of Pivdenno-Zakhidna Railway on the dynamics of operational freight turnover in 2007-2019

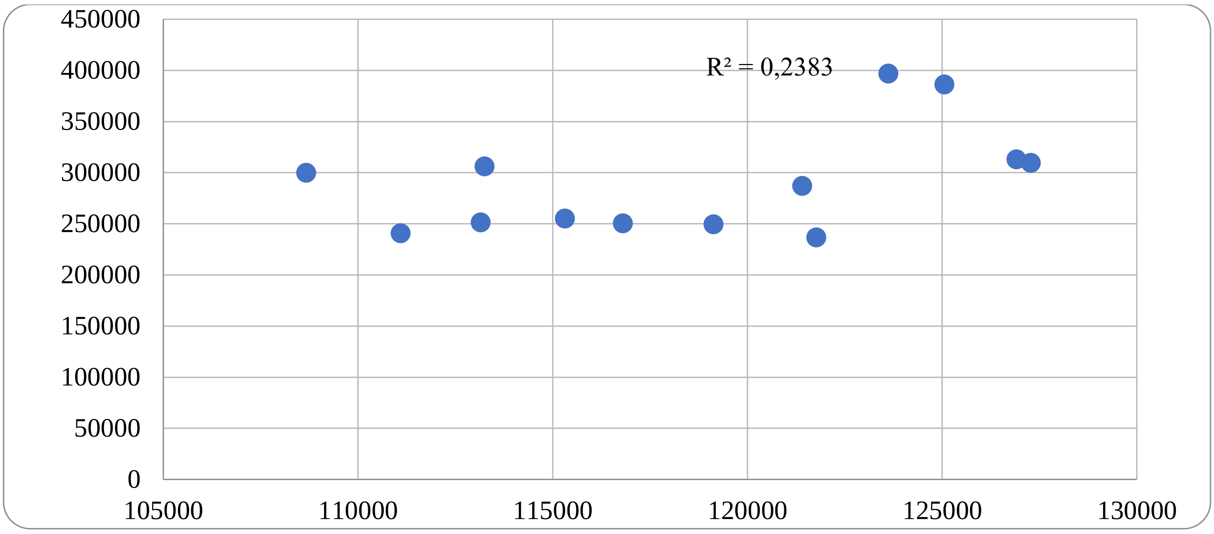

Figure 12: Dependence of emissions of Odeska Railway on the dynamics of operational freight turnover in 2007-2019

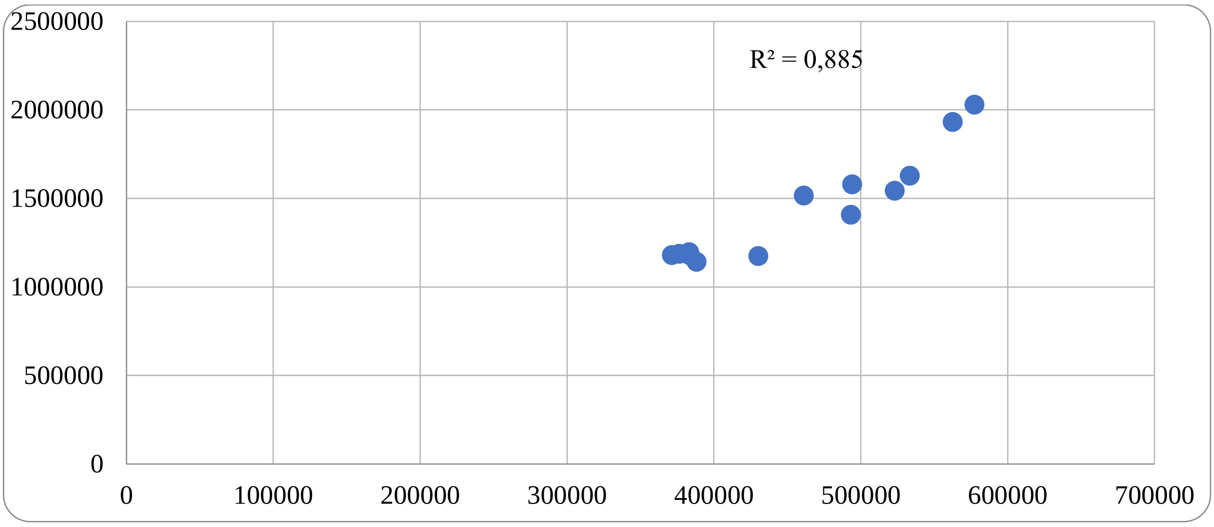

Figure 13: Dependence of emissions of JSC "Ukrzaliznytsia" on the dynamics of operational freight turnover in 2007-2019

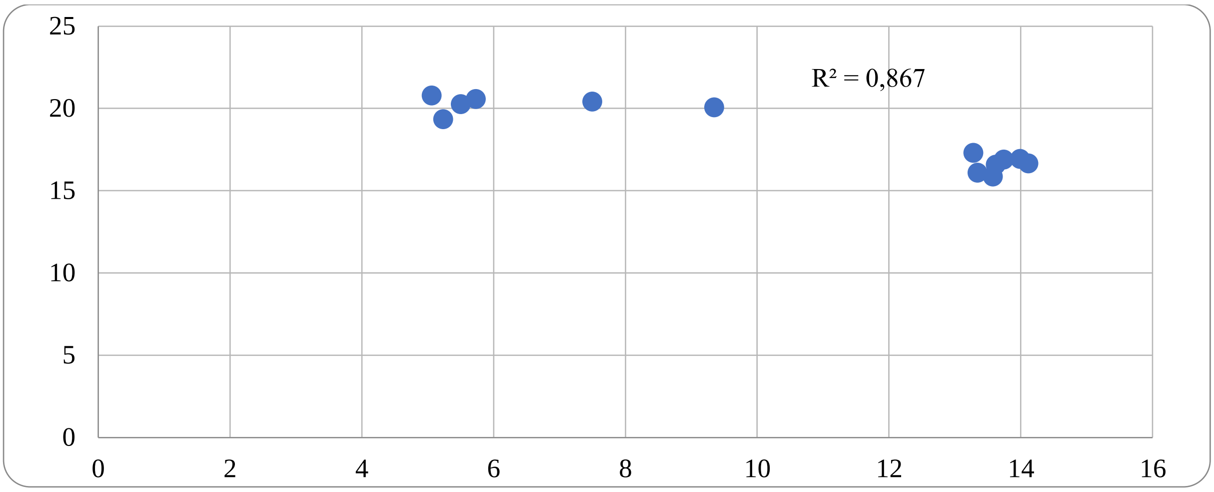

Figure 14: Dependence of the share of emissions of Lvivska Railway on the dynamics of the share of operational freight turnover in 2007-2019

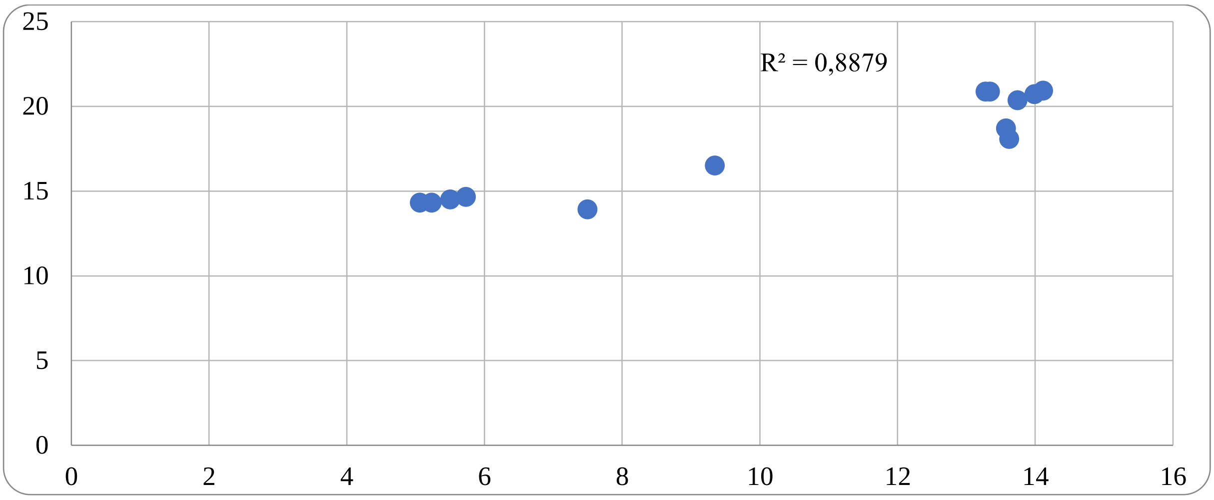

Figure 15: Dependence of the share of emissions of Donetska Railway on the dynamics of the share of operational freight turnover in 2007-2019

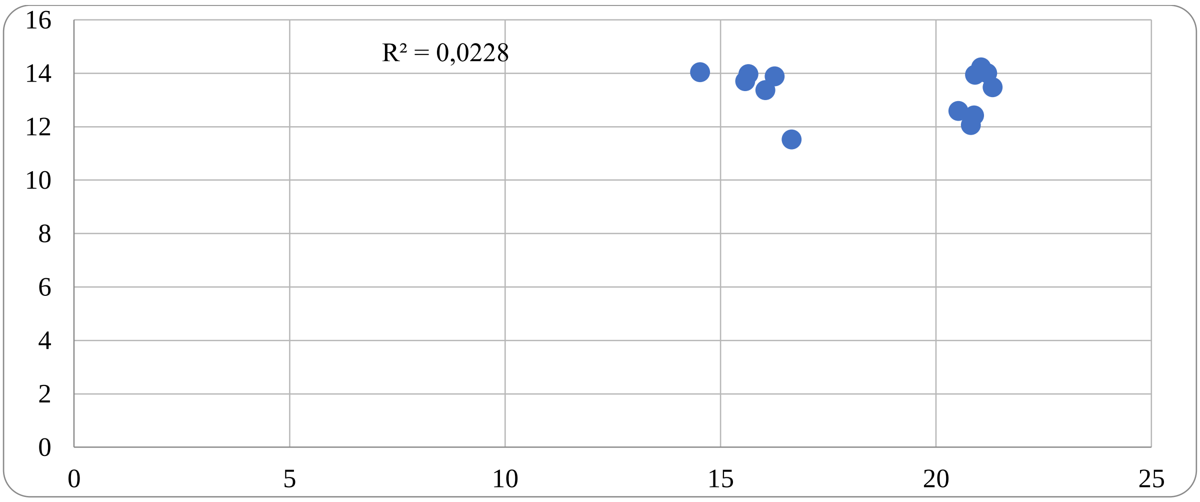

Figure 16: Dependence of the share of emissions of Prydniprovska Railway on the dynamics of the share of operational freight turnover in 2007-2019

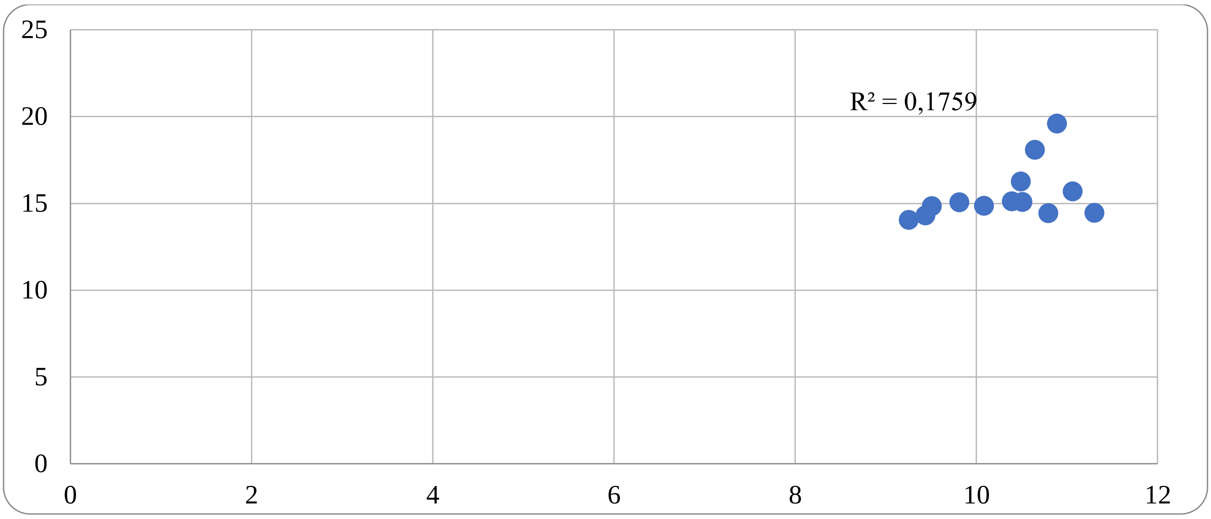

Figure 17: Dependence of the share of emissions of Pivdenna Railway on the dynamics of the share of operational freight turnover in 2007-2019

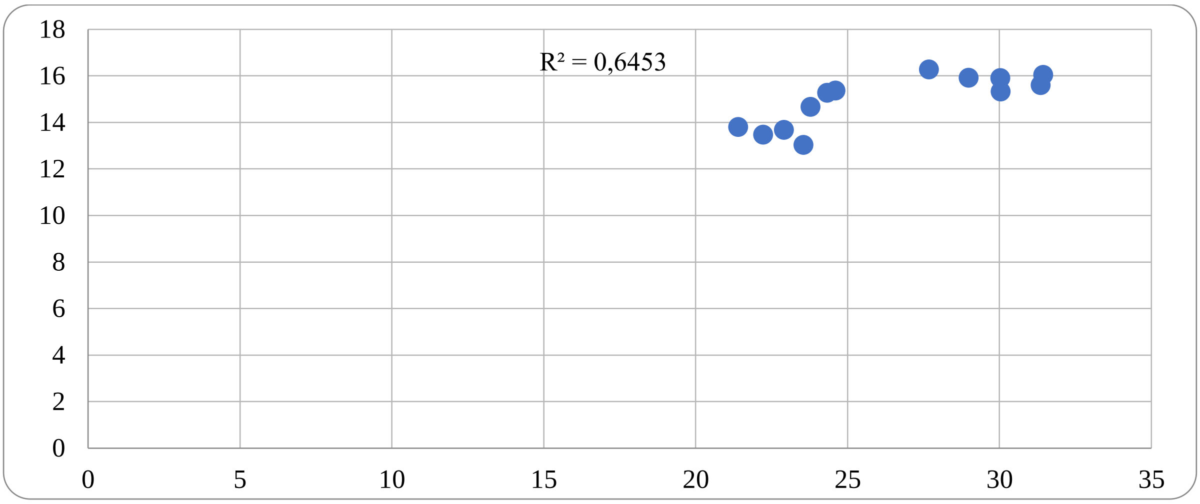

Figure 18: Dependence of the share of emissions of Pivdenno-Zakhidna Railway on the dynamics of the share of operational freight turnover in 2007-2019

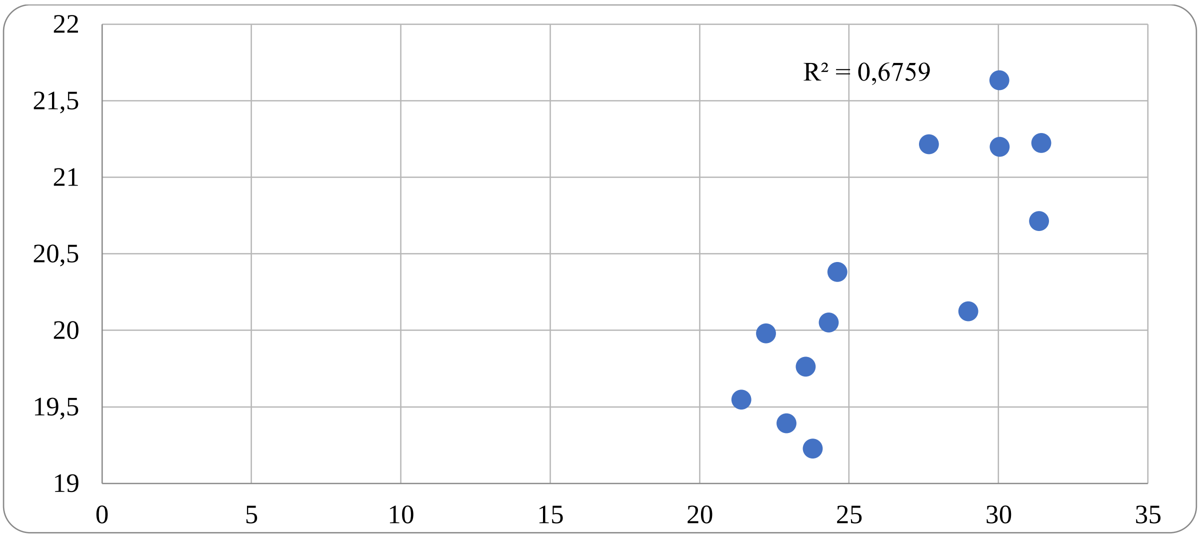

Figure 19: Dependence of the share of emissions of Odeska Railway on the dynamics of the share of operational freight turnover in 2007-2019

As a result of the study of the dependence of growth rates (decrease) of emissions by the railways of Ukraine, it was found that it exists for all railways except the Pivdenna Railway and Prydniprovska Railway (second level of the hierarchical model). This dependence can also be traced for JSC "Ukrzaliznytsia" as a whole. The calculation results confirm that environmental protection projects do contribute to reducing CO_2 emissions (Fig. 20-26). However, it is necessary to study why these conclusions are not valid for the Pivdenna Railway, because for some time it was the leader in the share of environmental expenditure.

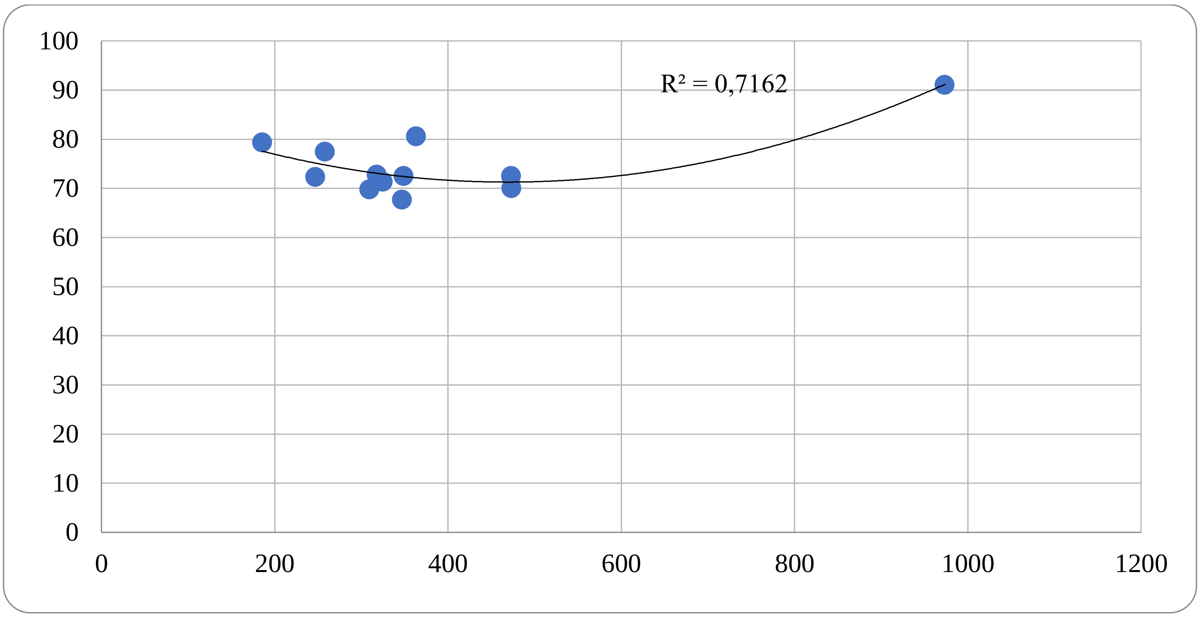

Figure 20: The dependence of growth rates of emissions of Lvivska Railway on the growth rates of environmental expenditure in 2007-2019

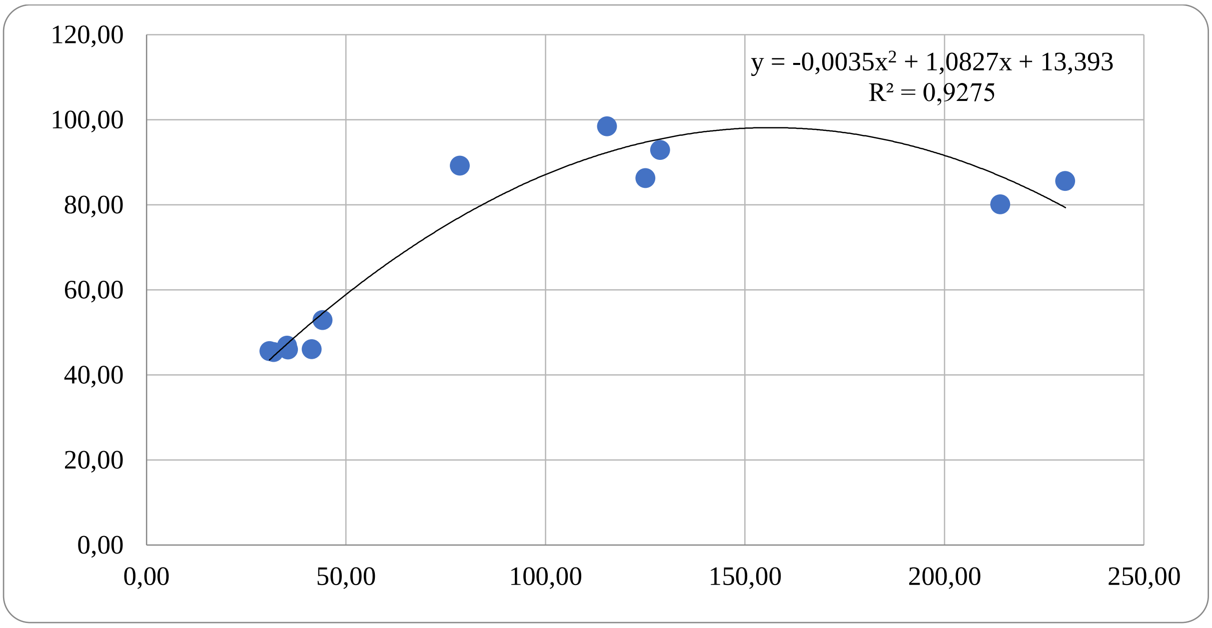

Figure 21: The dependence of growth rates of emissions of Donetska Railway on the growth rates of environmental expenditure in 2007-2019

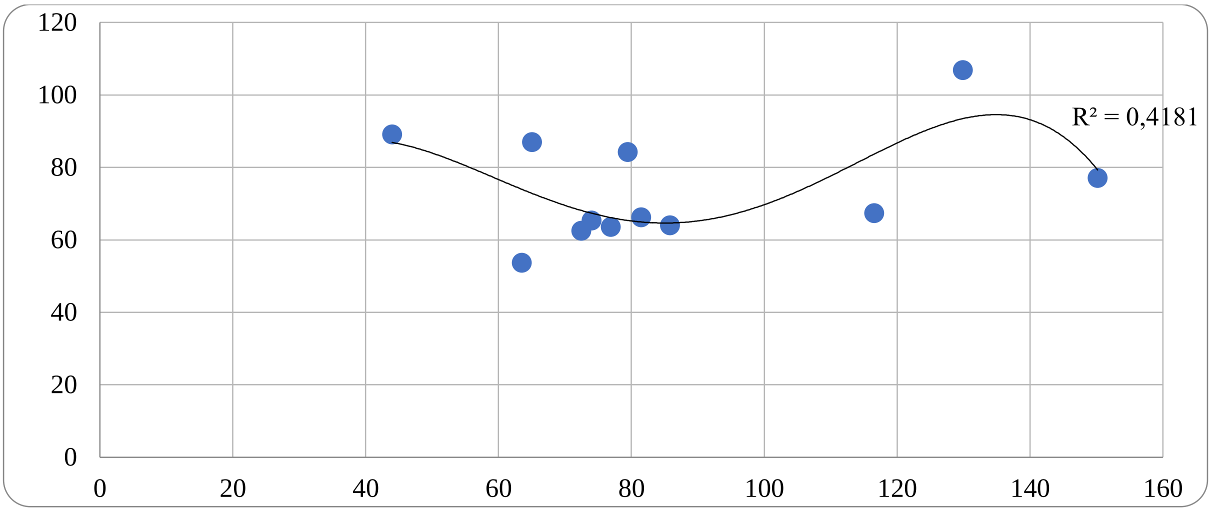

Figure 22: The dependence of growth rates of emissions of Prydniprovska Railway on the growth rates of environmental expenditure in 2007-2019

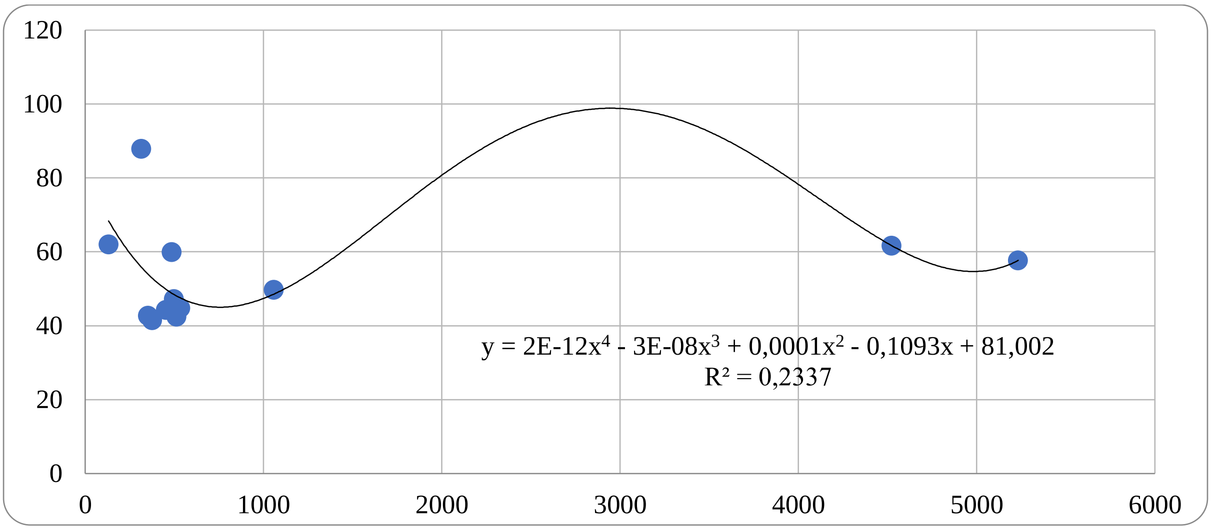

Figure 23: The dependence of growth rates of emissions of Pivdenna Railway on the growth rates of environmental expenditure in 2007-2019

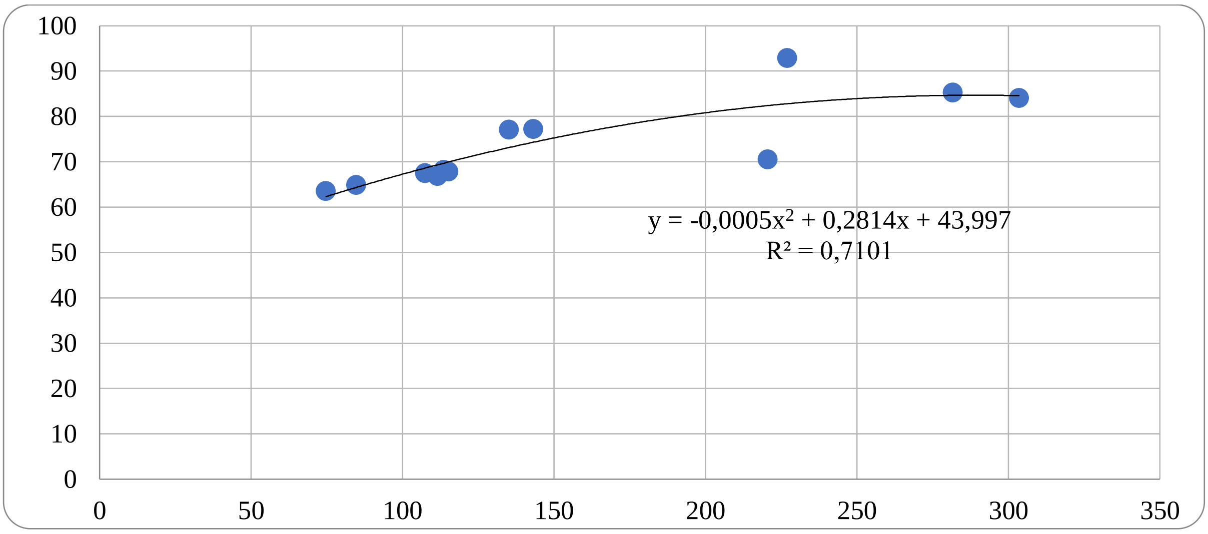

Figure 24: The dependence of growth rates of emissions of Pivdenno-Zakhidna Railway on the growth rates of environmental expenditure in 2007-2019

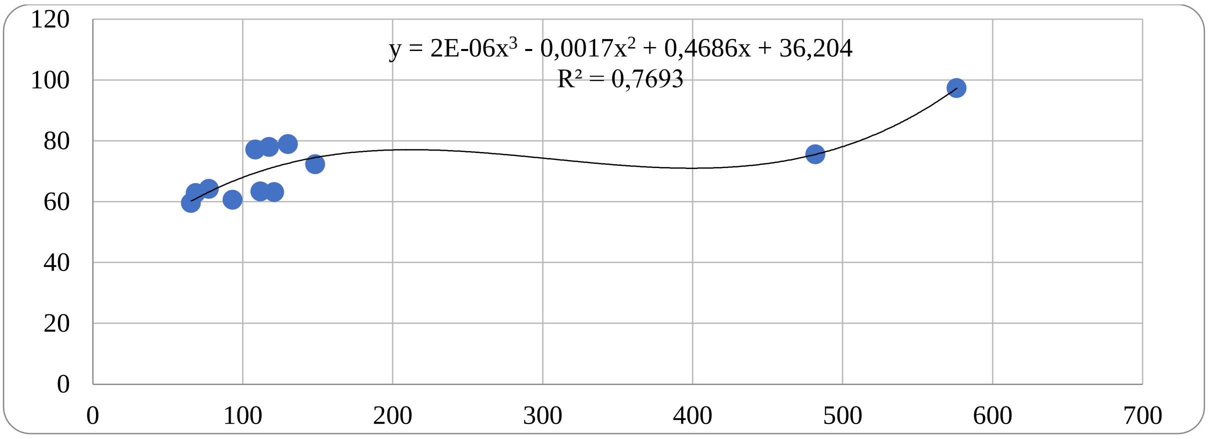

Figure 25: The dependence of growth rates of emissions of Odeska Railway on the growth rates of environmental expenditure in 2007-2019

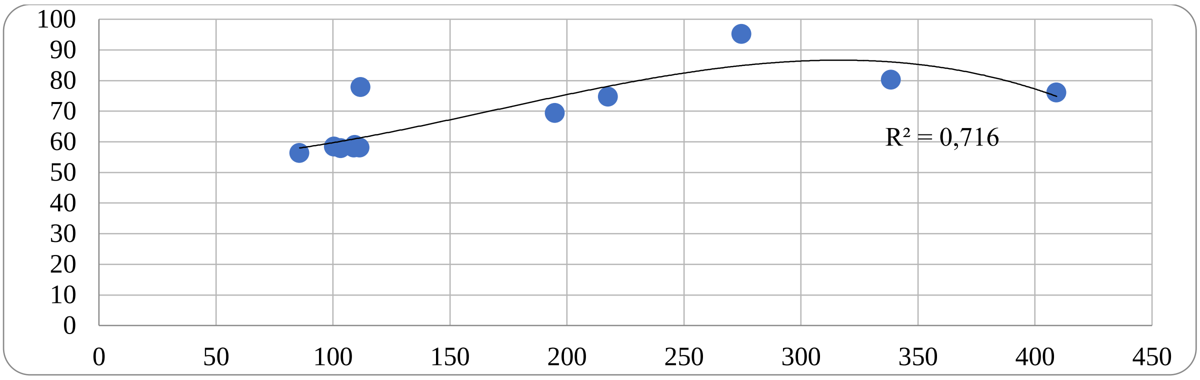

Figure 26: The dependence of growth rates of emissions of JSC "Ukrzaliznytsia" on the growth rates of environmental expenditure in 2007-2019

5. Conclusions and further research

It was practically implemented the proposed hierarchical model of dependence between: 1) operational turnover and the amount of CO_2 emissions by the relevant sources of pollution in terms of their volume and structure (the first level of the hierarchy); 2) environmental expenditure and the amount of CO_2 emissions (the second level of the hierarchy). In the future, the developed model can be applied to identify problematic objects in railway transport, for which the magnitude and share of environmental expenditure in total does not affect the reduction of CO_2 emissions. The proposed model allows to assess the indirect effectiveness of environmental projects on railways with the separation of objects that demonstrate the lack of relationship between the size of environmental expenditure and CO_2 emissions. It was found that the Pivdenna and Prydniprovska railways during the study period were not the largest consumers of diesel fuel, so this fact can not explain the lack of relationship between environmental expenditure and CO_2 emissions. Such a conclusion may be an indirect evidence of inefficient distribution and formation of environmental expenditure of Ukrainian railways. Subsequent studies of these railways may reveal the nature of the reasons for the lack of such a connection. The approbation of the model for other branches of the national economy seems promising.

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