IS THE EUROPEAN INFRASTRUCTURE READY FOR LONG HAUL ELECTRIC TRANSPORTATION? AN ANALYSIS OF A FREIGHT TRANSPORT FROM ROMANIA TO GERMANY USING AN ELECTRIC SEMI-TRAILER TRUCK

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Abstract: The heavy-duty vehicle sector is responsible for over 25% of the greenhouse gas emissions generated by road transport in the EU. In order to achieve their ambitious objectives stated in the” Fit for 55” Package, the European Institutionshave to provide the legal framework, that will compel the member states to assure the infrastructure to support the transition towards more sustainable modes of transport, and to put the Union on track for the full decarbonization of the transport sector by 2050. Thus, the new Alternative Fuels Infrastructure Regulation (AFIR) – part of”Fit for 55” Package,has to ensure there is sufficient public charging infrastructure to follow the deployment of zero emission cars and semi-trailer trucks. Accordingly, the top ranked European semi-trailer truck makershave to align their industrial plans and business activity to fully transition to zero-emission semi-trailer truck sales. The purpose of this analysis is to evaluate the possibility of a heavy-duty electric semi-trailer truckto carry out a trip on a frequent commercial route between Romania and Germany. The scientific paper is based on an analysis in the form of a case study generated on the basis of a theoretical requirement. The results will show to what extent electric vehicles and infrastructure are ready for this type of transport. After results examination, we found that our findings overlap with the literature and that there is still much room for improvement in this area. Major changes are needed, namely additional investments in infrastructure and subsequent detailed analyses of the opportunity to develop the use of electric vehicles..

Key words: battery electric trucks, European infrastructure, electric long-haul trips, AFIR regulation, zero emission vehicles, electric charging stations.

1. INTRODUCTION

The heavy-dutyvehicle (HDV) sector is responsible for over 25% of the greenhouse gas emissions from road transport in the EU. CO_2 emission standards for

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certain heavy-duty vehicles were first set in 2019, with targets for the period 2025-2029 and for the period after 2030, with a provision to review these regulations by 2022 [1].

On the 14th of February 2023, the Commission presented a proposal to revise the CO_2 emission standards for heavy-duty vehicles. Although the proposal is not part of the" Fit for 55" legislative package, it is closely linked to it as it contributes to the EU's target of reducing its net greenhouse gas emissions by at least 55% by 2030 compared to levels of 1990 and to achieve climate neutrality by 2050. The main proposed changes relate to the extension of the scope of the regulation to include buses and trailers, the definition of the term "zero emission vehicle" and the new EU emission reduction targets for 2030, 2035 and 2040 [1].

Even though, from an economic point of view, road transport is indispensable, acting as a backbone of trade, facilitating the movement of goods within and outside the EU (European Union), its environmental footprint is substantial: heavy vehicles account for less than 5% of on European roads, but are responsible for around 25% of carbon dioxide (CO_2) emissions from road transport and around 2–4% of total EU emissions. Despite the overall decrease in CO_2 emissions in various sectors in the EU, semi-trailer truck emissions have increased steadily over the last three decades (1990-2020), except for a short decrease in 2020 due to the COVID-19 pandemic. The sector's considerable greenhouse gas emissions underline its dual role as an economic catalyst and significant environmental threat [2].

Electrification quickly emerged as a potential solution to this challenge. Although there is no clear technological method for electrifying road freight transport to date, potential solutions include the direct use of electricity in battery-powered semi-trailer trucks and fuel cell semi-trailer trucks powered by green hydrogen from renewable electricity [3].

The EU supports the electrification of the transport sector through the "Fit for 55" legislative package, which aims to implement legal provisions, mandatory for the member states, which have the effect of reducing greenhouse gas emissions by at least 55% by 2030 [4]. By transitioning from predominantly diesel-powered semi-trailer trucks to electric ones, the aim is to significantly reduce direct emissions. In addition, as electricity grids continue to go green – thanks to the growing share of renewable energy – the estimated emissions reductions from electrified road freight transport continues to grow. While the conversion rates to electric semi-trailer trucks currently available on the commercial market in the EU is less than 1% of total vehicle sales, as indicated by the sales figures of heavy vehicle manufacturers, according to the standards of existing CO_2, there could be more than 600,000 such vehicles on European roads by 2030 [5].

Semi-trailer trucks deliver essential goods to consumers and keep society moving. They provide most of our daily needs, such as food or medical supplies. In addition, they support essential public services such as construction, garbage collection and firefighting and rescue services. Semi-trailer trucks are also the foundation of the European logistics and transport system. The demand for freight transport is increasing and all modes of transport will need to continuously improve to meet the needs of the future. Road transport is expected to remain the most used mode of goods transport [6].

Why would it be more important to switch from semi-trailer trucks that use conventional fuels (diesel and petrol) to electric semi-trailer trucks? While cars are parked most of the time, semi-trailer trucks are mostly in motion. A semi-trailer truck can easily drive up to 150,000 kilometers per year – 12 times more than a passenger ca [7]. For this reason, the scope of this paper is to analyze the sustainability of carrying out a transport of goods with an electric semi-trailer truck, in order to observe the existing advantages and disadvantages and to provide future improvement solutions.

2. METHODS AND SELECTION METHODOLOGY

In order to identify the current readiness of the long-haulroad freight with an electric semi-trailer truck, we designed a theoretical transport on an important commercial corridor from the industrial area of Sibiu to the industrial area of Munich, in Dingolfing. To reach the purpose of our study, we followed these steps: we selected a specific commercial road corridor in Europe, then we settled upon an electric semi-trailer truck, researched the legislation that regulates road freight transport, documented the charging stations and their capability to charge, on this specific route and the approximate costs to carry out this transport. This study tries to point out from both an economical and technical perspective the advantages and disadvantages of a battery electric semi-trailer truck. The same methodology was used for a diesel semi-trailer truck to establish a comparison in terms of route travel time and economic point of view.

2.1. Selecting the route

In order to achieve its the zero emission policies, the European Commission issued a regulation called AFIR -Alternative Fuels Infrastructure Regulation [4]. In accordance with the provisions of this regulation, a plan is established for the development of charging points so that semi-trailer truckscharging infrastructure will be located along the Trans-European Transport Network (TEN-T), which spans over 108,000 km of road network across the EU [8].

The TEN-T road network, as provided for in Article 9 of Decision 661/2010/EU, consists of existing, new or to be adapted high-quality motorways and roads, which:

- play an important role in long-distance traffic;
- bypass the main urban centers on the routes identified by the network;
- ensures interconnection with other modes of transport;
- connects the landlocked and peripheral regions with the central regions of the Union [8].

In addition to those listed above, the network should guarantee users a high, uniform and continuous level of service, comfort and safety. It also includes infrastructure for traffic management, user information, incident and emergency handling and management, electronic toll collection, or such infrastructure being based on active cooperation between European, national and regional traffic management systems [5]. Thus,we considered that choosing a route on the TEN-T core network, will be highly relevant for our study. As shown in figure 1(Corridor 9-Rhine-Danube of TEN-T – light blue color on figure), our transport will start inCristian (Sibiu) –Arad –Budapest–Vienna - Passau and willl end in Dingolfing (Munich) – 1.160 km [8].

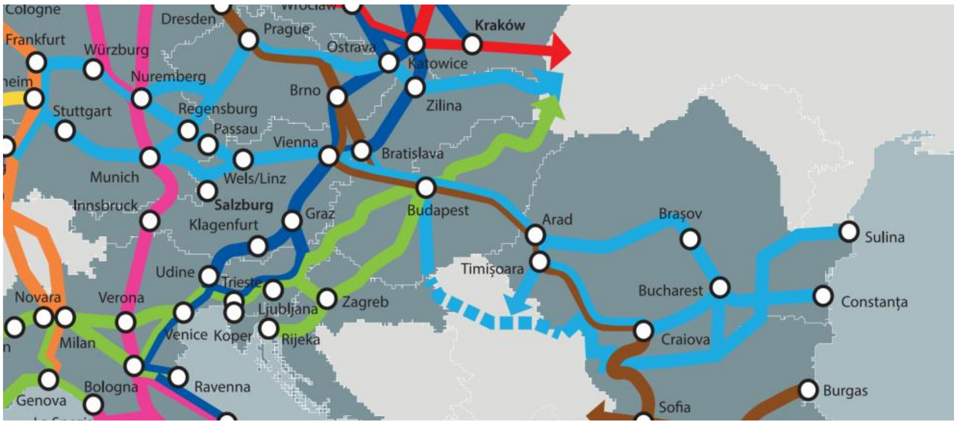

Fig. 1. The selected route integrated in the Corridor 9-Rhine-Danube of TEN-T[8]

2.2. Selecting the means of transport

The latest report of the expert group within [9] declared that Scania, Mercedes-Benz and Man semi-trailer trucks, are the three European frontrunners based on theirannounced ambition, strategy and readiness. All three aim for 100% new zero-emission semi-trailer truck (ZET) sales by 2040or earlier. Volvo semi-trailer trucks is the current market leader in battery-electric semi-trailer truck sales in Europe and themanufacturer with the most ambitious 2030 target (70% ZET sales share).Renault semi-trailer trucks and IVECO Groupare lagging behind in the transition. DAF closes the ranks with a very weak score, having no public ZETtarget for 2030. We selected four of these manufacturers, namely, Scania [10], Mercedes-Benz [11], Volvo semi-trailer trucks [12] and Renault semi-trailer trucks [13] and formally, requested the technical data and price offers through their official Romanian dealers, in order to decide which electric semi-trailer truck trailer is more suitable for the long haul between our point of departure and destination. First, we singled out the essential features presented in the technical data sheets as shown in the table 1 and secondly, a criterion analysis was carried out, taking into consideration the lowest purchase price, the highest range, the shortest time of charge and the longest period of warranty. Therefore, the best option for the task was Mercedes-Benz eActros 600 LS.

2.3. Identifying long-haul semi-trailer truck trips

In this study, we focus on BETs that use public chargers to reach their destination, including a single charge at the point of departure, e.g., depots [14]. We must consider the fact that [15] define HDVs long-haul, if they have a travel period of around 333 km using average travel speed on German roads and a buffer distance, resulting in 4.5 hours. In another paper, [16] use 350 km as a distance threshold and

[17] define a trip as being long-haul, ifit exceeds distances over 400 km. In our study, we follow the frequently used distance-based definition of "long-haul operation" that considers point of origin and destination with travel times over4.5 h or 360 km distance traveled using the typical average speed of semi-trailer trucks of about 80 km/h [14].

Table 1. ***Criterion analysis for the selection of an electric semi-trailer truck trailer***

Brand / **Features**	**Mercedes eActros 600 LS**	**Scania R400E**	**Volvo FH 42**	**Renault E-tech T**
Year of production	2024	2023	2023	2023
Purchase price *	320.000	365.000	392.000	350.000
Maintenance interval(km)	120.000	120.000	120.000	120.000
Range(km)	500	320	300	300
Charging time from 20-80%**	1 h	2 h	2 h and 30'	1 h and 20 '

*The prices are Euro and do not include VAT (value added tax).
** At direct current (DC) stations with a charging power of at least 135 kWh (kilowatt-hour).

2.4. Break and rest assumptions

We try to estimate the remaining range of the electric semi-trailer truck batteries on each main segment of the road, in order to recharge on time, before the batteries run lower than 20%, meanwhile we also applied the provisions of Regulation (EC) No 561/2006 of the European Union, which states that the daily driving period must not exceed 9 hours and drivers should stop driving at least 45 minutes, after a 4.5-hour continuous drive. Those two periods of time charging/driver's break did not, always, overlap.

2.5. Charging infrastructure

The selected electric semi-trailer truck has a charging capacity of 400 kW per hour at an average CCS Type 2 (Type 2 is standard for European and Asian vehicles from 2018 onwards, it's a triple-phase plug and can charge at a level of up to 43 kW;Combined Charging System is a version of type 2 with two additional power contacts allowing fast charging) charging point, resulting an approximate 60 minutes time frame to charge from 20% to 80% [18] and a 4-hour charging time, if the charging point has a100-kW output socket. Therefore, it is imperative to planand indicate in advance, the stations, which will mandatorymeet two conditions simultaneously:

- A loading power of at least 100 kw per hour;
- Access to the charging station as a semi-trailertruck.

2.6. Charging infrastructure

The average energy consumption rate for BETs varies significantly depending on a variety of factors. ICCT [19] and Suzan & Mathieu [17] consider that the energy efficiency of new semi-trailer trucks entering the fleet will reach 1.2–1.23 kWh/km in 2030. Speth [15] notesan energy consumption of 1.23 kWh/km. In their study, Lin and Zhou [20] use real-world driving data of energy consumptionfrom 18 electric semi-trailer trucks and found energy consumption of 0.80–1.20 kWh/km on urban roads and 1.30–1.80 kWh/km onhighways. Mareev [16] also find that real-world BET energy consumption rates are between 1.23 kWh/km and 1.94 kWh/km,depending on speed limits and road type and Al-Hanahi [21] pointed outtheenergy consumption of the BETs is between 1 and 1.75 kWh/km. The manufacturer Mercedes-Benz technical data report a 500 km range and 600 kWh of usable battery capacity, resulting a 1.2 kWh/km consumption, for our selected semi-trailer truck.

Table 2. ***The structure of the selected route and the consumption of the electric semi-trailer truck***

No.	**Road Category**	**Road Segment**	**Dist. [km]**	**Time [h and min]**	**Consumption [kWh]**	**Remained range [km]/ Capacity[kW]**		**Elapsed Time from departure [min]**
1.	National Road DN1 /DN7H	Cristian – Calea Șurii Mici	13.7	12'	16.44	**500** 486.3	**600** 583.5	12'
2.	Highway A1	Calea Șurii Mici – Coșevița	142	1h 46'	170.4	344.3	413.1	118'
3.	National Road DN68A	Coșevița - Margina	15	18'	18	329.3	395.1	136'
4.	Highway A1	Margina - Nădlac	157	1h 56'	188.4	172.3 **297**	206.7 **356,7**	252*+ 60'=312'
5.	Highway M43	Nădlac - Szeged	57	43'	68.4	240	288.3	369'
6.	Highway M5	Szeged - Gyál	137	1h 43'	164.4	103	123.9	472'**
7.	Highway M0	Gyál-Törökbálint	30	20'	36	**400** 370	**480** 344	492'+60'= (charging)= 552
8.	Highway M1	Törökbálint-Nickelsdorf	157	1h 57'	188.4	213	155.6	552'+60'+660'=1272***
9.	Highway A4	Nickelsdorf-Mannsworth	57	43'	68.4	156 **400**	87.2 **480**	1351'****+ 120'=1471'
10.	Express road S1	Mannsworth Vosendorf	18	13'	21.6	482	458.4	1484'
11.	Highway A21	Vosendorf-Hinterleiten	38	28'	45.6	444	412.8	1522'

12.	Highway A1 - A25	Hinterleiten-Passau	162	2h	194.4	282 **416**	218.4 **500**	1642'***** +60' (charging)= 1702'
13.	Highway A8 – A3	Passau-Deggendorf	128	1h 36'	153.6	288	346.4	1798'
14	Highway A92	Deggendorf-Dingolfing	45	32'	67.5	243	278.9	1830' = 1 day 6h 30'

At the point of origin, Cristian (Sibiu), the electric semi-trailer truck trailer will be fully charged, according with the Romanian provider tariffs, which are calculated depending on consumption thresholds as in equation 1 [22].

$$C_0 = 0{,}26 \text{ Euros} \times 500 \text{ kW} = 130 \text{ Euros} \qquad (1)$$

where C represents the charging cost, calculated according to each transitcountry/provider.

On the chosen route, we will pass through Hungary, Austria with the final destination Germany, so we will calculate the rate for 1 kWh, as we will find it on the Plugshare application - for Romania and Hungary and the Smatrics application[23] - for Austria and Charge Finder [24] in Germany.

* a stop is mandatory for the driver to take his mandatory 45-minute break, after crossing the border at Nădlac. At the MOL Magyarcsanád filling station, right after entering Hungary on the M43, there is a high-power charging station (equipped with CCSType 2, power output = 11-150 kW, DC charging costs – 309 Ft/ 1kWh + 1 Ft/ 1kWh after 30 minutes), where Ft represent the abbreviation for Forint, which is the Hungarian official currency.

During the break, for efficiency reasons, it will last for an hour, so the driver can rest and the semi-trailer truckcan charge.

SoC_1 = 206.7kW, we will charge the batteries with 150 kW, where SoC – state of charge.

$$C_1 = (309 \times 150) + (1 \times 30) = 46{,}350+30=46{,}380 \text{ Ft.}=117 \text{ Euros} \qquad (2)$$

** another battery charge will be necessary, immediately after entering the M0, because, we haveat our disposal, the Shell Szigetszentmiklós, high-power station (equipped with CCS Type 2, a power output of 350 kW, DC charging cost 280 Ft/kWh), where it also accepts trailers, a fact clearly mentioned in the application:

SoC_2=120 kw, charging time – 1 h, to achieve a 480 kW

$$C_2 = 360\text{Ft} \times 280 \text{ kW} = 100{,}800 \text{ Ft.} = 254 \text{ Euros} \qquad (3)$$

*** after one hour of driving, the driver will perform the mandatory 11-hour rest period in the first parking place arranged for this purpose, after which, at the end of this period, he will continue the journey to the border with Austria, without loading.

*Charging is required, we have a high-power station (equipped with CCS Type 2, power output = 200kW) near Lidl, before entering the Vienna ring road, where we will charge up to 80%, DC charging cost:

SoC_3= 87.2 kW, we will also correlate the mandatory 45-minute driver break with the 2-hour charging period.

$$C_3=9.90\ Eur.\ (pass/month) + 392{,}8\ kW\times 0{,}65\ Eur. + 29\ '\times 0{,}15\ Eur. = 270\ Eur. \quad (4)$$

**** When entering Passau we will charge, at OMV, at a high-power station (equipped with CCS Type 2, power output = 350kW, DC cost = 0.69 Euro/kWh, where we will charge up to 80%, SoC_4=218.4 kW, after one hour of charging we will reach almost 500 kw.

$$C_4=281\ kW\times 0.69\ Euros = 194\ Euros \quad (5)$$

$$Total\ cost\ with\ charging\ (on\ route) = 117 + 254 + 270 + 194 = 835\ Euros \quad (6)$$

$$Total\ cost\ with\ charging\ per\ transport = 130\ Euros + 835\ Euros = 965\ Euros \quad (7)$$

Meanwhile, for the diesel HDV, applying the same methodology, on the exact, same route, we have the following results: a) after 4 hours and 12 minutes of driving, the semi-trailer truck driver will take the mandatory break, provided by the law; b) upon entering Austria, at Nickelsdorf, the driver must take the mandatory 11 hours of rest after the 9 hours of driving; c) upon entering Germany, in Passau, the driver will have a 15-minute break, after which he will continue the route to the destination.

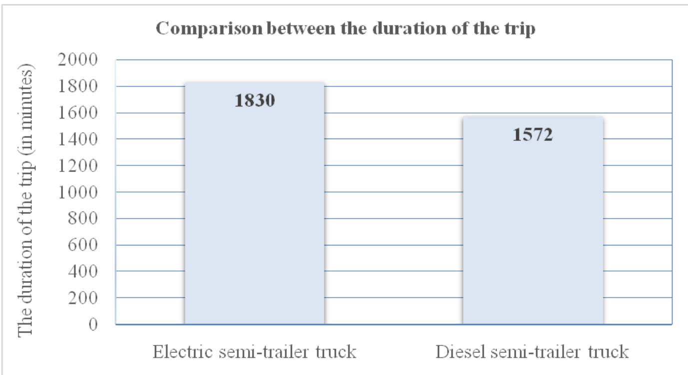

Fig. 2. The duration of the trip with the electric semi-trailer truck and with the diesel semi-trailer truck

The diesel semi-trailer truck was fueled at the point of departure, in Cristian,at the OMV Station, [25], where a liter of diesel costs 1.44 Euros/liter andthe total cost for the fuel supply was 1.600 Euros(the tank has a 1.110 diesel liters capacity).Taking into consideration that the consumption of Mercedes Actros 5 LFHS 1848 is 27 liters/100 km, as stated in the technical data sheet, and the consumption estimated for the 1.160 km of is 300 liters, the total cost with fuel per transport is 432 Euros.

The duration of the trip with an electric semi-trailertruck trailer was 1 day, 6 hours and 30 minutes, whilethe duration of the trip with a diesel semi-trailer truck trailer lasted 1 day, 2 hours and 12 minutes. The difference is not that big as shown in figure 2, but that is a relative fact, due to the fact that the research had its limitation as regards to the period of the trip.

4. DISCUSSIONS

The analysis of long-haul freight transport with an electric semi-trailer truck has highlighted several weaknesses of this mean of transport, but above all, deficiencies in the high-power charging infrastructure and legislative loopholes, which will discourage hauliers from converting their diesel semi-trailer truck fleets to electric propulsion. Reducing the negative effects of these problems and improving them would make electric freight transport cost-effective and sustainable.

4.1. Lack of high-power charging stations

There are two key factors for the widespread use of battery electric commercial vehicles: increased range and shorter charging times. Charging time, which can be quantified as distance per unit of time charged, should be considered for the whole fleet and should also take into account lost charging time due to late charging or even problems related to charging equipment (i.e., long queues, overheating, faulty errors). The implementation of the MCS (Megawatt Charging System – very fast high power charging system) provides the charging rate needed to achieve widespread adoption of battery electrification in the commercial vehicle market by increasing driving range gained per minute spent charging [26]. Commercial vehicle customers have very specific driving patterns. The increased charging rate offered by MCS will allow customers to cover as much distance as possible per day, using the mandatory break time in the hours-of-service regulations.

These regulations require drivers to take an occasional break during their driving cycle; the exact amount varies by location, but it is well understood that reducing charging times to fit within normal duty cycle breaks is an enabler for improved electrification for commercial vehicles. This is just one specific example of how the MCS charging rate can activate the market [26]. We must note the lack of any MCS along the analyzed route (neither charging application indicated the MCS).

4.2. The small number of special places for charging a semi-trailer truck semi-trailer at existing stations

Another challenge an electric semi-trailer truck driver faces is the space required at the charging point, when driving a semi-trailer truck. Given that the length of an assembly is approximately 15 meters or more, it is important to choose a charging station that allows access and has the necessary space, without inconveniencing the other vehicles, located in the perimeter. So, it is imperative to plan the transport route in detail and indicate the stations ahead, which will have to meet two conditions cumulatively: charging power of at least 100 kWh and access for a semi-trailer truck.

In our case, we identified only14 stations that meet these conditions (as in figure 3), with the help of the Plug Share application, which facilitates the location of the charging stations, the application of filters, according to the requirements of the situation. These stations, are not evenly spread, a fact that discourages electric road freight. Of course, there are other types of charging points, with less output power, but they are neither next to the highway, nor they allow semi-trailer trucks. Transport managers must calculate the stopping points for the drivers to charge both exactly and preventively. Still at this moment in time, there is not an electric semi-trailer truck with enough range that could cross this road segment without having to charge [27].

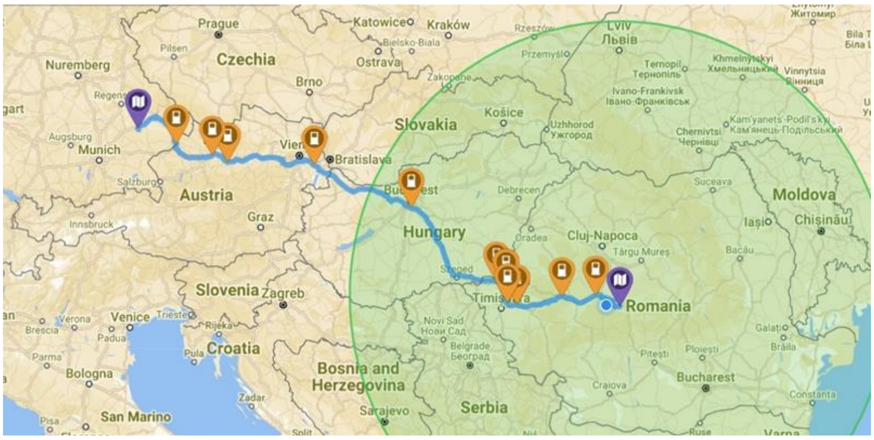

Fig. 3. Fast charging stations on the selected route

4.3. Unpredictability of charging station prices depending on ownership

As shown in figure 4, the charging cost with electricity is twice as high as the fuel supply cost for a transport, i.e., Cristian-Dingolfing, these costs will be doubled, when returning Dingolfing-Cristian.

If the price of diesel is somewhat predictable, with little fluctuation from one country to another (in our case study, there was no need to refuel, due to the tank large capacity), the price of electricity is calculated differently, depending on several factors:

• The state, on whose territory the charging station islocated and the rates regulated per kWh;

• The owner of the charging station;

• Effective charging time; there are stations, where, after a determined period of time, every minute spent at the charging point will be reflected in the final cost, aside the price of the kWh;

• The existence or not of a subscription; the tariffs without a subscription, are not profitable, at all.

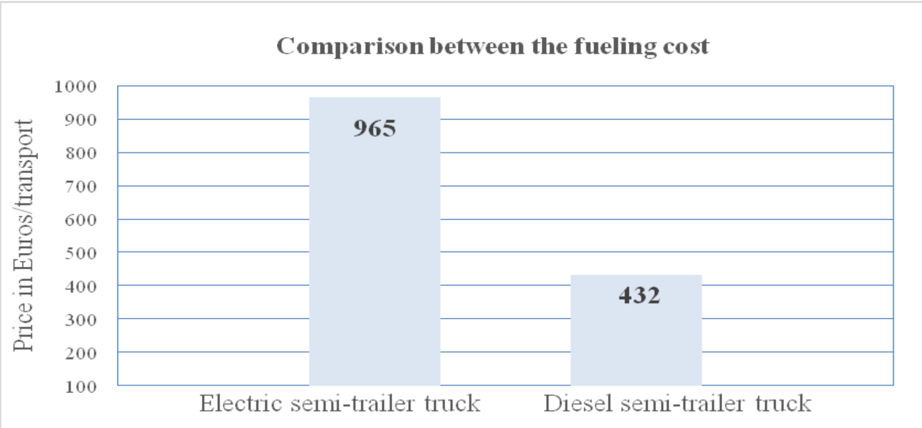

Fig. 4. The difference between fueling costs

As a solution to improve and encourage the use of electric semi-trailer trucks, we propose the development of a common kWh pricing policy at the level of the European Union, so that the carrier has, to a certain extent, the highest possible predictability and stability of the current price.

4.4. Lack of regulations on road tolls and property taxes

In order to encourage the purchase of electric passenger vehicles, the EU member states have granted various facilities, such as exemption from taxes and duties due to local authorities or special parking spaces or even the freeparking spaces.

At the level of HDV, there is not, at this moment, in Romania, nor at the European level, a clear policy that provides facilities for them. There was, at one point,a debate at the level of the decision-making forums of the EU, to eliminate road taxes (vignette, toll collection) for electric semi-trailer trucks, but it did not materialize, in a legislative act, to regulate this field, at the European level, so for the moment, there no road toll exemptions.

Also, the property taxes, which are quite high, in Romania, HDVs remained without a special regulation, so that, for now, at least on the Romanian territory, the law does not distinguish between an electric semi-trailer truck and a conventional fuel semi-trailer truck. Considering the other disadvantages that arise from the purchase of an electric semi-trailer truck, we can conclude that they are not a cost-effective solution, neither for the transporter nor for the end customer, who will feel all these additional costs in the final price of the product.

4.5. The inefficiency of purchase incentives, considering electric HDVs high prices

In Many European countries offer tax support to stimulate the market uptake of electric commercial vehicles, but these tax advantages and purchase incentives differ greatly from one member state to another [28].

Some states grant these benefits for the purchase of passenger vehicles, for the purchase of electric semi-trailer trucks or electric buses, or for the development of charging infrastructure. Of course, there are states that grant benefits for all sectors, but there are states that do not grant benefits at all for the electrification of road transport, among them we list: Hungary, Lithuania, Slovenia. Among the states with the biggest incentives for the purchase of an electric semi-trailer truck, we can mention: Austria, England, Belgium, Croatia, Cyprus, Finland, Germany, Iceland, Malta, Spain and Sweden [28].

As we can see in figure 5, an electric semi-trailer truck is 3 times more expensive than a diesel semi-trailer truck. Without the support of government funds or non-reimbursable funds granted by the European Commission, through its various programs or support packages, it will be impossible to convert heavy commercial vehicle fleets to the zero-emission restriction.

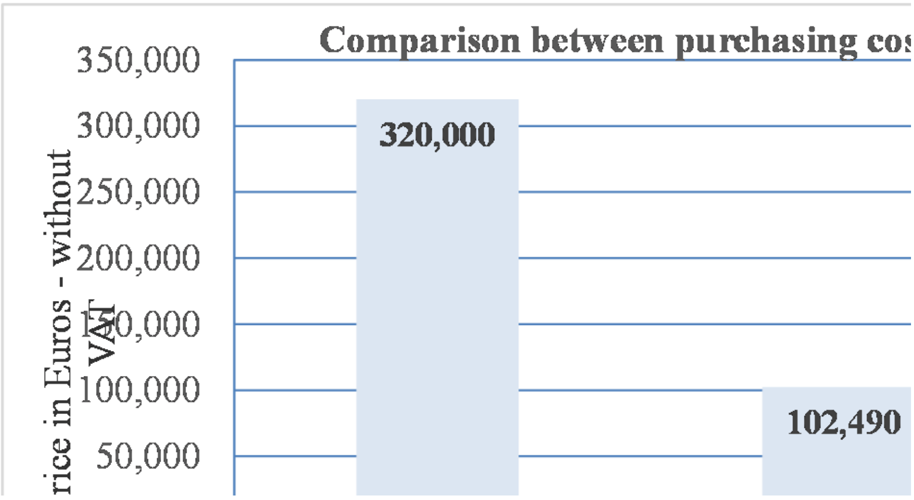

Fig. 4. The difference between purchasing costs

4.6. Unpredictability of trip duration due to a number of factors

Time plays a crucial role in the road transport of goods, being essential in the following aspects:

• Delivery efficiency: road freight must ensure pre-arranged deliveries, according to chosen deadlines. Thus, the consignee does not need to create safety stocks. This aspect eliminates excessive storage, the possible depreciation of goods during storage and the immobilization of financial resources for stocks.

• Cost reduction: Freight companies are looking for solutions to reduce costs and time to deliver goods.

• Influence on the cost of transportation: When referring to time as a factor influencing the cost of freight transportation, one must consider the transportation time, order time, delivery schedule, punctuality and frequency of runs.

• Legal regulations: there are legal regulations that control driving and rest time in the road transport of goods, legislated at the level of the member states. These are intended to ensure road safety and prevent driver burnout.

4.7. Limitations of the research

In conclusion, effective time management in road freight transport can lead to a number of benefits, including cost reduction, improved efficiency and compliance with legal regulations.

Given the vital importance of time in transport, our analysis could not identify to a scientific level of precision, the following issues that will cause unexpected delays, during a trip:

• The periods in which the mandatory breaks of the driver cannot be correlated with the battery charging period. In this situation, the transport time will increase, because at the moment, there is no regulation, which considers the charging period as a break and deducts it from the driver's service time.

• Waiting periods for performing customs formalities at state borders. The study carried out did not take into account the waiting time at the borders. It is known that there are queues, customs controls, which will cause delays, but the autonomy of the electric semi-trailer truck will be affected by these queues and therefore, most likely, at least one additional charge caused by these delays will be needed. An additional charge will result in higher costs and increased travel time.

• Battery charging time below 20% and above 80%. Electric semi-trailer truck manufacturers cannot estimate either the charging time, if the state of charge of the batteries drops below 20%, or the charging time required for the batteries to be fully charged. Therefore, if for various reasons, the driverlets the batteries drop below the 20% threshold, it will increase the charging time, which will generate additional costs and delivery delays.

• Route topography and weather conditions. Thermal extremes (too hot or too cold), as well as the differences in slope of the route, will play an important role on the state of charge of the battery, with direct effects on the transport time and charging costs. It is important to know these factors because they influence the range of the batteries to a great extent.

•Other types of costs such as: tires costs, tolls and insurance costs, drivers' salaries, miscellaneous other transport costs were not taking into consideration, although they were calculated, due to the fact their values are the same at some point or they differ slightly.

5. CONCLUSIONS

In the European Union, 732 electric semi-trailer trucks were sold in 2022 and 2.486 electric semi-trailer trucks in 2023 [6]. The number is not large, but it is a start. The models of electricsemi-trailer trucksare neither various, nor their autonomy is, on average, greater than 400 km, but the semi-trailer truck manufacturers have sensed the electrification trend of this sector and evaluate the necessary improvement solutions.

According to the data and analysis carried out in this study, it is not cost-sustainable to transport a certain quantity of goods on a major trade route with an electric semi-trailer truck at this moment in time. As presented infigures 3 and 4, the most important cost differences:the purchase cost and the supply cost for the two semi-trailer trucks are so great, that a transport company could not endanger their profits/survival by converting its diesel fleet, for decarbonization sake.

Considering that all the costs presented above and the delaying time risks will be reflected in theprice of the product reaching the final customer, it is reasonable to conclude that any product transported, at this moment, with an electric semi-trailer truck will not be able to be competitive or sustainable, due to the economical component of the sustainability.

Most certainly, technological developments at the level of charging infrastructure, diversity of models of semi-trailer truck heads, but also the development of legislation related to this new field, will change the balance in favor of electric semi-trailer trucks in the future.

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