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ASSESSING THE EFFICIENCY OF TRANSPORT INFRASTRUCTURE INVESTMENTS IN ROMANIA: A MULTIDIMENSIONAL APPROACH

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Abstract

Transport infrastructure plays a crucial role in the economic development and environmental sustainability of any region. This study focuses on evaluating the efficiency of transport infrastructure investments in Romania, examining their social, economic, and environmental impacts. The research adopts a comprehensive approach, integrating data from national and European sources to assess the long-term effects of these investments. Key findings highlight the need for a balanced investment strategy that considers energy consumption, pollutant emissions, land use and socio-economic inclusion. The study also proposes a methodology for determining the congruence factor, which balances environmental, social, and economic criteria to optimize infrastructure performance. These insights aim to guide policymakers in making informed decisions to promote sustainable development in the transport sector.

***Key words**: transport infrastructure, investment efficiency, environmental impact, socio-economic development, sustainable development, Romania, congruence factor, policy guidance.*

INTRODUCTION

Transport infrastructure, encompassing roads, railways, airports, and waterways, is the backbone of every economic activity, facilitating the movement of goods, services, and people. It plays a pivotal role in regional development, trade, and overall economic growth (Zaman & Geamănu, 2014). However, the development and maintenance of transport infrastructure entail substantial investments, often requiring significant public funds. Therefore, assessing the efficiency of these investments is crucial to ensure that they yield the desired economic, social, and environmental benefits.

In Romania, a country in the midst of economic transition and integration into the European Union policies, the efficient allocation of resources for transport infrastructure is of paramount importance. The country faced challenges related to aging infrastructure, regional disparities in development, and the need to align its transport system with European standards. In this context, a multidimensional approach to assessing the efficiency of transport infrastructure investments is warranted.

This study aimed to evaluate the efficiency of transport infrastructure investments in Romania by considering their economic, social, and environmental components. It analysed data from national and European sources to assess the impact of these investments on various aspects of Romanian society and the environment. The research also proposed a methodology for determining the congruence factor, a novel concept that aim to balance economic, social, and environmental criteria to optimize infrastructure performance.

The concept of sustainable development, encompassing economic, social, and environmental dimensions, has gained prominence in recent decades (Nidziy, 2017). In the context of transport infrastructure, sustainability implies a balanced approach that considers not only economic benefits but also the social and environmental impacts of projects.

Economic efficiency in transport infrastructure investments is typically assessed using cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) (Zaman & Geamănu, 2006). These methods quantify the economic costs and benefits of projects, helping decision-makers prioritize investments that yield the highest net benefits. However, they often neglect the broader social and environmental implications not taking in consideration corelated criteria from local, regional and global needs (Jovovic et al., 2017).

Social impact assessment (SIA) is a methodology used to evaluate the social consequences of projects, including their effects on communities, employment, and quality of life. Environmental impact assessment (EIA) evaluates the potential environmental harm caused by projects, such as pollution, habitat destruction, and resource depletion as well as the adaptation of project characteristics to climate changes in a circular economy concept to eliminate component obsolescence (Latouche, 2017).

In recent years, there has been a growing recognition of the need to integrate economic, social, and environmental considerations into the assessment of transport infrastructure investments. This has led to the development of multi-criteria decision analysis (MCDA) frameworks that incorporate a wider range of criteria beyond economic efficiency (Nicolau et al., 2024).

By financing projects that apply a multiparameter analysis regarding the efficiency of all pillars of the sustainable development concept we can achieve a green future for our future generations (Neaga, 2015).

State of the Art in Transport Infrastructure

Transport infrastructure is a critical component of economic and social development. The efficiency and effectiveness of transport systems directly impact a country's economic growth, regional development, and environmental sustainability. In the European Union, substantial investments have been made to modernize and expand transport infrastructure, focusing on improving connectivity, reducing travel times, and minimizing environmental impacts.

The Europe Union has established two important objectives: to interconnect Europe and achieve neutrality in the context of climate change until the year 2050. However, developing a cohesive transport infrastructure network, particularly at the borders between countries, remains a significant challenge that needs to be addressed. A thorough analysis of cross-border rail infrastructures in Europe, utilizing Geographic Information Systems (GIS), reveals that population size does not significantly influence the presence of these infrastructures, indicating that many densely populated regions remain unconnected by rail to neighbouring regions across national borders (Theisen & vom Berg, 2024). In the Figures 1 and 2 are presented the major railway and highway infrastructure projects from Europe.

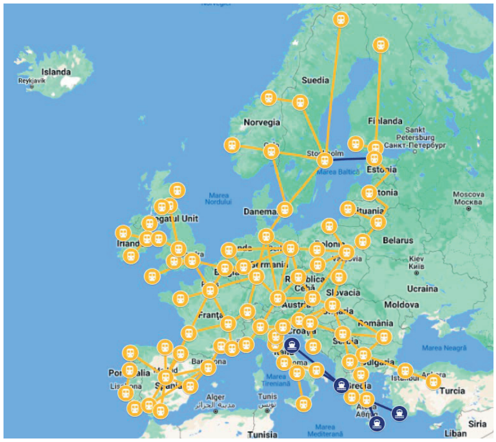

Figure 1. Major European railway lines in exploitation (EURAIL, 2024)

Figure 2. Major European highways in exploitation, extract from European Commission map

The evolving concept of smart highways aims to revolutionize traditional highway systems by integrating advanced sensing, communication, and control technologies to enhance safety, efficiency, and sustainability. Despite the promising potential, the development of smart highways faces significant challenges due to the lack of standardized evaluation criteria and the diversity of regional infrastructure conditions (Li et al., 2024).

Recent studies have quantified the CO_2 emissions from highway construction, revealing that the total emissions for an entire construction project can reach 10,605.2 $t \cdot km^{-1} \cdot lane^{-1}$. Notably, the raw material production and on-site construction phases contribute 95.2% and 4.8% of these emissions, respectively. These insights underscore the necessity for strategies that incorporate recycled materials and advanced construction technologies to effectively reduce the carbon footprint of transport infrastructure projects (Gao et al., 2024).

In the process of transport infrastructure development, comprehensive planning and assessment methodologies are mandatory to ensure projects are not only economically viable but also environmentally sustainable and socially responsible.

The assessment of transport infrastructure projects involves a multifaceted approach that integrates various studies and methodologies. Recent advancements have highlighted the importance of several critical assessments, including Do No Significant Harm (DNSH) Assessments, Environmental Assessments (EA), Risk Management Plans (RMP), and Environmental Impact Assessments (EIA), DNSH analysis.

Incorporating considerations of habitat connectivity and biodiversity along road and rail routes is imperative for enhancing ecological coherence.

Road kills pose a significant threat to biodiversity in areas where infrastructure projects are operational. Therefore, it is crucial for specialists to evaluate this criterion for each taxonomic biodiversity group (Nicolae & Stefan, 2022).

Transport corridors can significantly enhance habitat connectivity and support biodiversity, particularly for generalist and open-specialist species that thrive in early to mid-successional habitats. Physiological factors are crucial in determining species' dispersal abilities, emphasizing the need for vegetation management that considers representative communities rather than individual species.

Figure 3 illustrates important aspects in landscape ecology relevant to fragmented landscapes due to infrastructure development.

Figure 3. Illustration of Key Terms in Landscape Ecology (Cork et al., 2024)

These assessments evaluate the potential negative impacts, ensure that any adverse effects are minimized, adhering to stringent environmental protection standards, involving a detailed study of the environmental baseline, the identification of potential impacts, and the proposal of mitigation measures to address these impacts.

Cost-Benefit Analysis (CBA) is a critical tool for analyzing the economic feasibility and benefits of infrastructure projects. This method evaluates the costs of implementation against the expected economic returns, ensuring that resources are allocated efficiently and effectively.

Additionally, Climate Change Adaptation Plans involve measures to adapt infrastructure projects to anticipated climate impacts, addressing vulnerabilities and incorporating resilience strategies to mitigate the effects of climate change on infrastructure.

Traffic Studies analyze the impact of project-related traffic on local transportation networks, helping in understanding and mitigating potential congestion and improving overall traffic flow.

The planning and execution of transport infrastructure projects face several interconnected challenges, including the need for recycling, green infrastructure, renewable energy, biodiversity conservation, population growth.

Addressing these challenges requires a composite and complex approach to evaluation, ensuring that the best options for project development are chosen. This equilibrium can be obtained through meticulous planning and the integration of diverse assessment methodologies, ensuring that infrastructure projects contribute positively to sustainable development goals.

In conclusion, the assessment of transport infrastructure projects involves a multifaceted approach that integrates various studies and methodologies. By addressing the environmental, economic, and social dimensions of sustainability, these assessments ensure that infrastructure development aligns with broader sustainable development objectives. The rigorous evaluation of these factors enables policymakers to make informed decisions, fostering the development of infrastructure that is efficient and sustainable.

MATERIALS AND METHODS

This study utilized a mixed-methods approach, combining quantitative and qualitative data analysis. Quantitative data were obtained from national and European statistical databases, including Eurostat and the Romanian National Institute of Statistics (INSSE). These data covered various aspects of transport infrastructure, such as investment levels, network length, traffic volumes, energy consumption, and pollutant emissions.

Qualitative data were gathered through a review of the relevant literature on infrastructure projects in Romania. These sources provided insights into the decision-making processes, challenges, and opportunities related to infrastructure investments.

The analysis employed statistical methods to examine the relationships between transport infrastructure investments and economic, social, and environmental indicators. For example, regression analysis was used to assess the impact of investments on GDP growth, while correlation analysis was employed to examine the relationship between infrastructure development and employment rates.

The study also developed a methodology for calculating the congruence factor, which was based on a weighted average of economic, social, and environmental criteria. The weights assigned to each criterion were determined through a literature review and synthesis of expert opinions. The congruence factor formula is as follows:

Congruence Factor = $(w_e * E) + (w_s * S) + (w_{env} * ENV)$

where:

- w_e, w_s, and w_{env} are the weights assigned to economic, social, and environmental criteria, respectively.
- E, S, and ENV are the standardized scores for each criterion.
- $w_1, w_2, ..., w_n$ are weights assigned to additional attributes $A_1, A_2, ..., A_n$ to include in the analysis.

Example Attributes (A1, A2, ... An)

Additional attributes can be introduced that are relevant to the efficiency and impact of transport infrastructure investments. These attributes could include:

1. Traffic Flow Impact: Measure of how investments affect traffic congestion and flow efficiency;
2. Accessibility: Measure of improved access to essential services (education, healthcare) due to infrastructure projects;

3. Resilience: Measure of infrastructure's ability to withstand climate change impacts or natural disasters (Nicolae & Nicolae, 2023);
4. Adaptation: Evaluate how the future project can adapt to critical/global events (Fang, 2021);
5. Innovation: Measure of technological innovation or sustainability practices integrated into the infrastructure project.

By expanding the congruence factor formula to include additional attributes with impact weights, the analysis provides a more comprehensive assessment of the efficiency and impact of transport infrastructure investments. The proposed approach allows for an accurate evaluation that considers a broader range of criteria, enhancing decision-making processes for policymakers and stakeholders involved in infrastructure development.
The standardized scores are calculated by dividing the raw value of each criterion by its maximum value, ensuring that all criteria were on the same scale.

RESULTS AND DISCUSSIONS

The following tables present critical data on transport infrastructure and socio-economic impacts across various EU countries, providing a comprehensive overview of the comparative lengths of railway and highway networks and their associated socio-economic benefits. Table 1 highlights the extensive infrastructure in countries like Germany and France, which have substantial railway and highway lengths, facilitating efficient transport and robust economic activities.

Table 1. Comparative data of transport infrastructure in EU Countries

Country	Railway Length (km)	Highway Length (km)
Germany	33,590	13,181
France	29,640	11,882
Italy	16,788	6,957
Spain	15,718	17,228
Romania	10,627	982
Poland	18,515	4,765
Netherlands	7,029	2,758
Belgium	3,607	1,763

In contrast, Romania and Belgium show significantly lower figures, indicating potential areas for infrastructure development and investment. These disparities underline the varying stages of infrastructure maturity across the EU, with countries like Spain prioritizing highway development, evidenced by its 17,228 km of highways, compared to its 15,718 km of railways.
Table 2 summarizes the socio-economic impacts of transport infrastructure, emphasizing its role in job creation, economic growth, and environmental sustainability. Effective transport networks not only boost GDP by enhancing trade and mobility but also create numerous employment opportunities, fostering socio-economic development. Additionally, well-planned infrastructure can significantly reduce pollution, contributing to environmental sustainability. The data suggest that countries with more developed transport networks, like Germany and France, likely experience higher economic and social benefits compared to those with less extensive infrastructure. This analysis underscores the need for balanced investment in both railways and highways to achieve comprehensive socio-economic development, especially in countries lagging in infrastructure development.

Table 2. Summary of socio-economic impacts

Impact	Description
Employment	Creates jobs
Economic Growth	Boosts GDP
Environmental Sustainability	Reduces pollution

Economic impact

Transport infrastructure investments in Romania yielded mixed results in terms of economic efficiency. While some projects stimulated economic growth and improved connectivity, others were plagued by cost overruns, delays, and underutilization. A key challenge was the need to prioritize projects that aligned with national and regional development goals, ensuring that investments generated the highest possible economic returns.
For instance, the construction of the A2 motorway, connecting Bucharest to Constanța, led to a significant reduction in travel time and transportation costs, boosting trade and tourism in the region. However, other projects, such as the A3 motorway, faced delays and cost overruns, raising questions about their economic viability.

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Table 3. Trends regarding the goods transported on the rail and road infrastructure

Year	Rail Transport (thousand tons)	Road Transport (thousand tons)
1990	218828	1934362
1995	105131	616044
2000	71461	262943
2005	69175	306994
2010	52932	174551
2015	55307	198638
2020	49671	266523
2023	48867	321348

Table 3 presents the transport volumes for rail and road transport over selected years. The data illustrates the trends and changes in transport modes, highlighting the significant differences in volumes transported by rail and road across the years.

The Figure 4 below visually depicts the transport volumes for rail and road transport over selected years. By comparing the two modes of transport side-by-side, the graph provides a clear visual representation of the trends and fluctuations in transport volumes, emphasizing the changes and differences between rail and road transport from 1990 to 2023.

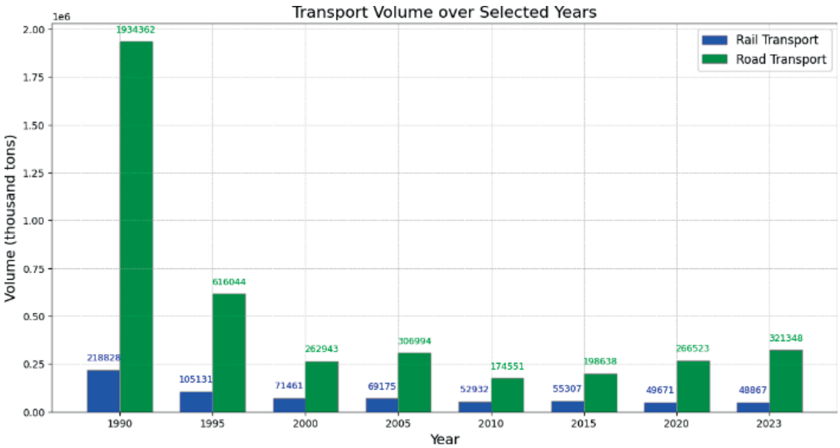

Figure 4. Quantity of goods transported, by types of transport. Time author adaptation from (INSSE, 2024)

The social impact of transport infrastructure investments in Romania was significant, particularly in terms of improved accessibility and mobility for citizens. The development of new roads and railways facilitated access to education, healthcare, and employment opportunities, especially in rural areas. However, there were also negative consequences, such as the displacement of communities and the disruption of social networks due to land acquisition for infrastructure projects.

For example, the construction of the Bucharest Ring Road led to the displacement of thousands of residents and businesses, causing social disruption and economic hardship for some communities (Dyllick & Hockerts, 2002).

The environmental impact of transport infrastructure investments in Romania raised concerns, primarily related to greenhouse gas emissions, air pollution, and land use changes. The country's heavy reliance on road transport, coupled with the growth in vehicle ownership, contributed to increased emissions and air quality problems (Zubala, 2022).

The relationship between energy consumption and greenhouse gas emissions is a crucial aspect of understanding the environmental impact of transport infrastructure. The methodology for GES evaluation must be in line with the European directives applicable now of the evaluation (IPCC, 2006). The analysis reveals a consistent increase in both metrics over time. Specifically, energy consumption, measured in kilotons of oil equivalent petrol, shows fluctuations but generally trends upwards from 1990 to 2020. Similarly, greenhouse gas emissions from railway and road transport exhibit a continuous rise.

Table 4. Energy consumption and GHG emissions of railway and highway projects

Year	Energy Consumption (kTo eq petrol)	Greenhouse Gas Emissions from Railway and Road Transport (kt CO_2 eq)	Railway Length (km)	Highway Length (km)
1990	345	11183	11348	72816
1995	396	8179	11376	72859
2000	339	9458	11015	78479
2005	413	12146	10948	79904
2010	407	13677	10785	82386
2015	379	15467	10770	85920
2020	416	18139	10769	86791

The Table 4 presents key data points related to energy consumption, greenhouse gas emissions, and the lengths of railway and highway networks over selected years. This data is crucial for understanding the trends and relationships between these variables in the context of transport infrastructure.

The Figure 5 shows the relationship between energy consumption and greenhouse gas emissions from railway and road transport. The plot includes a linear regression line, which helps to visualize the correlation between these two variables, offering a clearer understanding of how energy consumption impacts greenhouse gas emissions.

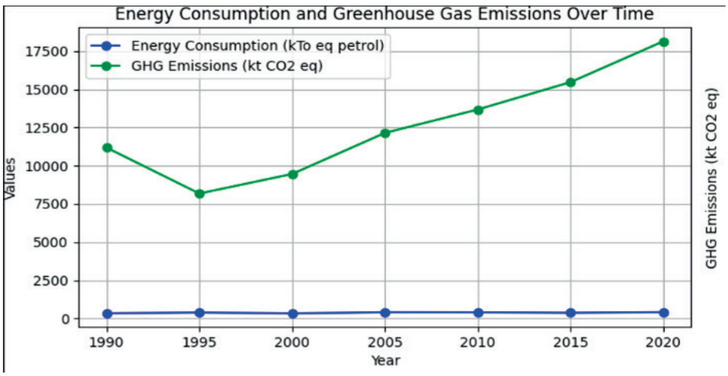

Figure 5. Energy Consumption and Greenhouse Gas Emissions Over Time. Time author adaptation from (INSSE, 2024)

A detailed scatter plot with a linear regression line underscores this relationship, showing a strong positive correlation (R-value = 0.739). The regression analysis indicates that for every additional unit of energy consumed, greenhouse gas emissions increase by approximately 25.77 kilotons of CO_2 equivalent. This statistically significant relationship (P-value = 0.043) highlights the environmental cost associated with increased energy consumption, underscoring the need for sustainable energy practices.

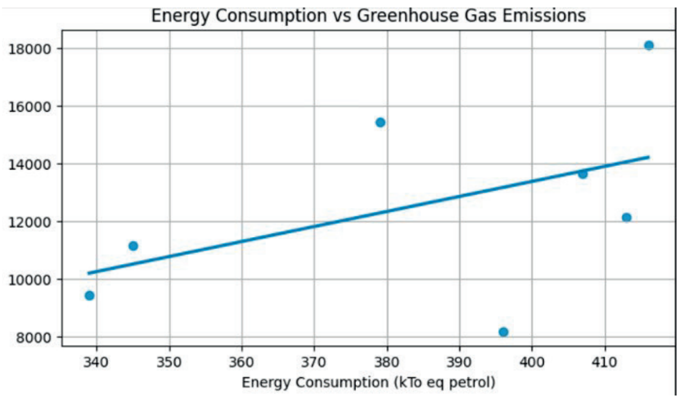

Figure 6. Energy Consumption vs. Greenhouse Gas Emissions. Time author adaptation from (INSSE, 2024)

The Figure 6 above shows the relationship between energy consumption and greenhouse gas emissions from railway and road transport. The plot includes a linear regression line, which helps to visualize the correlation between these two variables, offering a clearer understanding of how energy consumption impacts greenhouse gas emissions.

Our analysis also examines the changes in Romania's transportation infrastructure. The length of railway networks has seen a slight decline from 11,348 km in 1990 to 10,769 km in 2020, possibly reflecting a shift in transportation preferences or investment priorities over the years. Conversely, highway networks have expanded significantly, from 72,816 km in 1990 to 86,791 km in 2020. This expansion correlates positively with energy consumption (R-value = 0.57), suggesting that increased energy usage is associated with greater investment in road infrastructure.

Figure 7 presents the lengths of railway and highway networks over the selected years. By comparing the two modes of transport infrastructure, this graph provides a visual representation of the changes and growth in both railway and highway lengths, reflecting infrastructure development trends over time.

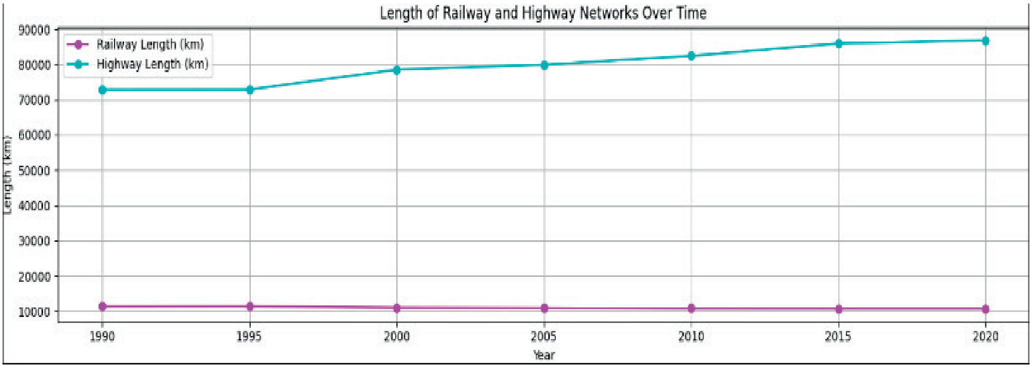

Figure 7. Length of Railway and Highway Networks Over. Time author adaptation from (INSSE, 2024)

The correlation heatmap from Figure 8 provides a visual summary of the relationships between various metrics, revealing key insights. The significant positive correlation between energy consumption and greenhouse gas emissions indicates that Romania's economic development and energy policies significantly impact environmental health. The reduction in railway length and the expansion of highway networks suggest a move towards road-based transportation, which typically has higher energy and environmental costs.

To address these issues, from the analysis we will consider the following projects to be efficient:

- Projects that promote renewable energy: investing in renewable energy sources such as wind, solar, and hydroelectric power can reduce dependence on fossil fuels, thereby decreasing greenhouse gas emissions.
- Projects that enhance public transportation: improving and expanding the railway network can offer a more sustainable alternative to road transport, reducing overall energy consumption and emissions.
- Projects that implement Energy Efficiency Measures: encouraging energy efficiency in industries, buildings, and transportation can lead to significant reductions in energy consumption and emissions.
- Projects that implement solutions for low energy consumption and greenhouse gas emissions reduction: a high positive correlation (0.74) indicates that as energy consumption increases, greenhouse gas emissions also rise.
- Projects that low energy consumption such as railway infrastructure: a moderate negative correlation (-0.51) suggests that increased energy consumption is associated with a reduction in railway length.

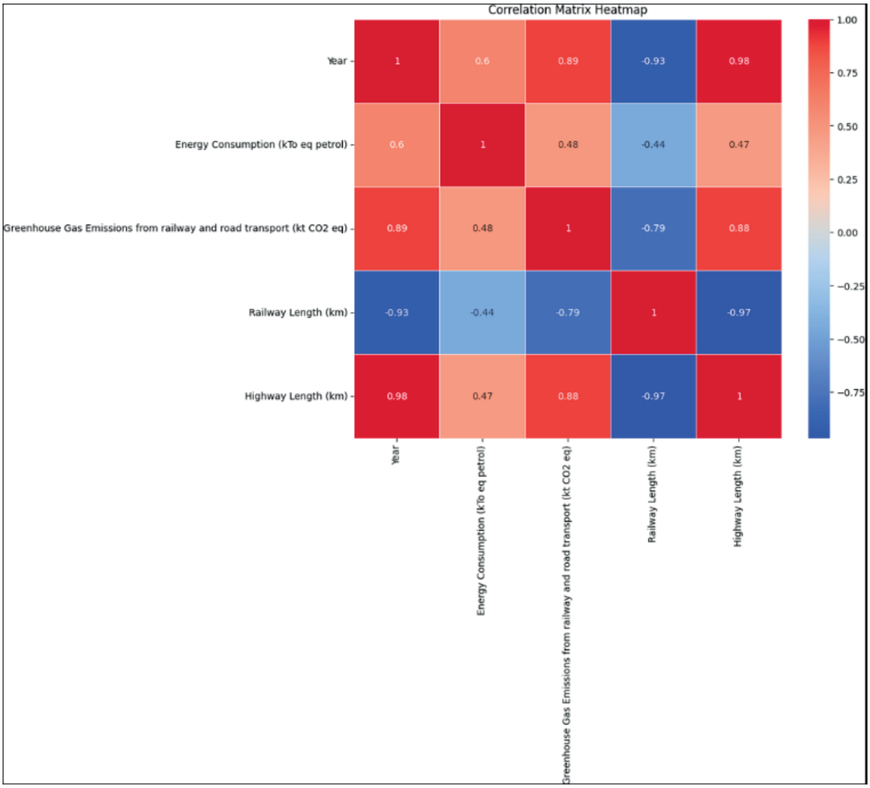

Figure 8. Correlation Matrix Heatmap. Author adaptation from (INSSE, 2024)

A transition towards more sustainable modes of transport, such as rail and clean energy public transport, is essential to mitigate the environmental footprint of the transport sector.
As shown in Figure 9, railways currently lead as the least polluting mode of transport in terms of greenhouse gas emissions.
Another explanation for the high emissions generated by road infrastructure is that in Romania, the existing roads are mostly small roads, which does not fill the requirements for a good traffic flow. The polluting emissions will increase in the future, if we continue to use the existing roads, while their rehabilitation and increase its category of use to a sustainable highway provides a downward trend for these emissions (Nicolae et al., 2021).
Carbon management is mandatory for all infrastructure projects, even if we are taking in consideration public transportations, goods and services transportation, or even resource transportation projects, like water transportation infrastructure as it needs to engage all the value chain to succeed in the neutrality objective (Sandu et al., 2023).

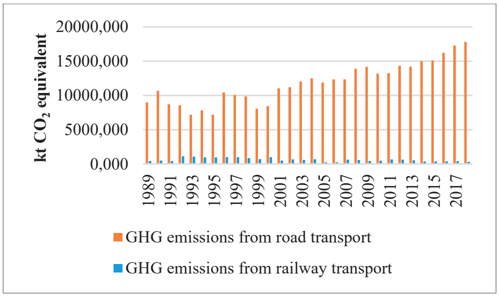

Figure 9. Comparison of emissions from rail transport and road transport over time. Author adaptation from (INSSE, 2024)

The Congruence Factor

To address the multidimensional nature of transport infrastructure efficiency, this study proposed a novel methodology for calculating the congruence factor. This factor represented a holistic assessment of a project's performance by integrating economic, social, and environmental criteria. The calculation involved assigning weights to each criterion based on their relative importance and then aggregating them into a single score.

The congruence factor methodology was applied to several transport infrastructure projects in Romania, revealing varying degrees of congruence between economic, social, and environmental objectives. Some projects demonstrated high economic efficiency but fell short in terms of social and environmental performance, while others achieved a more balanced outcome.

For example, the A2 motorway project scored high on economic efficiency due to its positive impact on trade and tourism. However, it scored lower on social and environmental criteria due to community displacement and increased emissions. In contrast, the rehabilitation of the Bucharest-Constanta railway line achieved a higher congruence factor by balancing economic benefits with social and environmental considerations.

As it can be seen in the Figure 10 it is easy to understand the graphic representation of a congruence factor analysis performed on a project with a moderately balanced performance across the economic, social, and environmental dimensions, along with a reasonable impact on traffic flow.

1st case study: Moderate Balanced Project

In this case study, the weights and standardized scores are as follows:

Weights:

- Economic: 0.4
- Social: 0.3
- Environmental: 0.2
- Traffic Flow: 0.1

Standardized Scores:

- Economic: 0.75
- Social: 0.65
- Environmental: 0.80
- Traffic Flow: 0.70

The Congruence Factor is calculated as follows:

Congruence Factor = (0.4×0.75) + (0.3×0.65) + (0.2×0.80) + (0.1×0.70) = 0.725

In Figure 10 we can observe that the project inclined more towards the economic factor, not being able to equilibrate the social and environmental factors, in the report with the traffic flow criteria.

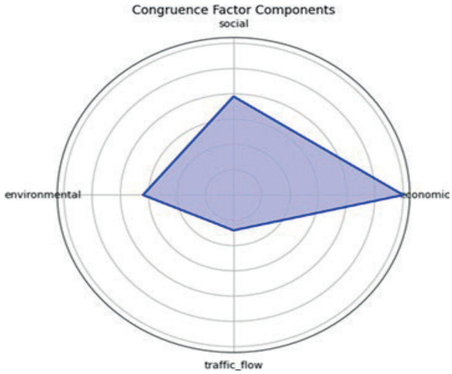

Figure 10. Congruence factor analysis graphic representation for a moderately balanced project

2nd Case study: Highly Balanced Project

In this case study, the weights and standardized scores are as follows:

Weights:

- Economic: 0.3
- Social: 0.3
- Environmental: 0.3
- Traffic Flow: 0.1

Standardized Scores:

- Economic: 0.95
- Social: 0.90
- Environmental: 0.92
- Traffic Flow: 0.88

The Congruence Factor is calculated as:

Congruence Factor = (0.3×0.95) + (0.3×0.90) + (0.3×0.92) + (0.1×0.88) = 0.919

This score reflects a project with exceptionally high performance across all dimensions, indicating a well-balanced and highly efficient project, as can be easily observed in Figure 11.

The analysis of Congruence Factors, yielding scores of 0.725 and 0.919 for moderately and highly balanced projects respectively, underscores the critical importance of integrating economic, social, and environmental criteria. This holistic approach ensures that transport infrastructure investments in Romania achieve sustainable development objectives, thereby optimizing their overall efficiency and impact.

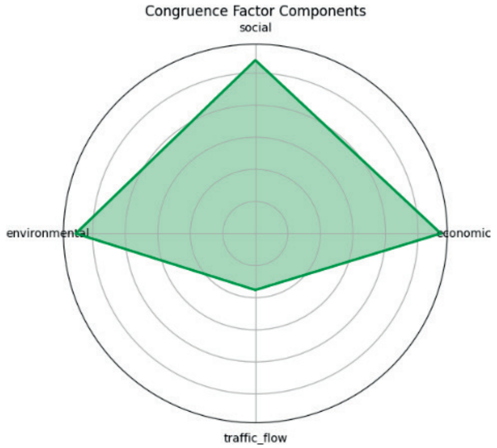

Figure 11. Congruence factor analysis graphic representation for a well-balanced project

CONCLUSIONS

Assessing the efficiency of transport infrastructure investments in Romania required a multidimensional approach that considered economic, social, and environmental impacts. While economic efficiency remains a critical factor, it should not be pursued at the expense of social and environmental well-being. The proposed congruence factor methodology offered a promising tool for evaluating the overall efficiency of infrastructure projects, promoting a more sustainable and balanced approach to development.

Limitations and future research

This study had some limitations. First, the availability of data on certain social and environmental impacts of transport infrastructure projects in Romania was limited. Second, the weights assigned to the criteria in the congruence factor calculation were based on expert judgment and may vary depending on the specific context and stakeholder preferences. Future research could explore the use of more robust methods for determining these weights, such as multi-criteria decision analysis techniques.

In conclusion, this study contributed to the growing body of knowledge on sustainable transport infrastructure assessment. The proposed congruence factor methodology offered a practical tool for policymakers and practitioners to evaluate the efficiency of transport infrastructure investments in a more holistic and sustainable manner. By considering the economic, social, and environmental dimensions of infrastructure projects, Romania can move towards a more sustainable and equitable transport system that benefits both present and future generations. Future research should focus on expanding the dataset to include a wider range of social and environmental indicators, as well as refining the weighting methodology for the congruence factor. Additionally, the application of the congruence factor to other sectors, such as energy and water infrastructure, could provide valuable insights for sustainable development planning in Romania.

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