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# COMPARISON OF RAILWAY PERFORMANCE IN THE EUROPEAN UNION BASED ON DEA ANALYSIS DURING COVID CRISIS

**Summary.** The efficiency of transportation systems has decreased due to restrictions to contain the spread of COVID-19. The purpose of the research was to analyze the efficiency of railways in connection with the impact of COVID-19 on rail transport itself. Thus, using data envelopment analysis we determined how the measures during the pandemic affected the efficiency of passenger and freight transport. The efficiency of the railway system was evaluated using a linear programming technique that measures the effectiveness of homogeneous decision-making units. The model's input variables consisted of technical attributes of railway tracks, while the output variables encompassed train operations, the conveyance of goods, and passenger transport. The results show the differences in railway efficiency between EU countries during the COVID-19 crisis. Our findings indicate that the COVID-19 crisis had a more substantial effect on the effectiveness of services than its impact on technical aspects. The results show the differences in railway efficiency between countries during the COVID-19 crisis. In the research, we found that the COVID-19 crisis had a negative impact on service effectiveness, as it decreased by more than 3%, while technical efficiency increased during the analyzed period, mainly at the expense of a lower number of train movements when transport equipment was not maintained. The differences between countries indicate the slow adoption of the necessary measures to mitigate the consequences of the COVID-19 crisis and the need for coordinated and flexible action by rail transport policymakers.

## 1. INTRODUCTION

The COVID-19 pandemic has markedly altered consumer behavior worldwide, impacting the timing, volume, and extent of purchases [1]. Consequently, the dynamics between producers and consumers have seen a substantial transformation. Supply chains were compelled to become more adaptable and resilient in response to the logistical hurdles. In most nations impacted, individuals were required to minimize the frequency of leaving their homes. Consequently, the emergence of COVID-19 significantly propelled the growth of the e-commerce industry.

In Italy, there was a surge in demand by 97% and 101% during the initial and subsequent weeks of the quarantine, respectively [2]. COVID-19 has illustrated how passenger and freight transport can experience severe repercussions that become apparent internationally. Nonetheless, the transport sector is slated to retain a crucial position in the society of the future [3].

The efficiency of transportation systems has decreased due to restrictions to contain the spread of COVID-19. Before COVID-19, passenger traffic was projected to rise by approximately 42% from 2010 to 2050, while rail freight traffic was anticipated to expand by up to 60% within the same timeframe [4]. However, the shockwave of COVID-19 has struck the transport sector hard. Owing to societal

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lockdowns, passenger and freight transport faced drastic disruptions. For instance, in March 2020, 75% of global companies reported disturbances in their supply chains due to transportation constraints, and 46% of international logistics firms encountered notable shipping delays [5].

Railway transport, with its infrastructure and superstructure, is important to supply chains and population mobility. In the shift towards a sustainable society, railway transportation plays an increasingly vital role in redirecting freight from roads to railways and expanding the utilization of public passenger transportation to serve the population's needs. A successful transition to a green society requires an efficient railway system capable of rapid adaptation to social and economic conditions. The COVID-19 crisis that occurred in 2020 had a major impact on various transport systems [6], especially in passenger transport, which also influenced changes in travel habits [7, 8].

EU countries adopted various measures in the field of transport that affected transport efficiency. In addition to restrictions on the implementation of passenger transport, which affected the operation of railways, countries also adopted various financial measures to limit the consequences of the crisis on the operation of railway systems. For instance, in the final quarter of 2020 (relative to the fourth quarter of 2019), the steepest declines in rail passenger numbers were noted in Greece (-68%) and Ireland (-74%). Other countries like the Netherlands (-61%), Italy (-61%), Slovakia (-54%), Slovenia (-53%) and Poland (-51%) also observed substantial reductions. Conversely, the pandemic's impact on rail passenger traffic during the same quarter was less pronounced in Bulgaria (-22%) and Estonia (-29%) [9].

The research conducted by IRG [10] enumerates the primary financial strategies embraced by distinct European nations, which include the modification of Track Access Charges-TAC (alterations in the level and benchmark of TAC, deferral of billing, easing of cancellation fees) and various governmental aids extended to the railway operations and infrastructure overseers (fundings of TAC, compensation for the loss of revenue for the infrastructure managers, compensation for revenue loss incurred by railway companies, access to loans, credit guarantees, and assistance for temporary unemployment and short-term work arrangements).

The efficiency of transportation systems has decreased due to restrictions to contain the spread of COVID-19. Different approaches can be used to measure performance. Markovits-Somogyi [11] suggests using Data Envelopment Analysis (DEA) as a suitable approach for measuring the efficiency of transport systems, which is also suitable for analyzing the efficiency of railway systems [12] and also for railway companies [13]. Petrovič and colleagues [14] employed the DEA methodology for a cross-national assessment of rail freight transportation. They concluded that the DEA method is suitable for analyzing the efficiency of rail transport. However, the efficiency is affected by the selection of countries and variables of the DEA model. The authors (ibid.) also concluded that a country can be efficient in the case of the VRS (variable return of scale) model and inefficient in the case of using the CRS (constant return of scale) model. A similar methodology was also used by Ghanem et al. [15] to compare the Turkish and EU railway efficiency. They found out that in addition to the technical characteristics of the railway infrastructure and superstructure, efficiency is also influenced by service quality and longer rail routes.

Regarding the choice of return of scale, Lan and Lin [16] found that the VRS model is prevailing in the rail industry. In the research, they used technical efficiency, where they used statistical data on the railway infrastructure and superstructure as input to the DEA model, and train movements as the output of the model. They also used the service effectiveness calculation, which presents the ratio of service consumption to service input. They found that efficiency and effectiveness scores are relatively low in the rail industry. In a separate investigation, Lan and Lin [17] discovered through a performance matrix that technical inefficiency and service ineffectiveness are adversely affected by the gross national income per capita, the proportion of electrified lines, and line density.

In the research, we limited ourselves to analyzing the efficiency of railways during the COVID-19 crisis. Tardivo and associates [3] discerned that amidst the COVID-19 crisis, rail services witnessed fewer disruptions than other transport modes. Nevertheless, there was a reduction exceeding 10% in the train kilometers covered in 2020, along with a decline of more than 40% in passenger kilometers and a decrease of over 5% in tonne-kilometers. In addition to the drop in passenger and freight transport, the IRG research [10] highlights the following impacts of COVID-19 on rail transport: limitation of the capacity of transport, timetable adjustments, the implementation of additional sanitary measures to prevent the spread of the virus, a decrease of tariffs of wagon rentals and the suspension of planned rail maintenance.

This paper compares the efficiency of railway transport through a DEA analysis. The research aims to determine the impact of COVID-19 on rail transport. The relevant research mainly analyzed the impact of the COVID-19 crisis on the operation of railway transport from a statistical point of view, but in no study could the use of the DEA methodology be found in the analysis of technical efficiency and service effectiveness, which is also a novelty of the research.

Based on previous research, we propose two hypotheses:

H1: The COVID-19 crisis has had an impact on efficiency in the railway sector.

H2: The COVID-19 crisis has had a different impact on technical efficiency and service effectiveness.

This paper contains an introduction with a literature review. Furthermore, the research methodology is given with the definition of the input and output variables of the DEA model, followed by the results and conclusion chapters.

## 2. METHODOLOGY

The effectiveness of rail transportation was measured using the Data Envelopment Analysis (DEA) method, a linear mathematical programming tool designed for assessing the performance of similar decision-making units (DMUs) [18]. Based on the characteristics of the DMUs and relevant research [16], we used the BCC (Banker, Charnes & Cooper) model [18]. In the research, we specifically analyzed technical efficiency, where we used the input orientation BCC model, and service effectiveness, where we used the output orientation BCC model.

The mathematical programming problem for the BCC input oriented is [18]:

$$\begin{gathered} \min z_0 = \theta - \varepsilon \cdot 1s^+ - \varepsilon \cdot 1s^- \\ Y\lambda - s^+ = Y_0 \\ \theta X_0 - X\lambda - s^- = 0 \\ 1\lambda \geq 1 \\ \lambda, s^+, s^- \geq 0 \end{gathered} \tag{1}$$

It applies to the BBC input-oriented model [18]:

- DMU is efficient if the following two conditions are satisfied θ=1 and all slacks are zero;
- DMU is efficient if $w_0=z_0=1$.

The mathematical programming problem for the BCC output oriented is [18]:

$$\begin{gathered} max z_0 = \phi + \varepsilon \cdot 1s^+ + \varepsilon \cdot 1s^- \\ \phi Y_0 - Y\lambda + s^+ = 0 \\ X\lambda + s^- = X_0 \\ 1\lambda \geq 1 \\ \lambda, s^+, s^- \geq 0 \end{gathered} \tag{2}$$

Based on relevant research [16, 17], we determined the input and output variables of the DEA model. For technical efficiency, we chose track length (X1), number of locomotives (X2), and number of railcars (X3) as input to the DEA BCC model and train movements (Y1 in thousand train-kilometers) as output. For service effectiveness, present input train movements (X4), number of transported passengers kilometers (Y2 in millions of passenger kilometers), and transported goods (Y3 in million tonne-kilometers) as the output of the DEA BCC output model.

The performance matrix of European countries is based on technical efficiency and service effectiveness. Fig. 1 presents the research model.

In order to compare the efficiency of rail transport in the EU during the COVID-19 crisis, we used statistical data for 2019 and 2020. The data are obtained from Eurostat [19] and the national statistical offices of European countries. Due to the lack of data, we used a different number of countries in the research depending on data availability. We determined the performance matrix only for countries where all data for 2019 and 2020 were available.

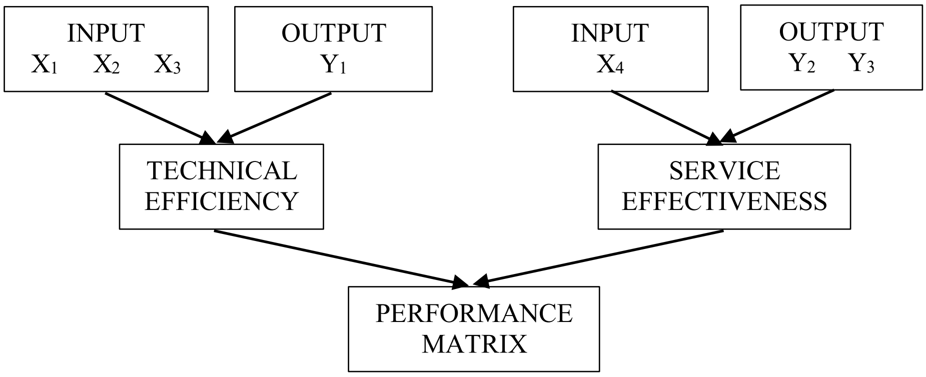


Fig. 1. Research model. Source: Own work

Table 1 shows descriptive statistics for technical efficiency, where we obtained data for 20 countries for 2019 and 17 for 2020. Among the analyzed countries, Estonia has the shortest railway network (variable X1), and Germany has the longest. Since not all data for Germany is available for 2020, the longest analyzed railway network in 2020 was in France. The average lengths of the railway networks of the analyzed countries were 15,182.90 km in 2019 and 12,329.59 km in 2020.

Ireland had the lowest number of locomotives (variable X2) in 2019, and Greece had the lowest number in 2020. Germany had the highest number in 2019, and Poland had the highest number in 2020. On average, the number of locomotives is around 1,000.

Lithuania had the lowest number of railcars (variable X3) in 2019, and Estonia had the lowest number in 2020. Germany had the highest number of railcars in 2019, and France had the highest number in 2020. The average value of railcars decreased from 1,350 in 2019 to 857 in 2020 due to the lack of data for certain countries.

The fewest train movements (variable Y1) in 2019 and 2020 were in Estonia, and the most were in Germany and France in 2020.

Table 1

Descriptive statistics for technical efficiency

| | | **INPUT** | | | **OUTPUT** |
|---|---|---|---|---|---|
| | | **$X_1$** | **$X_2$** | **$X_3$** | **$Y_1$** |
| Min | 2019 | 2.144 | 56 | 57 | 7.209 |
| | 2020 | 2.143 | 72 | 50 | 6.576 |
| Max | 2019 | 67.400 | 4.115 | 11934 | 1.069.572 |
| | 2020 | 53.382 | 3.671 | 4.613 | 338.670 |
| Mean | 2019 | 15.182,90 | 1.147,80 | 1.350,15 | 166.924,90 |
| | 2020 | 12.329,59 | 994 | 857,71 | 95.866,29 |
| SD | 2019 | 18.406,35 | 1.329,83 | 2.690,29 | 246.282,87 |
| | 2020 | 14.371,13 | 1.134,96 | 1.148,32 | 94.579,81 |

Source: Own work

Table 2 shows descriptive statistics for service effectiveness based on the data we obtained from 24 countries for 2019 and 21 countries for 2020. Data on train movements are similar to the calculation of technical efficiency, except that more data was available for 2020, which affects even the maximum completed train movements in 2020.

In 2019 and 2020, the fewest transported passengers (variable Y2) were in Lithuania, and the most were in Germany. The average number of transported passengers decreased significantly between 2019 and 2020 due to COVID-19 restrictions.

The fewest transported goods (variable Y3) were recorded in Ireland in 2019 and 2020, and the most were recorded in Germany. The average value of the transported goods did not change significantly between 2019 and 2020.

Table 2

Descriptive statistics for service effectiveness

| | | INPUT | OUTPUT | |
|---|---|---|---|---|
| | | $X_4$ | $Y_2$ | $Y_3$ |
| Min | 2019 | 7.209 | 359 | 72 |
| | 2020 | 6.576 | 237 | 74 |
| Max | 2019 | 1.069.572 | 100.252 | 119.470 |
| | 2020 | 1.049.799 | 57.797 | 109.219 |
| Mean | 2019 | 149.351,50 | 16.798,46 | 16.885,04 |
| | 2020 | 141.279,24 | 9.645,33 | 16.770,57 |
| SD | 2019 | 228.768,36 | 28.086,80 | 25.168,13 |
| | 2020 | 231.573,23 | 16.734,75 | 24.459,27 |

Source: Own work

The data were processed with SPSS and Open Source Data Envelopment Analysis solver.

## 3. RESULTS

The logistics sector has been significantly impacted by the COVID-19 crisis, especially in the realm of transportation. Wang and others [20] highlighted that the crisis led to constraints on import and export endeavors, a decrease in passenger travel, and increased expenses stemming from the demand for expedited delivery services. The examination of statistical data pertaining to railway transport from 2019 to 2020 primarily reflects variations in the operational aspects, such as the volume of transport activities (e.g., train movements, passengers transported, and goods conveyed), rather than alterations in the transportation infrastructure or equipment.The number of locomotives and railcars did not change during the observed period. Among the countries examined, the most pronounced declines in the number of train movements were seen in Latvia (25%), followed by Spain (23%) and France (20%). The mean reduction in the number of train movements amounted to over 10%, with a specific decline of 9% in passenger transport and 12% in freight transport. The great impact of the COVID-19 crisis is noticeable when we measure the transport work performed in passenger or ton-kilometers.

On average, the transported passengers decreased by more than 43%, and freight transport decreased by only around 5.5%. The biggest drops in the volume of passenger transport were recorded in Ireland (65%), Italy (62%), and Spain (57%). The demand for transport passenger services was mainly affected by individual countries' mobility restrictions because of the COVID-19 Pandemic. Tardivo and others [2021] underscored the distinctions between urban and suburban mobility in passenger transport. In urban environments, residents must decide between private and public transportation, while in suburban areas, the availability of private mobility options, such as electric bicycles or scooters, is more limited. The possibility of choosing different travel options and restrictions adopted by individual countries also influenced the drop in passenger transport.

In freight transport, the largest drops in the volume of transport work were in Latvia (46%), Estonia (19%), and Spain (17%). Loske [21] stated that the drop in freight rail transport resulted from longer waiting times at checkpoints and quarantine obligations for the workforce. In some countries, however, there was a noticeable increase in the volume of freight transport: Bulgaria (19%), Greece (13%), and Croatia (13%). The increase in demand for freight rail services in some countries was also influenced by stricter restrictions on road transport and price increases in maritime transport [3].

The technical efficiency of the railway system significantly contributes to the reliability of logistics chains [22]. The efficiency analysis showed significant differences between technical efficiency and service effectiveness (Table 3 and Table 4). Eleven of 20 countries achieved technical efficiency in 2019. The lowest result was achieved by Romania. The average efficiency of the analyzed countries is

0.830, with a standard deviation of 0.240. Slacks are found exclusively in countries deemed inefficient. These slacks reflect the remaining portions of inefficiency and are essential for moving the decision-making units toward the efficiency frontier. For most technically inefficient countries, it is necessary to balance equipment transport (locomotives and railcars) to achieve efficiency. Average performance improved in 2020 (the average efficiency is 0.923 with a standard deviation of 0.154). In most of the analyzed countries, the technical efficiency increased in 2020, but a lower technical efficiency was observed only in Croatia and Latvia. In Latvia, the decrease in the technical efficiency was very small (-0.002). It was only 0.2%.

To maintain the stability of logistics systems, the government provides financial support for the operation of railways. Financial measures adopted by states aimed at ensuring technical efficiency and smooth operation of railways and supply chains. Despite the lower demand for transport services, railway undertakings received different forms of state aid [10], which improved average technical efficiency during the crisis.

Table 3

Technical efficiency of BCC input-oriented model solution

| Country | Technical efficiency 2019 | Technical efficiency 2020 | Changes 2019-2020 |
|---|---|---|---|
| Austria | 1 | 1 | 0 |
| Croatia | 0.622 | 0.607 | - 0.015 |
| Czechia | 0.552 | 0.693 | 0.141 |
| Denmark | 1 | 1 | 0 |
| Estonia | 1 | 1 | 0 |
| France | 0.48 | 1 | 0.52 |
| Germany | 1 | n.a. | / |
| Greece | 1 | 1 | 0 |
| Hungary | 0.687 | 1 | 0.313 |
| Ireland | 1 | n.a. | / |
| Italy | 1 | n.a. | / |
| Latvia | 0.977 | 0.975 | - 0.002 |
| Lithuania | 1 | 1 | 0 |
| Poland | 0.388 | 1 | 0.612 |
| Portugal | 1 | 1 | 0 |
| Romania | 0.298 | 0.535 | 0.237 |
| Slovakia | 0.866 | 0.877 | 0.011 |
| Slovenia | 1 | 1 | 0 |
| Spain | 1 | 1 | 0 |
| Sweden | 0.733 | 1 | 0.267 |
| Average efficiency | 0.830 | 0.923 | 0.093 |
| Standard deviation | 0.240 | 0.154 | |

n.a. – not available
Source: Own work

Average service effectiveness was lower than average technical efficiency (see Tables 3 and 4) but with a higher standard deviation. The occupancy rate in the passenger railway market dropped by more than 40% on average [10], which had the greatest impact on service effectiveness. Only seven of the 24 states were efficient in 2019 and 2020. Service efficiency has decreased in most states in 2020 due to the state's COVID-19 restrictions. Croatia had the lowest service effectiveness in 2019 and 2020. The research by IRG [10] mentions that international supply chains encountered disruptions owing to grounded aircraft and the denial of entry for some cargo ships at ports, which impacted rail freight and service effectiveness due to a reduction in tonne-km. The service effectiveness across individual European nations is depicted in Table 4.

Based on calculated technical efficiency and service effectiveness, a performance matrix for 2019 (Fig. 2) and 2020 (Fig. 3) was established. The four countries are both technically and service-efficient. In 2019, these countries were Estonia, Greece, Latvia and Lithuania. For 2020, these countries are Estonia, Greece, Latvia, Lithuania, France, and Poland. Differences between countries arise due to the different efficiency of logistics systems and the ability to adapt to the conditions related to the COVID crisis. Restrictions, especially in passenger transport, also influenced changes in travel habits.

The comparison shows an improvement in technical efficiency, primarily due to the lower number of train movements covered with unchanged transport equipment. A drop in service efficiency is also noticeable, resulting from restrictions that certain countries have adopted. Lower service efficiency affects supply chain disruptions and lowers the reliability of logistics systems. Perkumiene et al. [23] emphasized the importance of logistics and transportation industries in industrial sectors in many countries, which is why improving service effectiveness is important. Tardivo et al. [3] proposed boosting internal consumption and supporting export and new investment, which affects the improvement of railway service effectiveness, to recover the European logistics and transport sector.

Table 4

Service effectiveness of BCC output-oriented model solution

| Country | Service effectiveness 2019 | Service effectiveness 2020 | Changes 2019-2020 |
|---|---|---|---|
| Austria | 0.596 | 0.557 | - 0.039 |
| Bulgaria | 0.350 | 0.372 | 0.022 |
| Croatia | 0.276 | 0.306 | 0.03 |
| Czechia | 0.467 | 0.434 | - 0.033 |
| Denmark | 0.438 | 0.385 | - 0.053 |
| Estonia | 1 | 1 | 0 |
| Finland | 0.581 | 0.557 | - 0.024 |
| France | 1 | 1 | 0 |
| Germany | 1 | 1 | 0 |
| Greece | 1 | 1 | 0 |
| Hungary | 0.383 | n.a | / |
| Ireland | 0.784 | 0.479 | - 0.305 |
| Italy | 0.636 | 0.523 | - 0.113 |
| Latvia | 1 | 1 | 0 |
| Lithuania | 1 | 1 | 0 |
| Luxembourg | 0.765 | n.a. | / |
| Netherlands | 0.541 | n.a. | / |
| Poland | 1 | 1 | 0 |
| Portugal | 0.695 | 0.535 | - 0.160 |
| Romania | 0.554 | 0.532 | - 0.022 |
| Slovakia | 0.478 | 0.397 | - 0.081 |
| Slovenia | 0.353 | 0.427 | 0.074 |
| Spain | 0.590 | 0.447 | - 0.143 |
| Sweden | 0.644 | 0.645 | 0.001 |
| Average effectiveness | 0.672 | 0.647 | - 0.025 |
| Standard deviation | 0.248 | 0.266 | |

n.a. – not available. Source: Own work

## 4. CONCLUSIONS

In the transition to a green society, rail transport is becoming an important part of transport systems and supply chains. Over the past few years, the logistics and transportation sector has experienced significant disruptions due to the COVID-19 crisis. Negative impacts were noticeable in all modes of transport, the share of transported work decreased the most in air transport. The railway system witnessed a more substantial impact of COVID-19 on passenger transport than freight transport, primarily due to the containment measures imposed by European nations to mitigate the spread of the virus. The COVID crisis also positively impacted logistics and transport by increasing demand.

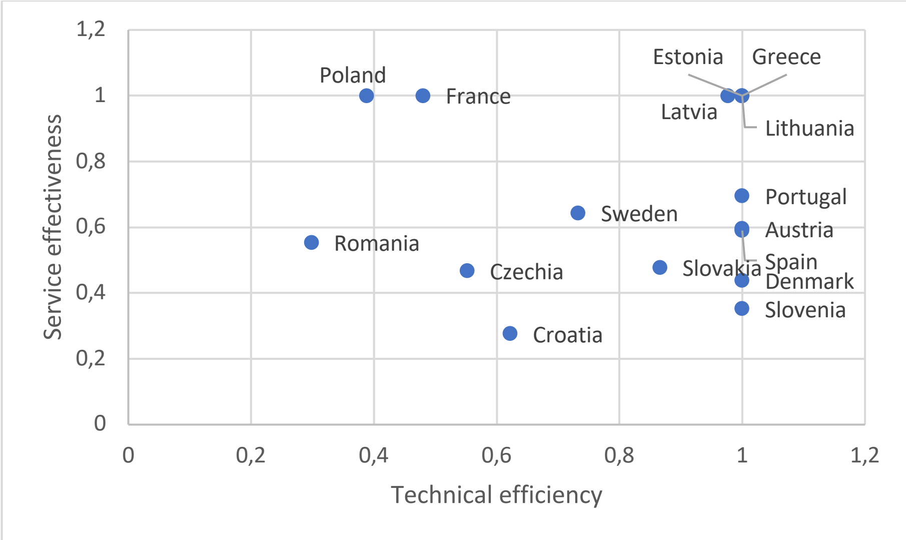


Fig. 2. Performance matrix 2019. Source: Own work

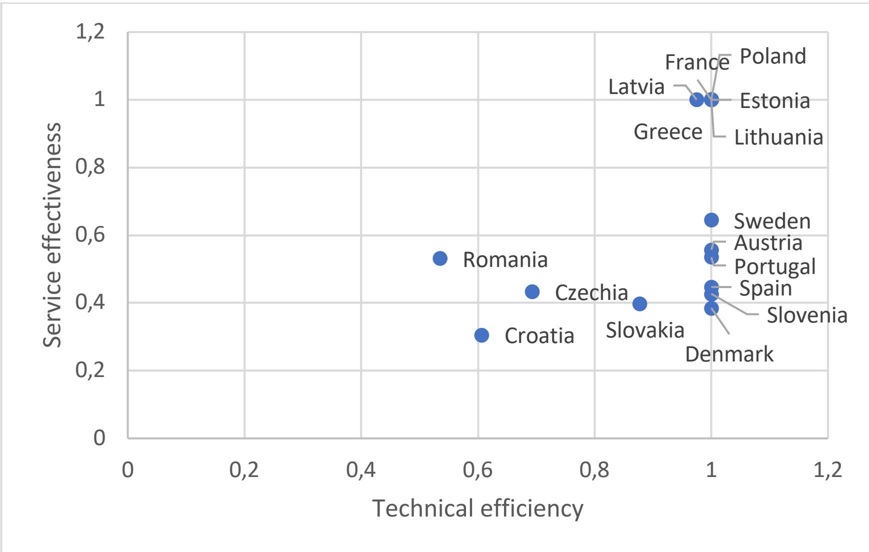


Fig. 3. Performance matrix 2020. Source: Own work

More than 40% fewer passengers were transported in 2020 than in 2019, as many people worked from home or used railway passenger transport exclusively for going to work. Compared to other modes, rail passenger transport has an advantage in adding passenger wagons, thereby limiting the transmission of the virus between passengers. Overall, the repercussions of the COVID-19 pandemic on freight traffic were considerably lesser in 2020 when juxtaposed with passenger traffic. In most EU nations, cargo services were prioritized, a development stemming from reduced passenger traffic. Compared to 2019, a drop of 7% was observed, totaling 413.8 billion net tonne kilometers. While most countries witnessed a decline, net tonne kilometers increased in Greece, Bulgaria, and Hungary. Additionally, Portugal and Norway exhibited robust growth in freight train kilometers. This paper analyzed the technical efficiency and service effectiveness using the DEA analysis. As input to the DEA model, we used technical data on the railway networks of European countries and the completed transport work, measured in train kilometers, passenger kilometers, and ton-kilometers. We calculated the efficiency of the railway system of European countries for the years 2019 and 2020 due to the analysis of the impact of COVID-19 on the efficiency of the railways. In this research, we found that the COVID-19 crisis negatively impacted service effectiveness, as it decreased by more than 3%, while technical efficiency increased during the analyzed period, mainly at the expense of the lower number of train movements when transport equipment was not maintained. This was confirmed by the statistical data.

The results support the hypothesis that the COVID-19 crisis impacted efficiency in the railway sector but had different impacts on technical efficiency and service effectiveness. The most efficient analyzed countries are Estonia, Greece, and Lithuania, which achieved technical efficiency and service effectiveness in both periods. Due to the lack of data, it was not possible to make a comparison for all EU countries.

Future research could analyze the measures adopted by European countries and their impacts on the efficiency and operations of infrastructure managers and railway undertakings. In the future, it will also be necessary to explore the possibilities of unifying measures at the EU level when dealing with situations similar to the COVID-19 crisis. The impact of COVID-19 was also strongly noticeable in passenger services. In the future, reconciling the imperative to prevent a severe recession with the need to protect the environment is paramount. It is essential to simultaneously prioritize environmental conservation and the need for mobility. Furthermore, there is a pressing need to facilitate the shift from environmentally unsustainable modes of transportation to more environmentally friendly alternatives.

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