

## Article

# Energy Management in the Railway Industry: A Case Study of Rail Freight Carrier in Poland

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**Abstract:** Energy is crucial to economic development, but its production usually has a negative impact on the environment. This ambivalence leads to the need for methods to improve energy efficiency. Transportation is one of the largest global energy consumers. Therefore, improving the energy efficiency of transportation is crucial for sustainable development. The aim of this article is to show the limitations of energy management in railways, resulting from the model of market regulation. The question in this context is whether only technological methods can be used in railways to steer its energy efficiency, as is suggested by the existing research. Critical analysis, desk research and a case study of Polish railway undertaking were used to find an answer to the research question. The discussion of the results shows that the European regulatory system leads to greater complications in the field of energy management than in other global regions, where railways are also important for the economy. Due to these limitations, rail operators use indirect methods to measure energy efficiency. Results indicate that although energy efficiency improvements are being achieved, they are mainly due to organizational measures and not technological ones as could be expected based on previous research.

**Keywords:** energy efficiency; transportation; railway transportation



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## 1. Introduction

Energy is essential for economic and social development, as well as for improving the quality of life. We could no longer imagine the modern world without access to energy. Ensuring energy security has become one of the fundamental tasks facing governments of individual countries. The increasing demand for energy on the one hand and dwindling resources of non-renewable energy sources on the other results in the need to acquire energy from alternative sources and to increase efficiency of energy consumption in various areas of the economy, agriculture and social life as well as appropriate energy management. Energy efficiency is defined broadly as the ratio between output, services, goods or energy and energy input (Directive 2006/32/EC) [1]. Energy efficiency should be considered in the wider context of sustainable development. Global Action Agenda 21 (1992) [2]—the basic document constituting the concept of sustainable development—defines major courses of action to improve energy efficiency in business, agriculture, transport and other areas of human activity.

One of the primary goals identified in Agenda 21 is to reduce the atmospheric impact of the energy sector by developing environmentally friendly and economically viable energy systems, based on renewable and clean energy sources, aimed at less pollution and more efficient generation, transmission and distribution of energy. The changes should be based on research into innovative green technologies and the transfer of environmentally friendly energy technologies to developing countries. Agenda 21 also envisages increased capacity for energy planning and management of an energy efficiency programme. Ground-breaking in its proposals to double prosperity while halving natural resource consumption

was the report “Factor Four”, prepared for the Club of Rome [3]. The authors of the report argued that the Factor Four revolution is necessary and technologically viable [4]. Nowadays, many of the solutions described in the report have already been implemented, although we still have not achieved satisfactory results.

Another report prepared for the Club of Rome, entitled “Factor Five. Transforming the Global Economy through 80% Improvements in Resource Productivity”, was also developed by a team of specialists led by E. U. von Weizsäcker and published in London in 2009 [5]. “Factor Five” is a certain complement and extension of “Factor Four”. Based on the assumptions of “Factor Four”, the authors show that there is a real possibility to achieve a five-fold improvement in resource productivity in key sectors of the economy, i.e., construction, transport, industry and agriculture.

The first decade of the new millennium brought various technological solutions that enabled the implementation of energy-efficient solutions. The awareness and approach of entrepreneurs to environmental protection issues has also changed. As indicated by the report entitled “The Business Case for the Green Economy. Sustainable Return on Investment” [6], the development of green economy sectors (renewable energy, increased energy efficiency, rational waste management, reforestation, development of integrated water management, reclamation of dry areas and sustainable agricultural development) has taken place. The report’s conclusion is that the green economy represents a business opportunity, and green investments not only pay for themselves but also enable them to succeed in the market. The report provides examples of positive rates of return on green economy investments and shows that green investments are not only financially profitable, but they also strengthen brand value and build a positive reputation of the company, which in turn translates into financial profits [4]. The issue of energy efficiency is present in almost all documents constituting the concept of sustainable development and programme documents of the European Union. Attention is drawn to the issue of scientific advice to decision makers in the area of sustainable development management and implementation of energy-efficient technologies [7]. Energy efficiency has also been the subject of research and scientific consideration for many years.

In the context of energy efficiency, numerous topics are addressed in the literature, such as: issues related to green energy [8], and renewable energy sources [9–11] (including photovoltaics [12,13] or the use of biofuels [14,15]), clean technologies for obtaining energy from coal [16], optimization processes for obtaining energy from natural gas [17], a variety of chemical reactions in the combustion of heavy fuel oils [18], as well as processes for reducing CO<sub>2</sub> and other greenhouse gases [19,20].

Compared to the previous research, in this article, we take a broader perspective and include the influence of regulatory framework of railways as well as organizational measures that can be implemented in railway undertakings in order to steer energy efficiency in this industry. The expected conclusion may be valuable for business as well as policy makers. The legislative perspective gains a special meaning nowadays, as the United Kingdom after having left the European Union is announcing revision of their regulatory framework and renationalization of railways.

There is also a growing number of articles that discuss the use of mathematical tools, numerical tools, artificial intelligence, and cognitive technologies to support energy efficiency improvement [21–26], energy management processes [11,27–31] as well as the role of managers in the management of energy supply companies [32]. Studies on energy management are quite numerous.

Railway companies are usually described in scientific literature from the perspective of economic efficiency [33], environmental efficiency [33–35], digital transformation of transport processes [36–38] or railway transport safety [39,40]. It is certainly a worthwhile idea to adopt solutions based on cognitive technologies and artificial intelligence [41–43] in the management processes of railway enterprises and use them for energy efficiency programming.

There are only a few studies on energy efficient railway companies per se; nevertheless, the authors emphasize the need to use innovative solutions to increase energy efficiency.

They point out, for example, the need to add the topology of the electric system to the data considered when designing the train trajectory [44], to use more efficient thyristor control algorithms [45], to improve the performance of the train control system using artificial intelligence technologies, deep reinforcement learning and imitation learning [26], to identify the value of features that reduce energy consumption using Artificial Intelligence tools [46].

Rail is considered as a low-carbon transportation mode. Besides the high level of electrification, energy efficiency in rail transport is one of the main reasons for the low carbon footprint of rail [47]. Railway infrastructure is perceived as a system good, constituting a natural monopoly. Therefore, to ensure market conditions for the use of this infrastructure, it is necessary to use at least partial mechanisms of regulation. Models of regulation, introduced in different countries, influence energy management in railway undertakings. The aim of this article is to show the limitations of energy management in railway companies, resulting from the adopted model of market regulation and to indicate the practical methods used by the participants in this market to improve their energy efficiency and to obtain a positive environmental effect.

The deregulation of railways in Europe was intended to eliminate monopoly and introduce market mechanisms. One of the main mechanisms of this deregulation, vertical separation, is the separation of infrastructure managers from carriers. In conjunction with the fragmentation of the railway system in Europe, it caused considerable complications in the accounting of traction energy supplied to individual operators in individual European Union countries. This hindered action aimed at improving the energy efficiency of railways and individual railway companies operating in the deregulated market. It also caused complications in the creation of a common European railway area, postulated by the European Union. Previous research in the field of railway energy efficiency has focused on technical aspects. The importance of activities related to the organization of the transport process and the rolling stock maintenance system was not revealed. We believe that such activities have a significant impact on improving the energy efficiency of the railway operator. The effects of the railway regulatory model and its implementation in the European Union countries on the energy efficiency of the railway system, as well as practical problems arising during the construction of a single European railway area, were also not revealed. This article, using the case study presented by DB Cargo Polska, contributes towards closing the research gap in this regard.

## 2. Materials and Methods

The issue of energy management in rail transport is presented using a case study due to its complexity and heterogeneity.

A case study is an empirical inference about a contemporary phenomenon in its natural context. The method allows answers to the research questions “how?” (e.g., how something is organized) and “why?” (e.g., why certain actions are taken). In-depth analyses also allow for a thorough understanding of the described phenomenon [48]. A comprehensive approach was adopted, based on observation, analyses of internal documentation, statistical data and other available source materials. Desk research analyses were also conducted, referring to public statistics documents, reports, qualitative analyses and publications.

The case study is preceded by the analysis of the situation of the railway industry in the world, Europe and Poland, where the company being the object of this study operates. This analysis contains elements of comparison of conditions and the way the railway industry is organized in particular geographical regions. These factors are important for the differentiation of energy efficiency between particular regions. The taxonomy used by the UIC—International Union of Railways—is adopted. The UIC is an international professional association of railway companies, and its statistics enable comparison of data concerning railways in different regions of the world, where rail plays an important role in the economy.

The choice of UIC statistics provides an appropriate context for railway performance in Europe, which is a region where railways have their historical roots and have developed intensively since the beginning of the 19th century [49]. The UIC data were obtained from UIC reports and studies available online. They mainly relate to operational parameters. UIC statistics are a valuable source of information due to the systematic presentation related to the importance of railways for the economy. For infrastructure data, publicly available data from Worldstat and Eurostat were used to show the level of development of the railway network. They better reflect the global diversity of the railway network.

Our analysis also includes a comparison of energy efficiency aspects of rail transport globally with its main competitor, road transport. UIC data were used in this regard, due to the operational nature of these data.

With respect to railways in Poland, the analysis presents the development path of the railway industry after the liberalization of the market in this country and the operating conditions of companies, which, like the case study subject, are engaged in rail freight transport. To conduct these analyses, a literature review was used.

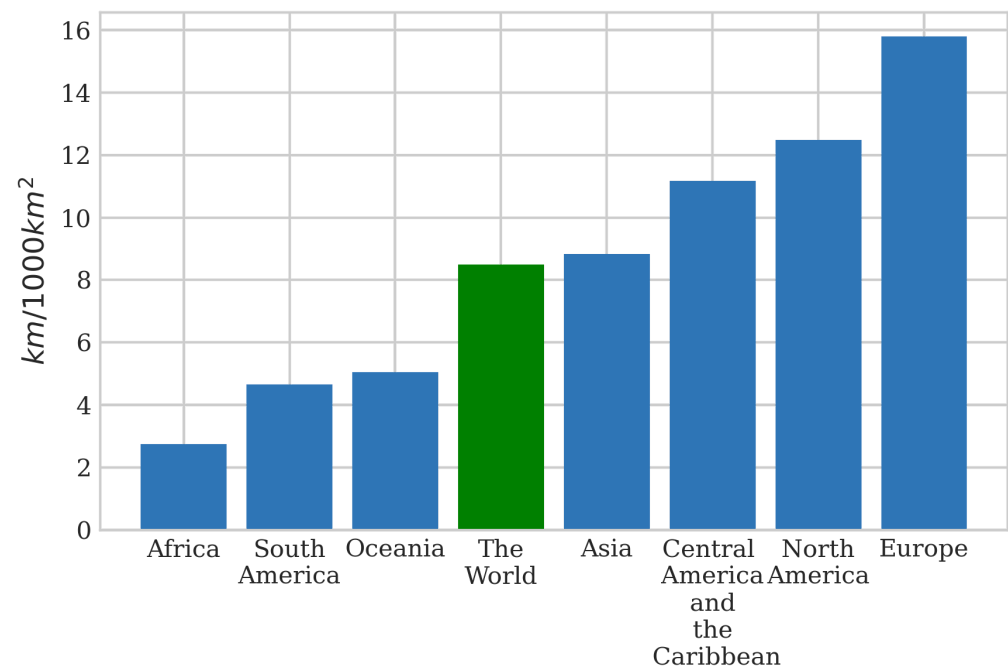
### 3. Results

As we show in the analyses conducted in this chapter, rail is a mode of transportation whose global environmental impact is relatively small. The diversity of the rail network in global regions, the level of technological development, and specific market regulations result in significant variation in energy efficiency and energy management methods across regions.

#### 3.1. Railways in Europe Compared to Other Regions

According to data published by the International Union of Railways (UIC) [47], rail transport globally accounts for less than 2% of transport energy consumption, which is about 0.5% of the total global energy consumption, with rail's modal share being about 7%. Rail is in a much better position in terms of energy efficiency than road transport, which is its main competitor in land transport. Road transport accounts for more than 75% of the total energy used in transport and its modal share is only 35%. If we assume that the share of energy consumption represents the input and the modal share represents the output of the system, then the global energy efficiency of rail can be evaluated in this perspective as almost eight times higher than the efficiency of road transport. It should also be noted that rail transport has significantly improved its energy efficiency in recent decades, as indicated by data published by the UIC on decreasing unit energy consumption on rail [47]. The density of the railway network in Europe is relatively high [50], as shown in Figure 1. This has several structural effects that affect how railways in Europe operate and how efficient they are. High network density results in numerous nodes and short line lengths [51]. On the other hand, high network density favors the development of intermodal transport, in which rail can play an important role by offering easy access to transshipment terminals [52].

In addition, the European railway area is divided by numerous national borders, which, given the diversity of infrastructure in terms of power supply to the catenary network as well as signaling and safety systems, and in some cases the rail gauge, generates additional constraints on railway traffic in Europe [53]. Comparing Europe, based on data published by UIC, to other regions where rail plays a significant role in the transport system [50], some interesting conclusions can be drawn. The modal share of rail is relatively small in Europe. It amounts to 8% for passenger transport and 12% for freight transport. As can be seen in Figure 2, the modal share of freight rail transport in the Russian Federation is as high as 88%, and the modal share of passenger transport in Japan is 30%. On the other hand, in the USA, the modal share of railway for passenger transport is less than 1%.

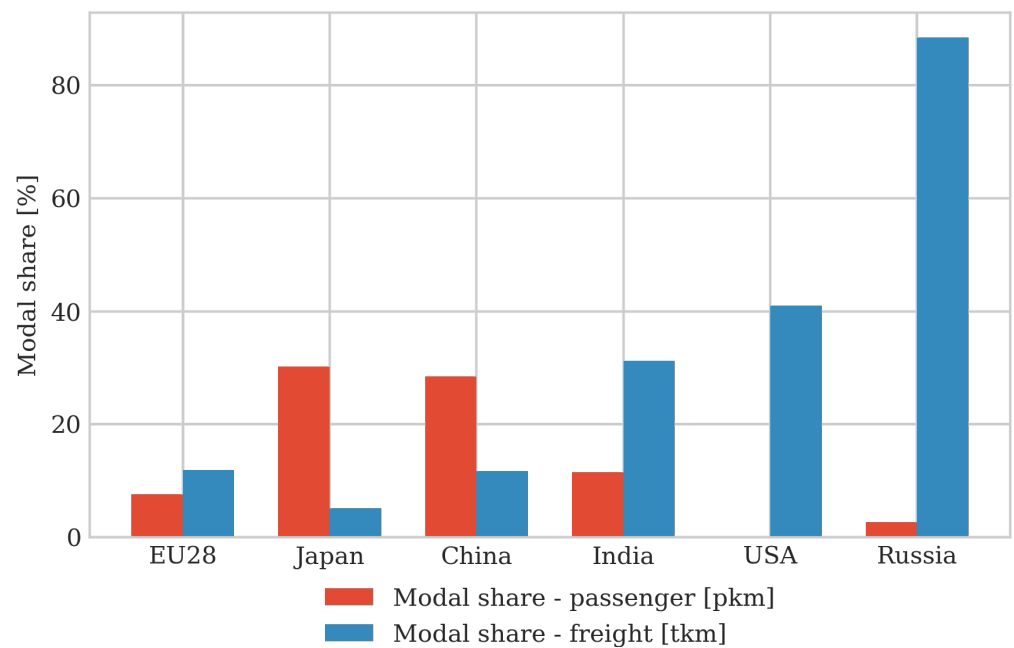


**Figure 1.** Density of railway network in km of railway lines per 1000 km<sup>2</sup>. Own study based on data from [50].

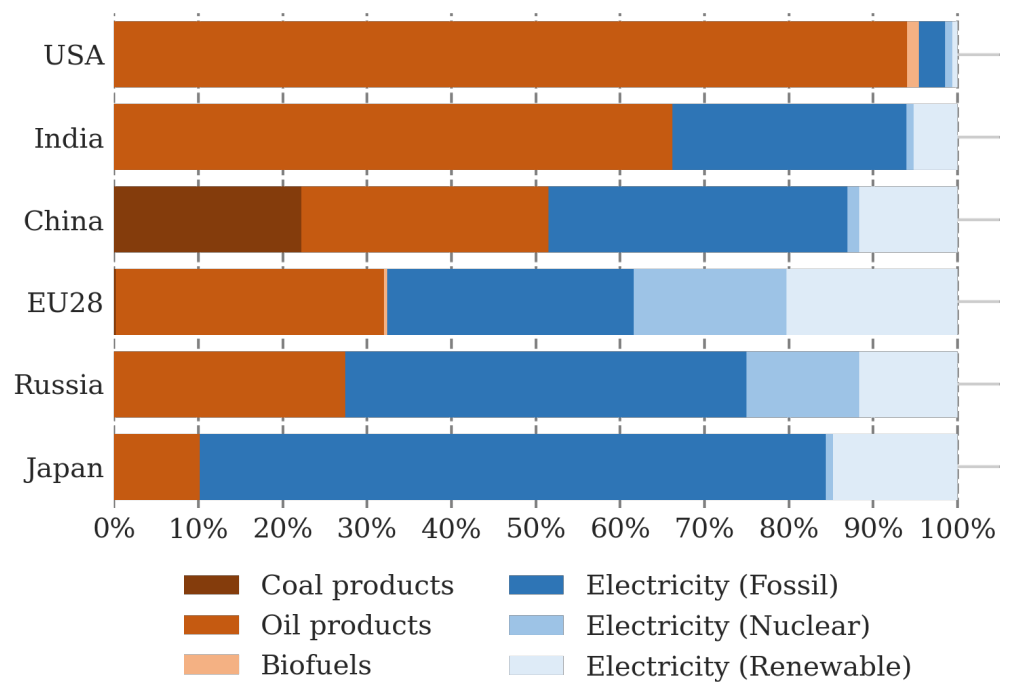
An important distinguishing feature for railways in Europe is the share of renewable energy in its energy mix. Europe compares best with other regions in this regard. However, Figure 3 shows that the total share of electricity in the rail energy mix is the highest in Japan.

In 2011, the European Commission published a White Paper entitled "Roadmap to a Single European Transport Area" towards a competitive and resource-efficient transport system. The paper calls for the creation of a transport system that will enable a 60% reduction in greenhouse gas emissions by 2050 [54]. According to the report "Electrification of the Transport System" published by the European Commission, one of the important factors enabling the achievement of environmental goals set by the White Paper is the reduction of unit energy consumption by rail transport by 30% by 2035 [55].

Commonly used measures of operational performance in rail transport are tonne-kilometers, abbreviated as tkm and calculated as the product of weight and distance of goods transport, and passenger-kilometers abbreviated as pkm and calculated analogously as the product of the number of passengers and transport distance. In relation to these performance units, expressing the output of rail transport, energy efficiency is calculated as the ratio of energy consumption in a given period to operational performance achieved in this period, expressed in tkm for freight transport, and for passenger transport, expressed in pkm. The summary below in Figure 4 shows how Europe is doing with its energy-efficient rail targets compared to the achievements of other regions.

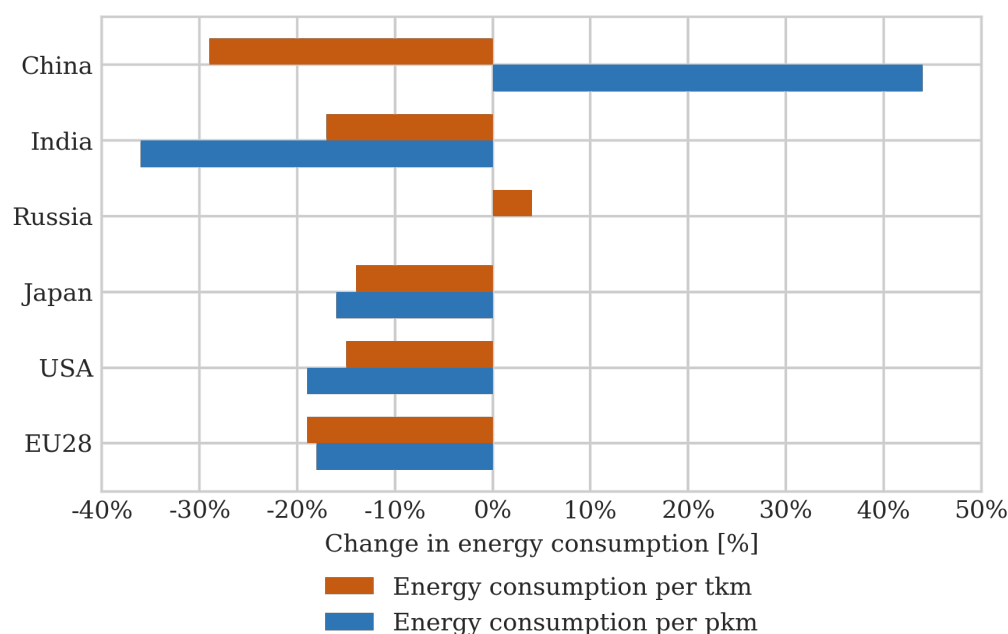


**Figure 2.** Modal share of rail in selected regions in 2015. Own study based on data from [47].



**Figure 3.** Share of energy sources in the energy mix of selected regions in 2015. Own study based on data from [47].





**Figure 4.** Change of unit energy consumption in the rail industry in selected regions in 2015 vs. 2005. Own study based on data from [47].

The progress in railway energy efficiency achieved by Europe was on a par with the progress in the USA and Japan. A significant increase in specific energy consumption in rail passenger transport in China can be explained by the dynamic development of high-speed rail in that country.

The following factors can be a source of energy efficiency improvement on the railways within the existing network [56–58]:

- reduction of the specific energy consumption of the traction vehicle while driving;
- reduction of the energy consumption of the traction vehicle during standstill;
- improvement of train driving technique by staff;
- optimization of the timetable on the electrified network in order to balance the network load;
- optimization of the rolling stock maintenance system, resulting in a reduction in energy consumption;
- reduction of energy used for the maintenance of the railway network and railway power network.

Improving energy efficiency in individual regions can be achieved with very different methods, due to the different energy sources used in these regions, which is shown in Figure 3. In the USA, diesel traction is dominant. Actions aimed at improving energy efficiency may include the technical development of the existing internal combustion engines and the improvement of the technique of driving a combustion traction vehicle [59]. The importance of such activities for railways in Japan is marginal due to the dominant electric traction there [60]. In turn, factors such as reducing energy consumption through regeneration or optimization of timetables aimed at equalizing power consumption will be of great importance in Japan [61]. In this context, the railway in Japan is similar to the underground railway, which, operating in a closed system, allows the use of mathematical algorithms for optimizing the timetable to improve energy efficiency [62]. The European rail network lacks the advantages of both American and Japanese railways. There is a large diversification in the field of energy sources, which means that sources of improving the energy efficiency of traction vehicles should be sought in the development of electric machines and internal combustion engines. Due to the high fragmentation of the infrastructure and the diversification of the power grid, optimization in terms of timetables is currently not a practical possibility.

The railway market in the European Union countries has been undergoing a process of deregulation since the 1990s. Previously, railway in individual European countries were organized as single monopolistic companies, controlling both infrastructure and railway transport. However, the deteriorating position of railway in inter-modal competition with road transport and the worsening financial condition of railway companies have led the European Commission to take action aimed at revitalizing the railway and to search for solutions introducing intra-modal competition in order to optimize use of the railway infrastructure in Europe [63]. Elimination of the monopoly in railway transport turned out to be a challenging task. The applied solution assumes the existence of system goods, which are the subject of a natural monopoly [64]. In the case of the railway, the infrastructure is considered to be such a goods system [65]. European deregulation of the railway market is based on vertical separation, i.e., separation of operators (i.e., companies which operate railway transportation) from railway infrastructure managers and establishment of rules of free access of operators to infrastructure (still managed as a natural monopoly). In addition to vertical separation, the deregulation of the European rail market has resulted in a horizontal separation, which is based on separation of freight and passenger operators, for which the regulations that are introduced assume separate licensing of operations. The separation of infrastructure within the framework of vertical separation referred to track infrastructure, along with related signaling, command, control and safety systems. It also referred to the railway electrification system and its power supply system.

The Directive on Railway Vertical Separation was issued in 1991 [66]. The first railway package, announced in 2001, gave guidelines for the allocation of railway network capacity and charges for access [67]. Since then, rail market reforms have been successively implemented in the member states, and successive packages have introduced detailed regulations for rail transport in Europe, as shown in Figure 5 below [68,69].

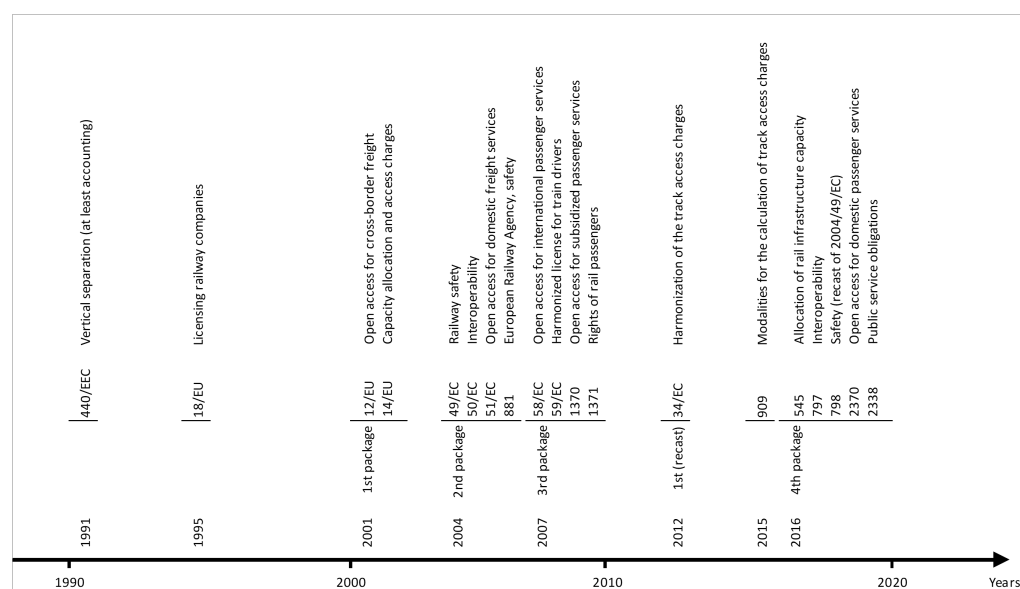


Figure 5. European legal acts on the deregulation of the railway market. Own study based on [68,69].

By way of comparison, it should be added that the model of railway market deregulation adopted for restructuring in the U.S. does not include the vertical separation, which is the basic principle of European deregulation. The American model is based on geographical separation, separating individual segments of the railway network in such a way that they are operated essentially by one operator. This model assumes that a particular network is operated by a single operator and that competition occurs between alternative networks offering connections between different regions of the country [70]. This choice was influenced by several factors that differentiate the American rail system from the European one. The lower network density, dominant private ownership of infrastructure,



lack of the technical differentiation characteristics as well as the liberal approach of the governments in Europe resulted in the fact that rail regulation, introduced by the Railway Revitalization and Regulatory Reform Act of 1976 and the Staggers Rail Act of 1980, only concerns the obligation imposed on railway operators to treat shippers using their rail transport services in a non-discriminatory manner.

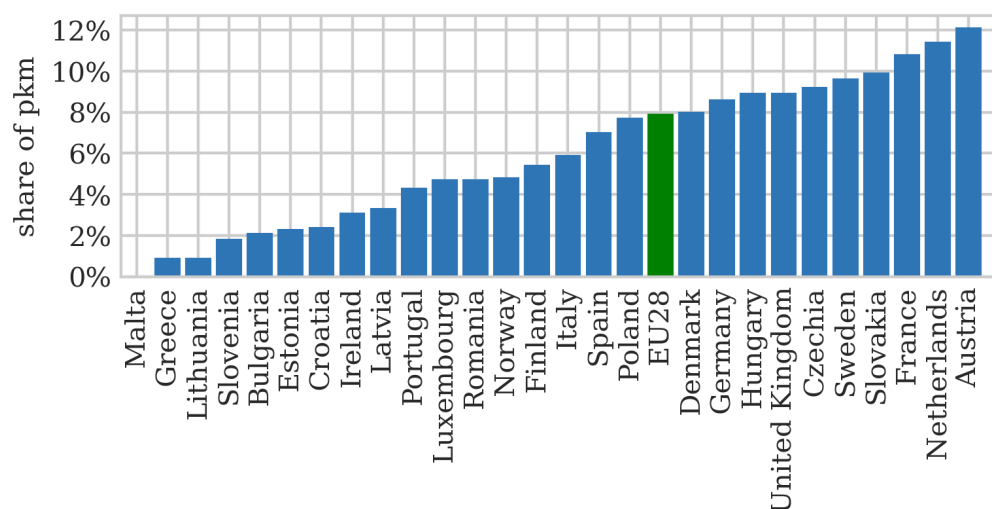
Taking into account the vertical and horizontal separation of the railways in Europe, the effects of which were deepened by the emergence of numerous new players on the railway market as well as the diversity of the systems of power supply to the railway network among the individual countries of the European Union and often also within those countries, the problem of accounting for the consumption of electric power supplying the railway network is not a trivial one. On the one hand, in a locomotive connected to a train, which travels between different power supply areas, the propulsion system must be switched. Thus, the locomotive sequentially receives power from different networks during a single journey. On the other hand, multiple locomotives belonging to different operators operate simultaneously in a homogeneous network area. The power consumption of the network has to be accounted for by multiple consumers. Furthermore, the decisions regarding the timetables are taken by the infrastructure manager, which limits the possibilities of the electric network manager to optimize energy consumption by balancing the power demand over time.

Before the deregulation of railways in Europe, this problem did not occur on such a large scale because monopolistic state-owned companies managed both the infrastructure (including the track system and the power supply network for trains) and operations on this network. Thus, there was no need to account for energy between sub-entities. Deregulation conducted according to the U.S. model avoids the problem of complex energy billing because the model still has only one operator on a segment of the network. Locomotives manufactured before the deregulation of railways in Europe were generally not designed for direct energy metering. Taking into account the life cycle of these vehicles, which is often 40 to 50 years, for the next few decades we can expect to see locomotives equipped both with and without metering devices on the European rail network. The issue of standardization of on-board devices, measuring the energy consumption on the locomotive and recognition of their measurements by individual managers of the railway power network, still remains the subject of efforts of both the European Railway Agency (ERA) and organizations associating managers of railway infrastructure [71–73].

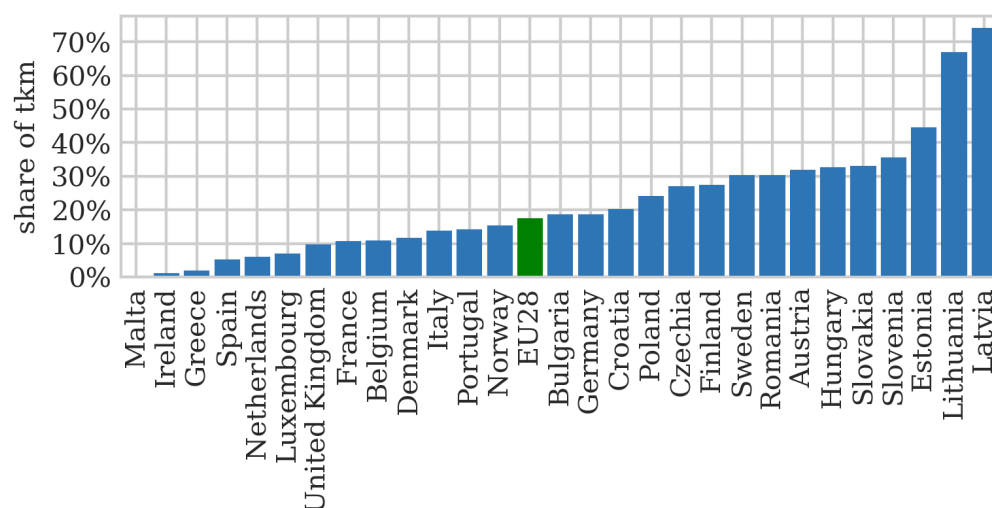
### *3.2. Railways in Poland Compared to Other European Countries*

The railway network in Poland, according to the Office of Railway Transport (UTK), which acts as the regulator in the country, had a length of 18,934 km in 2019, 61% of which are electrified lines [74]. After Germany and France, Poland thus has the third largest rail network in Europe. The network density in Poland according to UTK data reaches the value of 62 km per thousand square kilometers. According to Eurostat data, the modal share of rail in Poland for passenger transport in 2017 was 7.7%. As Figure 6 below shows, this share places the Polish railway at a level close to the European average, which for the EU28 countries was 8% [75].

The modal share of rail in Poland for freight transport in 2017 was 26.8%. As Figure 7 below shows, this gives the railway in Poland a position well above the average for EU28 countries in this respect [76].

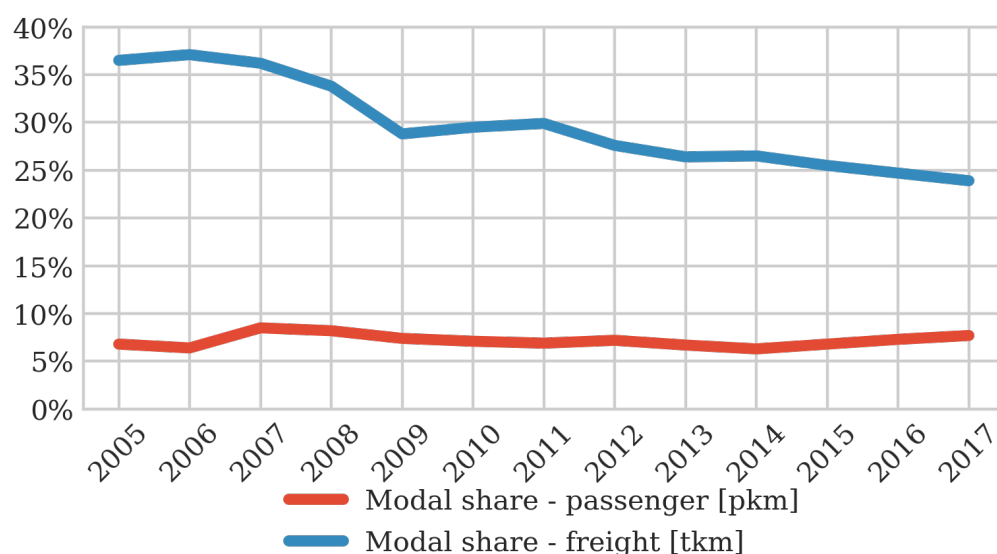


**Figure 6.** Modal share of railway transportation in passenger transport for selected European countries in 2017. Own study based on data from [75].



**Figure 7.** Modal share of railway transportation in freight transport for selected European countries in 2017. Own study based on data from [76].

Such a high modal share of rail transport in freight transport in Poland, compared to other EU28 countries, is mainly due to bulk coal transport in the country, which reflects the role of this raw material in the Polish energy mix. Given the scale of coal haulage in Poland, competition from road transport is limited in this respect. The negative dynamics of the modal share of rail in the freight market shown in Figure 8 below indicates that rail is not benefiting adequately from the economic development of the country. The effects of this development, in the form of an increase in freight transport, are consumed by other modes of transport, mainly road transport. The modal share of railway in passenger transport has remained constant during this period [75,76].



**Figure 8.** Dynamics of modal share of railway transportation in Poland. Own study based on data from [75,76].

The demonopolization of the rail market was introduced in Poland in 2003. The law governing the railway market was preceded by the Act on the Commercialization, Restructuring and Privatisation of the State Enterprise Polskie Koleje Państwowe (Polish National Railways—PKP), passed in 2000. On this basis, the former monopolist was restructured and adapted to the requirements of the European directives contained in the first railway package. In Poland, a holding model has been adopted, in which the infrastructure manager and the operators that formerly constituted the state monopoly are transformed into capitalized companies but remain integrated within the holding company, which exercises ownership functions over those companies. A similar model, but with varying levels of coordination within the holding company, was used in the deregulation of railways in Austria, France, Germany, Italy, Belgium, Slovenia and Latvia [77]. In 2015, a decision was made to sell PKP Energetyka, a company belonging to the PKP holding, to the American fund CVC Capital Partners. After the approval of the European Commission, the transaction was finalized [78], and thus, the management of the power grid, supplying the railways in Poland, was entrusted to a private company. Competition on the Polish railways appeared as early as 2003. Even before deregulation, there were companies that operated railway transport on separate lines, not belonging to PKP. These companies, having obtained licences for railway transport, became fully-fledged market players [79]. In subsequent years, new entrepreneurs appeared, obtained licences and started their transport activities. There were also companies, controlled by national carriers from other European countries, which started their business activity in Poland. According to the data of UTK, in 2020, 110 carriers in Poland were licensed to carry out railway freight transport [80]. The emergence of new players in the rail freight market results in a loss of market share by the national carrier. However, intra-modal competition has not protected the freight railway in Poland from the progressive loss of rail market share in inter-modal competition with road transport.

### 3.3. Energy Management in DB Cargo Polska

DB Cargo Polska has been present on the Polish market under the DB brand for more than ten years and is one of the leading players in the rail freight market, but its roots go back to the 1950s. It was then that the mining industry in Upper Silesia decided to set up companies specializing in the rail transport of coal between mines, power plants and coking plants located in the Upper Silesian industrial region, as well as in the haulage of sand, which at that time was used to fill up depleted mine excavations. A separate railway infrastructure network, belonging to the mining industry at that time, covering the entire area of the Upper Silesian industrial region, was used for these transports.

After the market liberalization in Poland in the 1990s, these companies were privatized through employee share ownership or investment funds. The development impulse for these companies was the deregulation of the railway market in Poland, which enabled them to obtain rail transport licences and freely develop their business using the national infrastructure, opened by the deregulation of the market also for alternative operators. These companies have grown organically and through acquisitions, expanding nationwide and building capital groups. Over time, these companies have also developed their management systems, using the experience and drawing on models from the industry of developed Western European economies [81]. Building increasingly complex corporate structures, these companies also took steps to establish corporate governance tailored to the scale of their operations [82]. At the beginning of the 21st century, attempts were made to consolidate these companies—initially internally and later with the help of external investors. Finally, at the end of 2009, they were purchased by Deutsche Bahn. At that time, a group of 31 companies was bought and consolidated through a series of mergers. Currently, DB Cargo Polska is part of the DB Cargo Group, which is a segment of Deutsche Bahn responsible for the development of the rail freight business in Europe.

After the political reform and market liberalization in Poland in the 1990s, interest in the concept of sustainable development and related corporate social responsibility emerged among Polish enterprises [79]. DB Cargo Polska is a company which declares its orientation towards sustainable development. Therefore, the optimization of energy consumption fits well with the company's strategy to ensure the achievement of both economic and environmental objectives. The area of the railway company's activity in which energy consumption is the highest is, of course, transport operation. The company uses both electric and diesel locomotives for this purpose for transport on non-electrified railway lines. Diesel shunting locomotives are used for first-mile and last-mile operations associated with sidings and terminals. Another area where the company consumes a relatively large amount of energy is rolling stock maintenance. For this purpose, the company uses repair facilities, which consume thermal and electrical energy. The remaining marginal part of energy consumed by the company is related to its administrative activities.

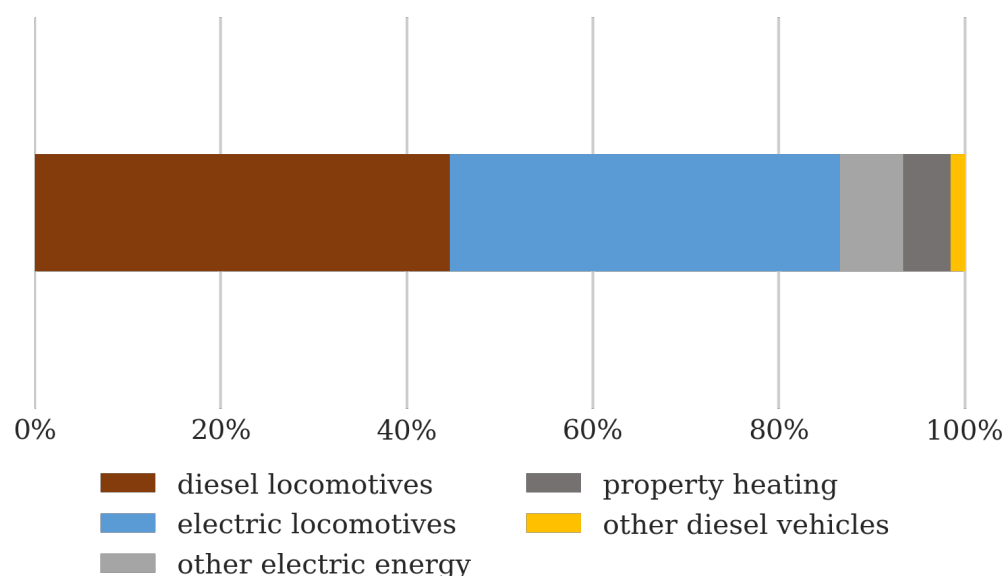
Electricity used to power the locomotives is purchased from the network manager, which in Poland is PKP Energetyka. This energy is a variable cost to the company, so its consumption is proportional to the transport performance of the company. Due to the problems with the direct accounting of electric energy consumed in the railway network (described in previous chapters), the statistical method is used for settlements with PKP Energetyka, which is based on the calculation of the company's share in the total transport performance of all carriers using the network in the settlement period. This method cannot be completely avoided until all vehicles running on the network and using electricity are equipped with on-board energy consumption meters approved by the power grid manager. Statistical billing of electricity consumption, when operating, makes it impossible to calculate the energy efficiency of a particular operator or a particular locomotive, since operators are charged for electricity consumption derived from the average energy efficiency of all operators that have used the network. The efficiency of the network itself (expressed in the ratio of energy consumed by operators to energy purchased by the network manager) is also of relevance here. Finally, the grid itself generates energy losses connected with its transmission as well as with the maintenance of transformer stations and other power equipment.

Taking into account this limitation with regard to the accuracy of accounting for traction energy consumption, DB Cargo Polska focuses on managing the overall energy efficiency of the company, understood as the relationship between the transport performance and energy consumed by the company. Although transport performance is equivalent to the company's main product, the energy consumed by the company is also used for additional services offered to customers as part of logistics or railway technology packages, such as loading or unloading goods, servicing customer rolling stock or servicing the railway infrastructure at a customer's siding. Thus, the energy included in the company's

statistics contributes to the generation of additional output, which makes the actual energy efficiency of the company higher than the results from the calculation based only on the transport performance.

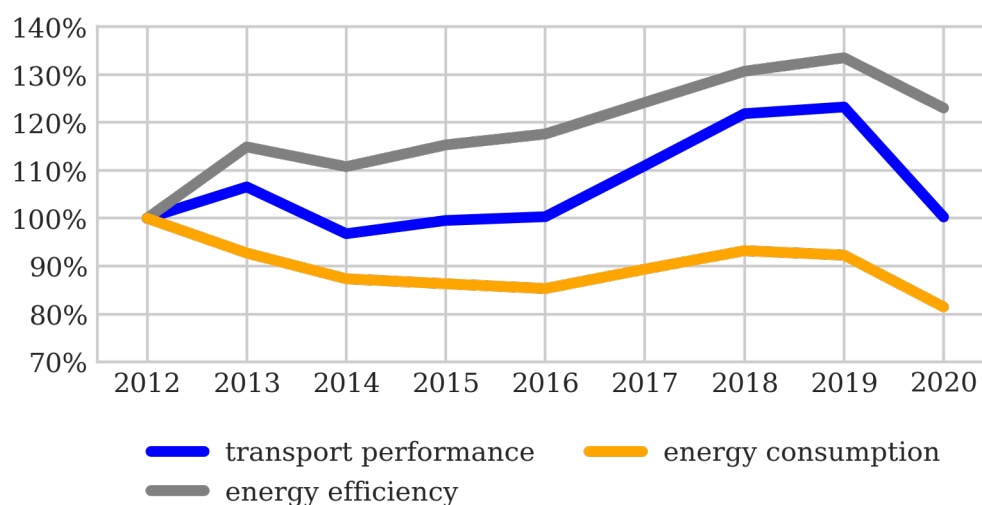
Therefore, the total energy consumption of the company consists of: (1) electric energy consumed by locomotives while operating transport, which is charged by the network manager based on the statistical method; (2) energy produced by generators of diesel locomotives used by the company to operate transport and shunting at customer's sidings and terminals; (3) energy produced by fuel engines of other vehicles used by the company; (4) electricity used to power machines in rolling stock repair plants and to light the company's property; (5) heat energy used to heat the company's property. The graph below shows the shares of the mentioned energy consumption components in total energy consumption of the company in 2020.

As can be seen from the diagram in Figure 9, the largest share of energy consumption in the company is that produced by diesel locomotive generators, and the total share of energy consumed by electric and diesel locomotives reaches 87%. The larger share of energy consumed by diesel locomotives than the electric locomotives (despite the electrification of railways lines in Poland amounting to 61%) is explained by the inclusion of the work of diesel shunting locomotives, used to perform the first and last mile transports as well as shunting at sidings and customer terminals, where the amount of performed tonne-kilometers is small in relation to the working time of the locomotive engine used to perform them. The company has achieved a positive trend in the dynamics of performed tonne-kilometers between 2012 and 2020. The graph below shows the dynamics of the transport work in comparison with the dynamics of the total energy consumption in these years. These two parameters allow to calculate the dynamics of the company's energy efficiency.



**Figure 9.** Structure of energy use in DB Cargo Polska in 2020. Own study based on company data.

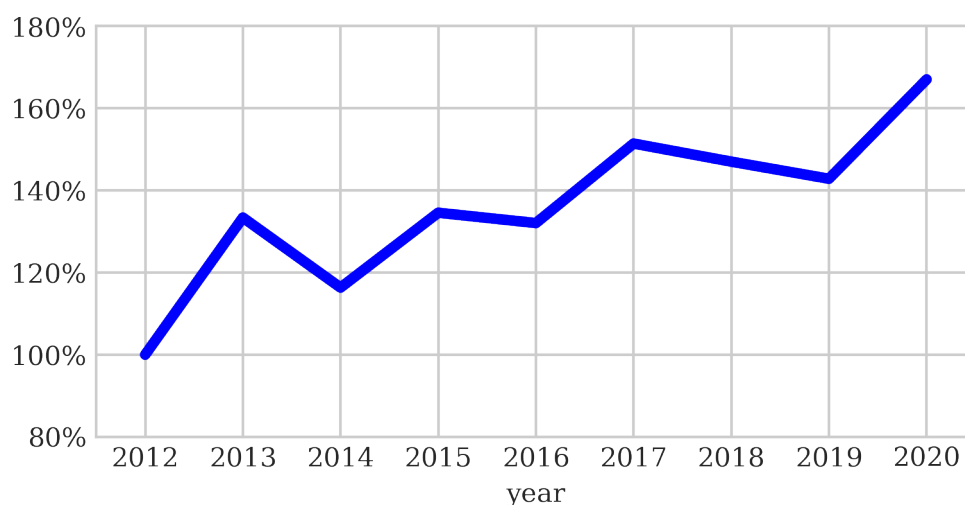
The break in the positive trend in 2020, shown in Figure 10, is due to the economic collapse caused by the COVID-19 pandemic. The company improved its energy efficiency, measured as the ratio of transport work to the total energy consumption of the company, by more than 20% between 2012 and 2020. The additional output produced by using this energy is not easy to operationalize, due to the variety of ancillary services sold. However, it has been assumed that the measure of this output will be the value of revenues generated by the company from services that do not constitute rail transport. The graph below shows the dynamics of the company's revenue from services that do not generate freight work.



**Figure 10.** Transport performance, energy consumption and energy efficiency of DB Cargo Polska, normalized to 2012. Own study based on company data.

As we can see in Figure 11, revenues from ancillary services had positive dynamics from 2012 to 2020, which means that the actual dynamics of the company's energy efficiency were higher than presented in Figure 10. In order to increase energy efficiency, the company undertook a number of optimization and innovation projects in all areas of its activity. The key area in which to look for potential savings in energy consumption is, of course, the locomotive fleet. The company has been investing in this area since the start of its activities within the Deutsche Bahn Group. The fleet of locomotives at the company's disposal after the takeover by DB consisted of electric locomotives whose average age in 2010 was 45 years. These locomotives were gradually being phased out of service and replaced with new electric locomotives which had the ability to regenerate electricity. After ten years of operation, the average age of the electric locomotives used by DB Cargo Poland in 2020 has decreased by 20 years. Taking the passage of time into account, this gives an effective improvement in the age of the fleet of 30 years. The diesel locomotives owned by the company in 2010 were gradually being replaced by newer-generation diesel locomotives, which were available for transfer to Poland from the resources of the DB Cargo Group in Europe. After ten years of functioning of the company, the average age of diesel locomotives has increased by only 2 years, which gives an effective improvement of 8 years. This information illustrates the scale of the modernization of the company's locomotive fleet. While the improvement in the quality of the company's fleet of diesel locomotives is reflected in the dynamics of the company's overall energy efficiency shown in Figure 10, the improvement in the quality of the electric locomotive fleet is not, because the statistical method of accounting for energy consumption with the network manager makes it impossible to reflect the actual energy consumption of a particular operator.





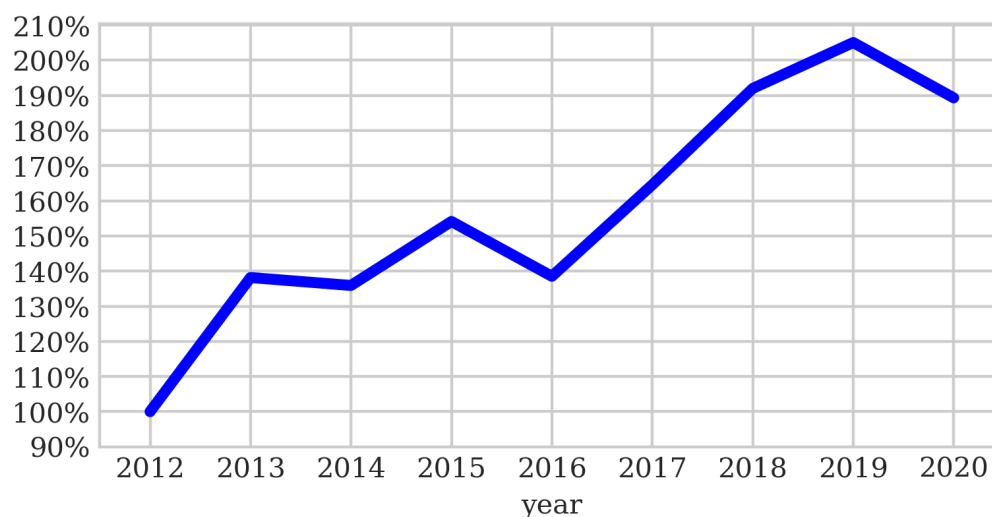
**Figure 11.** Revenue from non-transport services of DB Cargo Polska, normalized to 2012. Own study based on company data.

The environmental impact of electric locomotives used by the company is determined not only by their energy efficiency, but also by the energy sources used by the network manager. DB Cargo Poland therefore has no direct influence on what sources of energy are used by electric locomotives belonging to the company. Looking for ways to reduce the carbon intensity of its operations, in 2020, the company signed a letter of intent with PKP Energetyka, which aims to enable the purchase of energy from renewable sources and settlement of this purchase between PKP Energetyka and DB Cargo Poland. It should also be mentioned here that the gradual modernization of the fleet resulted in a reduction of the time spent on preventive and emergency maintenance of locomotives, thus reducing the production reserve and improving the productivity of the fleet. In addition, the company worked on the operational productivity of its fleet by reducing the waiting periods of locomotives between successive train services. These actions—in addition to improving financial efficiency—were also aimed at reducing unproductive energy consumption by locomotives during waiting times. This is particularly important in the case of diesel locomotives, which need to maintain proper engine temperature during periods of negative temperatures, which result in fuel consumption. Figure 12 below shows the dynamics expressed in tonne-kilometers per locomotive of the productivity of DB Cargo Poland's fleet of line locomotives used in 2012–2020.

Rolling stock maintenance is also an important operational area in terms of energy consumption. The savings in thermal and electrical energy achieved by DB Cargo Polska in this area result mainly from the restructuring it has undertaken and the process innovations implemented as part of that restructuring. In 2012, the company had maintenance workshops with a total roofed area of more than 101,000 m<sup>2</sup>. Work in these workshops was organized mainly in the nest system, which resulted in the fact that the rolling stock stayed for a long time in the plant, which resulted in a high demand for the space, on which repair operations are performed. As the number of locomotives and wagons of older types was reduced and their productivity improved, some plants were closed and properties were sold. In 2013, a new wagon inspection repair system, organized in the pipeline system, was implemented. This organization—based on lean manufacturing methodology, commonly used in the automotive industry—had not been used in the rolling stock service before. The introduction of this innovation has significantly shortened the time spent in the repair shop and further reduced the amount of space used by the company for rolling stock maintenance. By 2020, the company was using a total of less than 47,000 m<sup>2</sup> of covered space to service its own rolling stock, while at the same time selling some of its production

capacity to customers outside the company. Thus, the company reduced the size of its repair facilities by 53% between 2012 and 2020.

In terms of administrative activities, the actions aimed at improving energy efficiency came down to reduction of the used office space, thermomodernization of owned properties and modernization of lighting.



**Figure 12.** Locomotive productivity of DB Cargo Polska in tkm per locomotive, normalized to 2012. Own study based on company data.

#### 4. Discussion and Conclusions

The energy efficiency of railways is globally much higher than that of its main competitor, road transport. Despite the advantage in energy efficiency, as well as the European Union's policy declarations regarding the planned increase in the importance of railways, in recent decades, railways have been losing market share in land transport to road transport. Given the much lower energy efficiency of road transport, this has resulted in a deterioration of the energy efficiency of the European transport system.

The European railway system is characterized by considerable complexity in comparison to other railway systems in the world, i.e., due to different energy supply systems of the network and national borders separating areas served by national railway network managers. The opening of the railway market in Europe has increased this complexity by introducing intra-modal competition. This results in a multitude of operators using individual national networks and operating across national network boundaries. The locomotive fleet in Europe is not completely equipped with on-board energy consumption meters. As a consequence, network managers and operators need to deal with a lack of transparency in settlements. Hence, we can conclude that numerous limitations exist for optimization activities in the field of railway energy efficiency.

Railways in Poland still have a relatively large share in freight transport, which is largely due to the high importance of coal in the country's energy mix. Deregulation of the railways in Poland has resulted in the emergence of a relatively large number of players in the rail freight market.

DB Cargo Poland has been operating under the DB brand since 2010, but its legal predecessors were providing rail freight services before the market liberalization in Poland. Due to the lack of transparency in the energy efficiency of electric locomotives, the company manages its energy efficiency mainly by using a global indicator of energy consumption per unit of transport performance. Actions to improve the company's energy efficiency consisted mainly of improving the operational productivity of the locomotive fleet, modernizing this fleet, and optimizing the fleet maintenance process. Due to the problems with transparency in accounting for energy consumed by electric locomotives, not all of the

action taken could be reflected in the positive trend in energy efficiency recorded by the company between 2012 and 2020.

Based on the literature review presented, the analysis performed, the business case considered and the discussion above, the following conclusions can be drawn. The model of rail transport market regulation introduced in the European Union has had a significant impact on the energy efficiency of railways. This model has led to an increase in the complexity of the billing system for electricity consumption. Limited transparency in this respect leads to the use of the indirect energy efficiency management methods of railway companies presented on the example of DB Cargo Polska, which makes it difficult to assess the effectiveness of individual activities aimed at improving energy efficiency as well as reducing the negative environmental impact by railway companies. The far-reaching liberalization of the rail market in Europe, the purpose of which was to use market mechanisms to improve the economic efficiency of European railways, has so far failed to break the advantage of road transport, which still takes over most of the transport work generated by economic growth on the European continent. This liberalization has led to fragmentation of the railway system and economic optimization on the microscale of individual enterprises. Due to the commercialization of the management of the power network, presented on the example of the sale of PKP Energetyka, the company, acting for its statutory goals, does not have to take into account the economic effects as well as environmental effects that can be achieved, for example, by reducing energy consumption for the benefit of grid maintenance, significant from the entire railway system. The example of DB Cargo Polska also shows that despite the existing limitations, railway companies undertake various activities aimed at improving their energy efficiency and are in a position to demonstrate the combined effectiveness of their activities. Obtaining transparency in the scope of the effects of individual activities without breaking the existing interoperability barriers and unifying the billing system for electricity consumption in Europe seems to be impossible, and the possibility of reducing electricity consumption in the railway system by implementing optimization of timetables, as is the case in systems underground, seems to be still unreachable.

Given the limited access to energy efficiency data for specific vehicles and individual segments of the power grid, it would be advisable to undertake research by market regulators who could access this type of data. It would also be interesting to study the effectiveness of the electrification of the railway network or the unification of the parameters of the current used in the European railway network, from the perspective of railway energy efficiency.

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## References

1. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on Energy End-Use Efficiency and Energy Services and Repealing Council Directive 93/76/EEC. Available online: <https://eur-lex.europa.eu/legal-content/pl/TXT/?uri=CELEX%3A32006L0032> (accessed on 14 April 2021).
2. United Nations. Agenda 21: Earth Summit: The United Nations Programme of Action from Rio. 1993. Available online: <https://sustainabledevelopment.un.org/outcomedocuments/agenda21> (accessed on 14 April 2021).
3. von Weizsäcker, E.U.; Lovins, A.B.; Lovins, L.H. *Mnożnik Cztery: Podwojony Dobrobyt-Dwukrotnie Mniejsze Zużycie Zasobów Naturalnych*; Polskie Towarzystwo Współpracy z Klubem Rzymskim: Rome, Italy, 1999.
4. Kuzior, A. *Aksjologia Zrównoważonego Rozwoju*; Belianum: Banská Bystrica, Slovakia, 2014.
5. von Weizsäcker, E.U.; Hargroves, C.; Smith, M.H.; Desha, C.; Stasinopoulos, P. *Factor Five*, 1st ed.; Routledge: London, UK, 2009. [CrossRef]
6. UNEP. The Business Case for the Green Economy: Sustainable Return on Investment. 2012. Available online: <http://www.unep.org/greeneconomy/Portals/88/documents/partnerships/UNEP%20BCGE%20A4.pdf> (accessed on 14 April 2021).
7. Kuzior, A. Polskie i niemieckie doświadczenia w projektowaniu i wdrażaniu zrównoważonego rozwoju [Polish and German Experiences in Planning and Implementation of Sustainable Development]. *Probl. Ekorozwoju-Probl. Sustain. Dev.* **2010**, *5*, 81–89.
8. Lyulyov, O.; Pimonenko, T.; Kwilinski, A.; Dzwigol, H.; Dzwigol-Barosz, M.; Pavlyk, V.; Barosz, P. The Impact of the Government Policy on the Energy Efficient Gap: The Evidence from Ukraine. *Energies* **2021**, *14*, 373. [CrossRef]
9. Bartnikowska, S.; Olszewska, A.; Czekala, W. Stan obecny przyłączeń instalacji OZE do systemu elektroenergetycznego [The current state of connection issues of renewable energy sources installations to the electrical grid]. *Polityka Energetyczna Energy Policy J.* **2017**, *20*, 117–128.
10. Van Meerbeek, K.; Ottroy, S.; De Meyer, A.; Van Schaeybroeck, T.; Van Orshoven, J.; Muys, B.; Hermey, M. The bioenergy potential of conservation areas and roadsides for biogas in an urbanized region. *Appl. Energy* **2015**, *154*, 742–751. [CrossRef]
11. Cho, Y.S.; Choi, Y.H. Methodology for Implementing the State Estimation in Renewable Energy Management Systems. *Energies* **2021**, *14*, 2301. [CrossRef]
12. Xiong, S.; Hou, Z.; Zou, S.; Lu, X.; Yang, J.; Hao, T.; Zhou, Z.; Xu, J.; Zeng, Y.; Xiao, W.; et al. Direct Observation on p- to n-Type Transformation of Perovskite Surface Region during Defect Passivation Driving High Photovoltaic Efficiency. *Joule* **2021**, *5*, 467–480. [CrossRef]
13. Jiménez-Castillo, G.; Rus-Casas, C.; Tina, G.; Muñoz-Rodríguez, F. Effects of smart meter time resolution when analyzing photovoltaic self-consumption system on a daily and annual basis. *Renew. Energy* **2021**, *164*, 889–896. [CrossRef]
14. Mayer, F.D.; Brondani, M.; Carrillo, M.C.V.; Hoffmann, R.; Lora, E.E.S. Revisiting energy efficiency, renewability, and sustainability indicators in biofuels life cycle: Analysis and standardization proposal. *J. Clean. Prod.* **2020**, *252*, 119850. [CrossRef]
15. Rodias, E.; Berruto, R.; Bochtis, D.; Busato, P.; Sopegno, A. A Computational Tool for Comparative Energy Cost Analysis of Multiple-Crop Production Systems. *Energies* **2017**, *10*, 831. [CrossRef]
16. Szlęk, A.; Werle, S.; Schaffel, N.; Wilk, R. Czyste technologie pozyskiwania energii z węgla oraz perspektywy bezpłomieniowego spalania [Clean coal energy technologies and perspective of flameless coal combustion]. *Rynek Energii* **2009**, *83*, 39–45.
17. Balku, Ş. Analysis of combined cycle efficiency by simulation and optimization. *Energy Convers. Manag.* **2017**, *148*, 174–183. [CrossRef]
18. Tic, W.; Junga, R. Wpływ katalizatorów metalicznych na efektywność energetyczną i ekologiczną spalania ciężkich olejów opałowych [The impact of metallic catalysts of heavy fuels oil combustion on the energetic and ecological efficiency]. *Przemysł Chem.* **2017**, *1*, 122–124. [CrossRef]
19. Wang, T.; Xu, L.; Chen, Z.; Guo, L.; Zhang, Y.; Li, R.; Peng, T. Central site regulation of cobalt porphyrin conjugated polymer to give highly active and selective CO<sub>2</sub> reduction to CO in aqueous solution. *Appl. Catal. B Environ.* **2021**, *291*, 120128. [CrossRef]
20. Miśkiewicz, R. Efficiency of Electricity Production Technology from Post-Process Gas Heat: Ecological, Economic and Social Benefits. *Energies* **2020**, *13*, 6106. [CrossRef]
21. Radulescu, B.A.; Radulescu, V. Numerical Modeling of Intelligent Heating Systems to Improve their Energetic Efficiency. In Proceedings of the 2019 International Conference on Electromechanical and Energy Systems (SIEMEN), Craiova, Romania, 9–11 October 2019; IEEE: Craiova, Romania, 2019; pp. 1–7. [CrossRef]
22. Luna, T.; Ribau, J.; Figueiredo, D.; Alves, R. Improving energy efficiency in water supply systems with pump scheduling optimization. *J. Clean. Prod.* **2019**, *213*, 342–356. [CrossRef]
23. Meng, F.; Xu, B.; Zhang, T.; Muthu, B.; Sivaparthipan, C.B. Application of AI in image recognition technology for power line inspection. *Energy Syst.* **2021**. [CrossRef]
24. Agostinelli, S.; Cumo, F.; Guidi, G.; Tomazzoli, C. Cyber-Physical Systems Improving Building Energy Management: Digital Twin and Artificial Intelligence. *Energies* **2021**, *14*, 2338. [CrossRef]
25. Chen, Y.Y.; Chen, M.H.; Chang, C.M.; Chang, F.S.; Lin, Y.H. A Smart Home Energy Management System Using Two-Stage Non-Intrusive Appliance Load Monitoring over Fog-Cloud Analytics Based on Tridium's Niagara Framework for Residential Demand-Side Management. *Sensors* **2021**, *21*, 2883. [CrossRef] [PubMed]
26. Zhang, M.; Zhang, Q.; Lv, Y.; Sun, W.; Wang, H. An AI based High-speed Railway Automatic Train Operation System Analysis and Design. In Proceedings of the 2018 International Conference on Intelligent Rail Transportation (ICIRT), Singapore, 12–14 December 2018; pp. 1–5. [CrossRef]

27. Lopez-Ibarra, J.A.; Goitia-Zabaleta, N.; Camblong, H.; Milo, A.; Gaztanaga, H. Intelligent and Adaptive Fleet Energy Management Strategy for Hybrid Electric Buses. In Proceedings of the 2019 IEEE Vehicle Power and Propulsion Conference (VPPC), Hanoi, Vietnam, 14–17 October 2019; IEEE: Hanoi, Vietnam, 2019; pp. 1–6. [\[CrossRef\]](#)
28. Hell, C.R.; Ilie, C. Study on the further development of energy efficiency networks in the context of sustainable management of organizations. *Qual.-Access Success* **2019**, *15*, 21–36.
29. Salem, I.B.; Taghouti, L.; Ouni, L.E.A. Development and test of an energetic management package for industrial process efficiency. *Electron. Gov. Int. J.* **2019**, *15*, 21. [\[CrossRef\]](#)
30. Gandenberger, T.; Frauendorf, J.; Wellbrock, W. Lean und Green—Energieeffizienz in der industriellen Produktion [Lean and green—Energy efficiency in industrial production]. *ZWF Zeitschrift für Wirtschaftlichen Fabrikbetrieb* **2017**, *112*, 417–420. [\[CrossRef\]](#)
31. Kharazishvili, Y.; Kwilinski, A.; Sukhodolia, O.; Dźwigoł, H.; Bobro, D.; Kotowicz, J. The Systemic Approach for Estimating and Strategizing Energy Security: The Case of Ukraine. *Energies* **2021**, *14*, 2126. [\[CrossRef\]](#)
32. Kuzior, A.; Kwilinski, A.; Hrozny, I. The Factorial-Reflexive Approach to Diagnosing the Executors' and Contractors' Attitude to Achieving the Objectives by Energy Supplying Companies. *Energies* **2021**, *14*, 2572. [\[CrossRef\]](#)
33. Yang, Q.; Hu, X.; Wang, Y.; Liu, Y.; Liu, J.; Ma, J.; Wang, X.; Wan, Y.; Hu, J.; Zhang, Z.; et al. Comparison of the impact of China's railway investment and road investment on the economy and air pollution emissions. *J. Clean. Prod.* **2021**, *293*, 126100. [\[CrossRef\]](#)
34. Murta, A.L.S.; Freitas, M.A.V.D.; Ferreira, C.G.; Peixoto, M.M.D.C.L. The use of palm oil biodiesel blends in locomotives: An economic, social and environmental analysis. *Renew. Energy* **2021**, *164*, 521–530. [\[CrossRef\]](#)
35. Feng, M.; Wu, C.; Lu, S. A New Operation-Oriented Mixed Integer Linear Programming Model for Energy-Efficient Train Operations. In Proceedings of the 10th International Conference on Power and Energy Systems (ICPES), Chengdu, China, 25–27 December 2020; IEEE: Chengdu, China, 2020; pp. 350–355. [\[CrossRef\]](#)
36. Vasilenko, M.; Kuzina, E.; Bepalov, V.; Drozdov, N.; Tagiltseva, J.; Korenyakina, N.; Prokopchuk, V.; Nadolinsky, P. Digital technologies in quality and efficiency management of transport service. *E3S Web Conf.* **2021**, *244*, 11046. [\[CrossRef\]](#)
37. Jabłoński, A.; Jabłoński, M. Social Perspectives in Digital Business Models of Railway Enterprises. *Energies* **2020**, *13*, 6445. [\[CrossRef\]](#)
38. Sirina, N.; Yushkova, S. Polygon Principles for Integrative Digital Rail Infrastructure Management. *Transp. Res. Procedia* **2021**, *54*, 208–219. [\[CrossRef\]](#)
39. Olentsevich, A.A.; Konyukhov, V.Y.; Guseva, E.A.; Konstantinova, M.V.; Olentsevich, V.A. Automation of the splitting-up processes of freight trains on the gravity sorting yards in the railway transport system. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1064*, 012029. [\[CrossRef\]](#)
40. Staszek, M.; Mikulski, J. Zastosowanie symulacyjnych programów komputerowych do przeprowadzania dowodów bezpieczeństwa urządzeń elektronicznych na przykładzie analogowego komparatora [An application of simulation software to conducting safety proofs of electronic devices on the example of an analog comparator]. In *Komputerowe Systemy Wspomagania Prac Inżynierskich*; Kosma, Z., Ed.; Wyższa Szkoła Inżynierska w Radomiu: Radom, Poland, 1994.
41. Kuzior, A.; Kwilinski, A.; Tkachenko, V. Sustainable development of organizations based on the combinatorial model of artificial intelligence. *Entrep. Sustain. Issues* **2019**, *7*, 1353–1376. [\[CrossRef\]](#)
42. Tkachenko, V.; Kuzior, A.; Kwilinski, A. Introduction of artificial intelligence tools into the training methods of entrepreneurship activities. *J. Entrep. Educ.* **2019**, *22*, 10.
43. Kwilinski, A.; Kuzior, A. Cognitive Technologies in the Management and Formation of Directions of the Priority Development of Industrial Enterprises. *Manag. Syst. Prod. Eng.* **2020**, *28*, 133–138. [\[CrossRef\]](#)
44. Riego-Martinez, J.; Perez-Alonso, M.; Duque-Perez, O. Influence of the rail electrification system topology on the energy consumption of train trajectories. *IET Renew. Power Gener.* **2020**, *14*, 3589–3598. [\[CrossRef\]](#)
45. Barinov, I.A.; Melnichenko, O.V. Power IGBTs Application in AC-Wire DC-Motor Locomotive Thyristor-Based Power Circuit for Regenerative Brake Energy Efficiency Increase. In Proceedings of the 2019 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), Sochi, Russia, 25–29 March 2019; IEEE: Sochi, Russia, 2019; pp. 1–5. [\[CrossRef\]](#)
46. Furutani, R.; Kudo, F.; Moriwaki, N. Case study on detecting feature value for energy efficiency in railway operations. *Jpn. Railw. Eng.* **2017**, *2017*, 16–18.
47. International Union of Railways. Railway Handbook 2017. Available online: [https://uic.org/IMG/pdf/handbook\\_iea-uic\\_2017\\_web3.pdf](https://uic.org/IMG/pdf/handbook_iea-uic_2017_web3.pdf) (accessed on 14 April 2021).
48. Wójcik, P. Znaczenie studium przypadku jako metody badawczej w naukach o zarządzaniu [The importance of the case study as a research method in management science]. *E-Mentor* **2013**, *1*, 17–22.
49. Rossberg, R.R., Ed. *Geschichte der Eisenbahn [The History of Railways]*; Faunus Verlag: Basel, Switzerland, 1977; pp. 5–32.
50. WorldStat. List of countries of the World—Density of railways. Available online: [http://en.worldstat.info/World/List\\_of\\_countries\\_by\\_Density\\_of\\_railways](http://en.worldstat.info/World/List_of_countries_by_Density_of_railways) (accessed on 14 April 2021).
51. Mortimer, P.; Islam, D.M.Z. A comparison of North American and European railway systems—A critique and riposte. *Eur. Transp. Res. Rev.* **2014**, *6*, 503–510. [\[CrossRef\]](#)
52. Kramarz, M.; Dohn, K.; Przybylska, E.; Knop, L. Scenarios for the Development of Multimodal Transport in the TRITIA Cross-Border Area. *Sustainability* **2020**, *12*, 7021. [\[CrossRef\]](#)
53. Frey, S. *Railway Electrification Systems & Engineering*; World Technologies: Delhi, India, 2014.



54. European Commission. Roadmap to a Single European Transport Area—Towards a Competitive and Resource Efficient Transport System. White Paper. 2011. Available online: <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF> (accessed on 14 April 2021).
55. European Commission. *Electrification of the Transport System*; Studies and Reports; Technical Report; European Commission: Brussels, Belgium, 2017.
56. Popescu, M.; Bitoleanu, A. A Review of the Energy Efficiency Improvement in DC Railway Systems. *Energies* **2019**, *12*, 1092. [CrossRef]
57. International Union of Railways. *Technologies and Potential Developments for Energy Efficiency and CO<sub>2</sub> Reductions in Rail Systems*; Technical Report; International Union of Railways: Paris, France, 2016.
58. Gunsellmann, W. Technologies for increased energy efficiency in railway systems. In Proceedings of the 2005 European Conference on Power Electronics and Applications, Toulouse, France, 11–14 September 2005; IEEE: Dresden, Germany, 2005; p. 10. [CrossRef]
59. Tolliver, D.; Lu, P.; Benson, D. *Analysis of Railroad Energy Efficiency in the United States*; North Dakota State University, Upper Great Plains Transportation Institute, Mountain-Plains Consortium: Fargo, North Dakota, 2013. Available online: <https://www.ugpti.org/resources/reports/downloads/mpc13-250.pdf> (accessed on 1 July 2021).
60. Lipsy, P.Y.; Schipper, L. Energy efficiency in the Japanese transport sector. *Energy Policy* **2013**, *56*, 248–258. j.enpol.2012.12.045. [CrossRef]
61. Hayashiya, H. Recent Trend of Regenerative Energy Utilization in Traction Power Supply System in Japan. *Urban Rail Transit* **2017**, *3*, 183–191. [CrossRef]
62. Bärmann, A.; Martin, A.; Schneider, O. Efficient Formulations and Decomposition Approaches for Power Peak Reduction in Railway Traffic via Timetabling. *Transp. Sci.* **2021**, *55*, 747–767. [CrossRef]
63. European Transport Policy for 2010: Time to Decide. White Paper. Available online: [https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2001\\_white\\_paper/lb\\_com\\_2001\\_0370\\_en.pdf](https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2001_white_paper/lb_com_2001_0370_en.pdf) (accessed on 14 April 2021).
64. Crozet, Y. Rail freight development in Europe: How to deal with a doubly-imperfect competition? *Transp. Res. Procedia* **2017**, *25*, 425–442. [CrossRef]
65. Katz, M.L.; Shapiro, C. Network Externalities, Competition, and Compatibility. *Am. Econ. Rev.* **1985**, *75*, 424–440.
66. Council of the European Communities. Council Directive on the Development of the Community's Railways. 1991. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31991L0440&from=EN> (accessed on 14 April 2021).
67. Directive 98/5/EC of the European Parliament and of the Council of 16 February 1998 on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification. In *Core EU Legislation*; Bloomsbury Publishing: London, UK, 1998. 22. [CrossRef]
68. Friebel, G.; Ivaldi, M.; Vibes, C. Railway (De)Regulation: A European Efficiency Comparison. *Economica* **2010**, *77*, 77–91. [CrossRef]
69. Ait Ali, A.; Eliasson, J. European railway deregulation: An overview of market organization and capacity allocation. *Transp. A Transp. Sci.* **2021**, 1–25. [CrossRef]
70. Posner, H. *Rail Freight in the USA: Lessons for Continental Europe*; Technical Report; Community of European Railway and Infrastructure Companies: Brussels, Belgium, 2008.
71. European Rail Infrastructure Managers. EIM Position Paper on Energy Meters on Electric Trains. Available online: <https://eress.eu/media/38232/eim-position-paper-on-energy-metering-on-electric-trains.pdf> (accessed on 14 April 2021).
72. European Rail Infrastructure Managers. EIM Position Paper on Cross Acceptance of On-Board Energy Measuring Systems. Available online: <https://eress.eu/media/1064/eim-cross-acceptance-of-energy-measuring-systems.pdf> (accessed on 14 April 2021).
73. Gatti, A.; Ghelardini, A. The European Energy Measurement System on board trains. In Proceedings of the 9th World Congress on Railway Research, Challenge A: A More and More Energy Efficient Railway Session A4—Energy Efficiency, Lille, France, 22–26 May 2011.
74. Urząd Transportu Kolejowego [Polish Office of Rail Transport]. Podsumowanie 2020. Przewozy Pasażerskie i Towarowe [Summary of 2020. Passenger and Freight Transportation]. Available online: <https://utk.gov.pl/pl/dokumenty-i-formularze/opracowania-urzedu-tran/16653,Podsumowanie-2020-przewozy-pasazerskie-i-towarowe.html> (accessed on 14 April 2021).
75. Eurostat. Modal Split of Passenger Transport. Available online: [https://ec.europa.eu/eurostat/databrowser/view/t2020\\_rk310/default/table?lang=en](https://ec.europa.eu/eurostat/databrowser/view/t2020_rk310/default/table?lang=en) (accessed on 14 April 2021).
76. Eurostat. Modal Split of Freight Transport. Available online: [https://ec.europa.eu/eurostat/databrowser/view/t2020\\_rk320/default/table?lang=en](https://ec.europa.eu/eurostat/databrowser/view/t2020_rk320/default/table?lang=en) (accessed on 14 April 2021).
77. Fitzová, H. European railway reforms and efficiency: Review of evidence in the literature. *Rev. Econ. Perspect.* **2017**, *17*, 103–120. [CrossRef]
78. European Commission. *Answer Given by Ms Vestager on Behalf of the Commission*; European Commission: Brussels, Belgium, 2015. Available online: [https://www.europarl.europa.eu/doceo/document/P-8-2015-012731-ASW\\_PL.pdf](https://www.europarl.europa.eu/doceo/document/P-8-2015-012731-ASW_PL.pdf) (accessed on 14 April 2021).
79. Staszek, M. Relacje z interesariuszami w ramach modelu odpowiedzialności społecznej przedsiębiorstwa na przykładzie DB Cargo Polska [Relations with stakeholders within the corporate social responsibility model based on the example of DB Cargo Polska]. *Etyka Biznesu Zrównoważony Rozw. Interdyscyplinarne Stud. Teoretyczno-Empiryczne* **2020**, *3*, 7–21.



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80. Kolejowi Przewoźnicy Towarowi w Polsce. *Badanie Przewoźników, Którzy Licencje Uzyskali w Latach 2013–2020 [Rail Freight Carriers in Poland A Survey of Carriers That Were Licensed between 2013 and 2020]*; [Polish Office of Rail Transport]; Technical Report; Urząd Transportu Kolejowego: Warszawa, Poland, 2021.
  81. Jabłoński, A.; Jabłoński, M.; Staszek, M. Studium przypadku: Integracja systemu controllingu z systemem zarządzania jakością na przykładzie przedsiębiorstwa usługowego [Case study: Integration of controlling system with quality management system on the example of a service company]. *Control. Rachun. Zarządcza* **2005**, *9*, 12–17.
  82. Jabłoński, A.; Jabłoński, M.; Staszek, M. Studium przypadku: Organizacja systemu informacyjnego controllingu w grupie kapitałowej [Case study: Organization of controlling information system in a capital group]. *Control. Rachun. Zarządcza* **2006**, *1*, 18–27.