IE592 – Graduation Project

Relationship between Fuel Demand and Freight Transport and Mileage of Non-Resident Trucks in Germany

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Abstract

Fuel consumption in the transportation sector is critical to economic and environmental sustainability. This thesis delves into a comprehensive analysis of diesel fuel consumption by Non-Resident Trucks patterns, focusing on Heavy Goods Vehicles (HGVs) in the European context, with a particular emphasis on Germany. The study employs a multidimensional approach, integrating time series analysis, regression modelling, and correlation analysis to unravel the intricate dynamics influencing fuel consumption by non-resident trucks in Germany. The methodology encompasses the collection of extensive datasets, incorporating mileage, toll data, fuel price differentials, and other pertinent variables. Time series analysis, including double exponential smoothing, reveals temporal patterns, while regression modelling dissects the multifaceted factors impacting fuel consumption; meanwhile, correlation analysis adds a layer of robustness to the findings, accounting for the variables involved in the methodology. Results from the analysis offer valuable insights into the correlation between domestic fuel consumption in Poland, Diesel fuel price differences between Poland and Germany and the fuel consumption of Polish trucks in Germany. The study examines the implications of this correlation on fuelling behaviours, shedding light on the intricate relationship between domestic consumption trends and cross-border fuelling practices. Also, the forecasting component utilises advanced modelling techniques to predict future fuel consumption trends, aiding stakeholders in strategic decision-making. The thesis concludes with a discussion of the practical implications of the findings, suggesting avenues for optimising fuel consumption, enhancing sustainability, and guiding policy decisions in the transportation sector. This research contributes to the growing body of knowledge on fuel consumption dynamics, presenting a nuanced understanding of the interplay between domestic consumption patterns and cross-border fuelling behaviours.

Dedication

I extend my heartfelt gratitude to my Parents, **Amer** and **Nadia Abu Daieh**, and I sincerely appreciate their unwavering support and shared journey. Your tireless dedication and collaborative spirit have been instrumental throughout my educational pursuits, spanning the challenging five-year journey between Amman and Frankfurt. This dedication is a testament to your profound impact; I aspire to make you proud with the culmination of this thesis.

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Table of Contents

List of Figures

List of Tables

List of abbreviations and variables

ARIMA	Autoregressive integrated moving average
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office for Economic Affairs and Export Control)
BALM	Bundesamt für Logistik und Mobilität (Federal Office for Goods Transport)
BMDV	Bundesministerium für Digitales und Verkehr – Kontakt (Federal Ministry of Transport and Digital Infrastructure)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EU	European Union
GVW	Gross Vehicle Weight
HGV	Heavy Goods Vehicle
KBA	Kraftfahrt-Bundesamt (Federal Motor Transport Authority)
SDG	Sustainable Development Goals
ViZ	Verkehr in Zahlen

1 Introduction

1.1 Overview

Germany is one of the world's leading economic titans within the Group of 20 [1], securing the fifth spot based on GDP [2]. It possesses a deep-seated comprehension of the imperative to tackle fuel consumption and CO_2 emissions within the expansive canvas of global climate transformation. The nation's leadership has dramatically decreased its ecological footprint, harmonising its diplomatic efforts with esteemed international accords like the Paris Agreement and the Sustainable Development Goals (SDGs) [3]. Notably, Germany assumed the role of a gracious host for the United Nations Climate Change Conference (COP23) in Bonn in 2017 [4].

Germany is pursuing the United Nations' Sustainable Development Goals (SDGs) [5]. It closely correlates with the SDGs, which are in Figure 1, with an unbreakable commitment that pulsates with sustainability, creativity, and social responsibility, especially in areas as important as clean energy (SDG 7), industry and innovation (SDG 9), and climate action (SDG 13). The nation's ambitious 'Global Energy Transformation Programme' (GET.pro), a masterstroke that directs the transition towards renewable energy sources and actively prunes greenhouse gas emissions, charts profound progress on the canvas of SDG 7 [6].

Additionally, Germany's commitment to innovative manufacturing, research and development, and wholehearted acceptance of sustainable practises inject new life into the achievement of SDG 9, fostering a vast and sustainable industrial sphere. Furthermore, Germany is a leading force in the worldwide pursuit of SDG 13. Due to its unwavering commitment to climate action, it is ready to tackle the consequences of climate change worldwide, strengthened by solid laws designed to reduce CO_2 emissions. Germany's commitment to these SDGs exemplifies its pioneering leadership in navigating the maze of complex global issues. In addition, it cultivates a more just, ethical, and sustainable world.

The Climate Action Goal (SDG 13) calls for urgent action to combat climate change and its impacts. Reducing fuel consumption, especially in transportation and industry, directly decreases greenhouse gas emissions, particularly carbon dioxide (CO_2), a primary driver of climate change. Actions to reduce fuel consumption align with several targets and indicators under SDG 13, including:

1. 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
2. 13.2: Integrate climate change measures into national policies, strategies and planning

3. 13.3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
4. 13.4: Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible.
5. 13.5: Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.

Reducing fuel consumption, particularly in the transportation sector, can significantly reduce CO_2 emissions and contribute to the global efforts to combat climate change and achieve the targets set out in SDG 13, which positively impacts other SDGs, such as those related to clean energy (SDG 7), sustainable cities (SDG 11), and responsible consumption and production (SDG 12), among others.

Figure 1 UN Sustainable Development Goals. Adapted from [5]

German Aerospace Center (DLR) is Germany's national aerospace, energy, and transportation research centre. DLR's purpose includes exploring the earth and the solar system, researching to protect the environment, creating environmentally pleasant technologies, and promoting mobility, communication, and security. DLR's research portfolio covers the four focus areas of aeronautics, space, transportation and energy, from basic research to innovative applications.

DLR's Institute of Transport Research investigates the interrelationships and interactions of transport, the economy, society, and the environment, which are integrative and systemic. It bases its research on analysing and modelling the mobility behaviour of private households and companies. Close partnerships exist with universities, research institutions, and national and international economic, administration, and political institutions. Significant customers of the institute are national ministries, the European Commission, associations, and leading industrial companies. The topics covered are maintaining mobility, protecting the environment, saving resources, and improving transportation safety.

The Federal Ministry for Digital and Transport (BMDV) publishes annually Verkehr in Zahlen (ViZ), which is a German term that means "Transportation in Numbers". It typically refers to a publication that includes annual values on investments in infrastructure and data on transport infrastructure, accidents, traffic volume, and performance to information on the daily mobility behaviour and emissions of Germans [7]. ViZ is a valuable resource for public research and the general public to gain insights into the current state and trends in transportation, helping inform decisions and policies related to transportation infrastructure and services: the DLR and the German Institute for Economic Research (DIW) are currently processing the Publication.

The connection between transportation, sustainability, and achieving the United Nations' SDGs is more critical than ever in a time marked by enormous environmental concerns and a need for sustainable solutions. This thesis sets out a scope at the intersection of these domains to understand the complex relationships between transport, its economic and sociological consequences, and their significant environmental impacts.

1.2 Problem Statement

An urgent problem appears in the Institute for Transport Research context, where the complex relationships among transport, economics, society, and the environment are comprehensively studied. Currently, the transport sector in Germany emits over 95% of its CO_2 emissions through road traffic [8]. The fact that road freight transport accounts for about 30% of these emissions based on fuel use adds to the concerning nature of this number [9]. As a result, solving this problem by switching to zero-emission vehicles and using renewable fuels has an enormous potential for reducing CO_2 emissions in the transportation sector.

A significant proportion of road traffic emissions are assumed to be attributable to freight transport. Sources that cannot be precisely verified think around fifty million tons of CO_2. 40% of the tollable mileage on the German trunk road network is performed by non-resident trucks.

Freight transportation in ViZ focuses on the data collected inside the German borders with a lack of focus on the non-resident trucks refuelling abroad (mainly to benefit from lower diesel prices in Eastern European countries) but then providing driving and transportation services in Germany (in the form of entry, exit, transit and cabotage journeys) as a result of that the institute seeks for validation for the fuel consumption numbers in Germany to achieve the country's goal with sustainable solutions.

As mentioned, there is a gap in ViZ that did not include the foreign trucks, so to fill the gap, Figure 2 can simplify the situation for the transport performance of HGV in Germany.

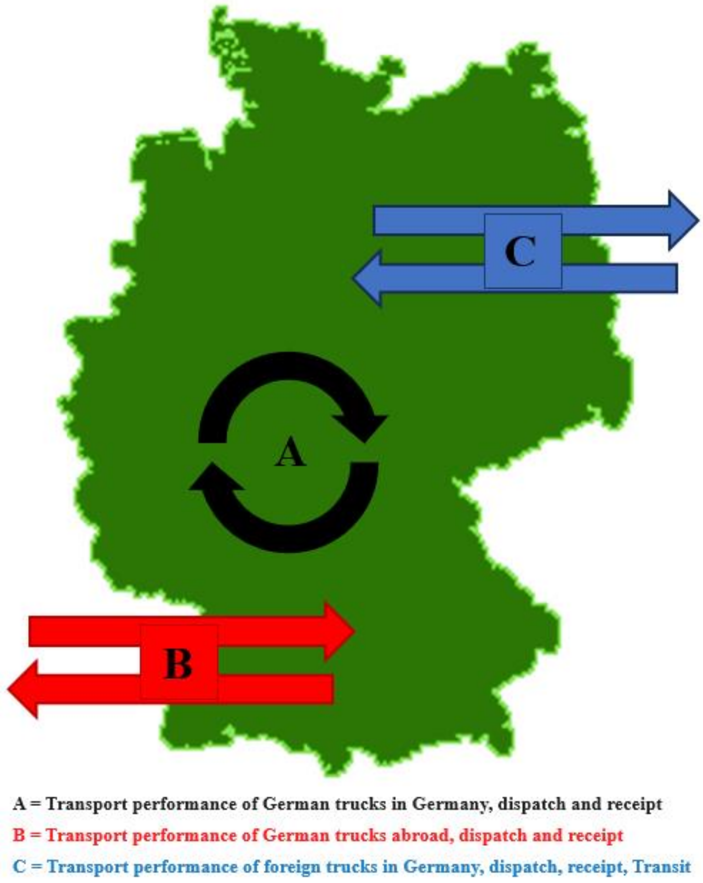

Figure 2 Transport performance in road freight transport.

ViZ data and the other data sets used in the fuel consumption calculations and fuel tanking in Germany are mainly based on estimations and sometimes surveys, which raise questions about the accuracy and validity of these estimations.

After comparing the fuel sales by the Federal Office of Economics and Export Control (BAFA) with the domestic consumption by the TREMOD emission model, it was clear that the gap between 1990 and 2018 diesel fuel consumption is higher with increasing years, which gives an explicit assumption that a significant number of trucks have the majority of diesel consumers import fuel more than sold in the country.

Federal Motor Transport Authority (KBA) statistics regarding foreign truck's mileage is more estimation than an accurate number or a systematic method that depends on a sample survey for each state and includes only European Union (EU) countries, Switzerland, and Norway without having other trucks from other nationalities. In contrast, Federal Office for Goods Transport (BALM) toll statistics include all foreign trucks on all federal highways by collecting the toll electronically with the expansion of the roads inclusive since it was presented in 2005.

1.3 Objectives

- Primary Goal: Establish a methodology for validating the accuracy of existing data for fuel consumption through new calculations.
- Secondary Goal: Understand and quantify relationships between road freight performance and heavy truck mileage in Germany and its European surroundings.
- Thesis Focus: Connect transport performance and fuel usage to achieve more environmentally friendly and sustainable transport practices.
- Challenges Addressed:
  a) Acknowledge the inherent complexity of predicting cross-border fuel consumption.
  b) Develop a solid data methodology for accurate quantitative analysis in the context of road freight transportation.
- Alignment with Sustainability (SDGs):
  a) Sustainability, a core principle of the SDGs, supports our investigation.
  b) Explore pathways for the transition to zero-emission vehicles and the utilisation of regenerative fuels in the road freight sector.
  c) Investigate policy and decision support as potential avenues for reducing CO_2 emissions and fostering a more sustainable transportation landscape.

2 Literature Review

A crucial part of this thesis is the literature review, which provides a complete overview of the current body of knowledge in calculating gasoline consumption by non-resident trucks and addressing the topic of tank tourism. This section seeks to completely comprehend the present status of research, theories, and empirical findings related to cross-border transportation and the complexities of fuel consumption estimation by examining and analysing the relevant literature. Significant insights, gaps, and contributions from prior studies were uncovered through this inquiry, laying the groundwork for building a solid framework and approach for this research undertaking.

2.1 Mileage and Fuel Consumption Calculation

The fuel consumption calculation plays a crucial part in CO_2 emissions estimations. This calculation involves mileage calculation based on a model calculation, differentiated by vehicle and drive types according to the national concept, then consists of a calculation model from many federal data sources [10]:

1. Central Vehicle Register (ZFZR): the Federal Motor Transport Authority (KBA) stores the vehicle and holder data of all vehicles with registration plates transmitted by the local registration authorities and additionally by the insurance companies, as well as the data of the central and safety inspections shared by the technical inspection institutions and plays a crucial role in ensuring the effective management and regulation of the national vehicle fleet [11]. This data is only related to passenger cars [10].

2. Tabulated NEDC (New European Driving Cycle) fuel consumption figures refer to the standardised values for fuel consumption generated through the NEDC test procedure. These values are typically compiled and published by the KBA. The NEDC test is designed to provide a standard method for assessing vehicle fuel consumption and emission levels, ensuring uniformity and comparability across different models and manufacturers. These tabulated figures serve as a reference for evaluating the fuel efficiency of vehicles and informing consumers about their expected performance under standardised driving conditions [12].

3. Test and standard consumption from Auto Motor und Sport (AMS): It describes the fuel consumption values obtained and reported by the automotive publication Auto Motor und Sport during their testing and assessment of various vehicles. These values are typically

standardised and represent the average fuel consumption measurements under specific driving conditions and parameters. AMS conducts thorough evaluations and tests to provide reliable and comparable fuel consumption data to help consumers decide when selecting and purchasing vehicles [13].

4. The Handbook of Emission Factors for Road Transport (HBEFA): for emission calculations in numerous studies and other applications, a standard data source provides emission factors for all current vehicle categories (PC, LDV, HGV, urban buses, coaches, and motorcycles), each divided into diverse types, for a wide variety of traffic situations. Emission factors include all regulated and the most critical non-regulated pollutants, fuel/energy consumption and CO_2. It is the product of a joint effort by funding agencies and development partners in six countries (Germany, Switzerland, Austria, Sweden, Norway, France) [14].

DLR structured a model for fuel consumption calculations as illustrated in Figure 3; national consumption results from multiplying the total mileage by average fuel consumption.

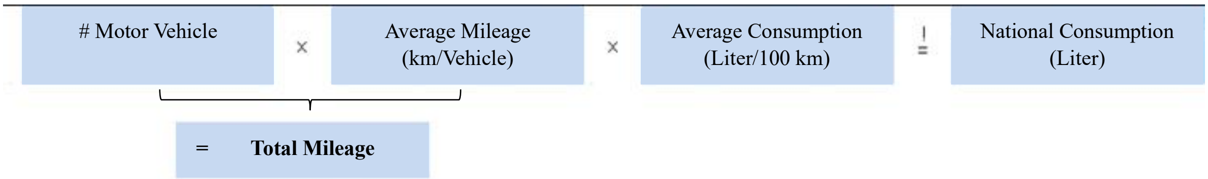

Figure 3 Calculation concept of the ViZ mileage calculation [10]

The ViZ calculation model performs detailed model calculations of the average mileage of all vehicle types and the average fuel consumption of the German passenger car fleet annually [10]. The computations yielded yearly mileage numbers separated by vehicle type. Furthermore, each vehicle type and year's total and average fuel consumption data are displayed [10].

In addition to sales quantities, the balances of imports and exports in cross-border traffic must be included in the overall fuel consumption of motor vehicles. BALM data from automated permanent counting stations at and near border crossings were analysed for this aim [10].

2.2 German HGV Toll

Until 1995, all vehicles were allowed to use German highways. Then, in 1995, Germany became a member of the Eurovignette system, which collects payments for the use of roads in several EU member states using time-based vignettes for heavy goods vehicles HGVs weighing more than 12t gross vehicle weight (GVW). The fees were determined in its final version in June 1999 based on the number of axles and the emission standards of the cars [15].

The federal government decided in August 2001 to introduce an electronic toll collection system on German motorways. The system's launch was scheduled for August 2003 but had to be postponed several times due to technical and organisational difficulties. Eventually, the system operated successfully in January 2005 [15].

A distance-based toll for heavy trucks was introduced in Germany on January 1, 2005. The toll obligation initially applied to trucks with a gross vehicle weight of twelve tons or more on the approximately 12,800 km federal freeways and a few national roads. Then, in October 2015, the toll obligation was reduced to a minimum permissible gross weight of 7.5 tons. In July 2018, it was extended to all federal roads, meaning the toll network now covers around 52,000 km. This has also increased the toll road sections from approximately 8,500 to over 141,000 km. This change often means that the annual figures are only comparable to a limited extent; weight categories were introduced in January 2019. This categorisation is compared with the former by the number of axles, especially for lighter commercial vehicles with a maximum permissible weight between 7.5 and 18 tonnes [16].

2.3 Comparison of BALM toll statistics and KBA statistics

The problem can be recognised in the very different rates of change. Notably, in 2018, but also the years 2009 to 2011 and 2013, the differences are too significant to be due to different delimitations. A sample survey such as the KBA road haulage survey contains uncertainties compared to an almost complete toll survey. Calculating the respective inland kilometres according to the distance work can also lead to deviating results. However, it becomes problematic if the differences in the rates of change become very large or even, as in 2018 (and also in 2009 and 2011), have different signs. In addition, it seems implausible that the KBA results are higher than the toll statistics 2017 and significantly lower in 2018 [17].

In addition to the highly different rates of change, there are also implausible differences in the order of magnitude for some countries. When comparing countries, the KBA statistics should be higher than the toll statistics, as they include smaller lorries and additional roads. The toll statistics for Romania are around twice as high in all three years - even if the KBA for Romania does not record empty journeys, this is entirely implausible. The KBA statistics for other countries (especially the Czech Republic, Belgium, Bulgaria, Estonia and Portugal) are also significantly lower in some cases. This problem was exacerbated in 2018 [17].

Table 1 Difference between toll statistics and KBA statistics. Adapted from [17]

	2016 (Mkm)	**2017 (Mkm)**	**2018 (Mkm)**
Belgium	24	14	36
Bulgaria	128	204	355
Estonia	26	37	43
France	-18	-14	1
Poland	-975	-1,377	-336
Portugal	23	42	44
Romania	549	578	636
Slovakia	-74	-167	-83
Czech Republic	373	559	739

Poland is critical in terms of foreign road freight transport. In 2018, Poland accounted for around 40 - 45 % of the total volume of kilometres driven. In terms of the additional transport performance (tonne-kilometres) reported by the KBA, this figure is almost 50%. The rates of change for road freight transport from Poland had different signs in the toll statistics and the KBA statistics in 2018: +9.3% in the toll statistics and -8.2% in the KBA statistics. Due to Poland's particular importance, such contrasting developments significantly impact the presentation of overall traffic.

2.4 Fuel Different Prices Impact

A case study in Switzerland used an extensive panel data set from 1985 to 1997 to analyse gasoline demand trends within the Swiss border areas bordering Italy, Germany, and France. The empirical data show that the petrol price disparity strongly and statistically significantly influences fuel consumption. The predicted price elasticities show notable responsiveness, demonstrating that a 10% decrease in the Swiss petrol price corresponds to a 17.5% rise in demand. To broaden the scope of the analysis, the estimated equation is used to model the impact of fuel tourism on petrol consumption inside border regions and the possible implications of a planned CO_2 tax. Notably, the simulations show that, on average, between 1985 and 1997, estimated fuel tourism accounted for approximately 9% of overall gasoline sales, while introducing a hypothetical CO_2 tax is predicted to curtail fuel tourism in the three border regions significantly [18].

Raising the average prices of automotive diesel in Catalonia and Madrid relative to prices in Aragon has a positive and significant long-term effect on sales of this fuel in Aragon. Bearing in mind that the volume of commodities transported passing through Aragon and having their final destination in these Communities accounts for (on average for the period 2000– 2005) approximately 62% of goods transported through Aragon with a goal in the regions analysed in this study, the results confirm the particular sensitivity of the purchases of diesel in Aragon concerning the behaviour of prices in these two Communities. As expected, the estimated long-term elasticities also indicate the negative effect of diesel price in Aragon upon purchases in this region and, by contrast, the positive effect associated with vehicle registration behaviour. Furthermore, the econometric analysis of the short-term reactions of demand for automotive diesel in Aragon shows that the evolution of relative prices in neighbouring communities has rapidly affected purchase figures in Aragon [19].

2.5 Fuel Tax Impact

Fuel taxes vary among European nations, resulting in fiscal competitiveness and the unintended consequence of cross-border fuelling, which results in more kilometres driven. An empirical study in the Netherlands found that even with a small price differential of around five cents per litre, roughly 30% of Dutch automobile owners residing near the border prefer to fill up in Germany, where gas outlets are readily placed. Surprisingly, even though the journey expenses outweigh the financial benefits, around 5% of automobile owners living 30 km from the border still choose to fuel in Germany [20].

Drivers exhibit substantial variability in responses to the option of fuelling abroad, with an average trade-off between the price difference and distance travelled at 0.5 cents per litre per kilometre. This low implicit value of time involved in cross-border fuelling trips aligns with their often being combined with shopping excursions. Various countries have devised innovative solutions to counter fuel-fetching trips, such as Singapore, where a high fuel tax compared to neighbouring Malaysia prompted the government to enact a law mandating cars leaving the city-state to have at least 75% tank capacity, enforced by fines. This measure effectively curtailed cross-border fuel fetching [20].

Italy uses an unusual approach to discourage cross-border fuelling to Slovenia. Italian drivers are given a smart card with distance and licence plate information near the border. These cards are used by border-region petrol stations to adjust taxes based on distance, preventing large-scale cross-border gasoline fetching [20]. Luxembourg uses fiscal competition to recruit drivers from neighbouring nations, providing cheap gasoline taxes. Despite possible environmental consequences, the balance between lower taxation from its inhabitants and increased money from foreign drivers is favourable for tiny nations [20].

As a result, Germany has implemented a regional gasoline price differential, particularly in areas bordering Eastern Europe and Luxembourg. Former East Germany, close to Poland, even sells petrol at a loss. Norway demonstrates spatial graduation by levying more gasoline taxes in Troms to support local infrastructure, resulting in lower fuel usage without a noticeable negative impact on transportation. These examples show various tactics and their consequences on cross-border fuelling behaviour [20].

Spatial differentiation of gasoline taxes is recommended, with lower rates near the border and higher ones further away. According to the simulation research for the Netherlands, this strategy might significantly influence refuelling decisions. However, issues like compensation claims from petrol station owners in high-tax areas and the possibility of fraud linked with other systems must be addressed. The practicality of regional tax differentiation depends on a country's spatial structure and density, making it a complicated policy decision impacted by factors such as population density in border zones [20].

2.6 Geographic Proximity Impact

The observed differential in fuelling behaviour between those living near Belgium and those residing near Germany suggests that the latter carefully analyses the benefits and downsides of driving an extra few kilometres to a German gas station when determining where to get fuel. However, individuals in the former group need to display this conduct, even though gasoline price variations between Belgium and the Netherlands are more significant than those between Germany and the Netherlands. On the one hand, the increase in excise charges for diesel and Liquefied petroleum gas (LPG) on January 1, 2014, resulting in financial advantages from fuel tourism for individuals residing near Germany, might be a viable explanation for this variance. As a result, some people chose to cross the border to get fuel from a German petrol station rather than a Dutch one. On the other hand, residents near Belgium had already participated in cross-border fuelling before the rise in excise charges [21].

The fact that price differentials between the Netherlands and Belgium do not affect the likelihood of domestic gasoline purchases shows that the impact of pricing is only temporary. Over time, most Dutch people may hesitate to travel more distances for cheaper gas. This hypothesis is confirmed by the results, which consider the time elapsed since the rise in excise charges and their interactions with distance to the nearest border. Price differentials no longer substantially impact fuelling behaviour in any model. This tendency remains true for people up to 10 km from the German border. Those living up to ten kilometres from the border were less likely to buy gasoline in the Netherlands in the first quarter of 2014 than those living at least thirty kilometres from the border. However, the similar impacts in the second quarter of 2014 were half the size and insignificant [21].

2.7 Exchange rates

Research from Hungary highlights the impact of the economic crisis on the increase in day visitors to Hungary, particularly those motivated by shopping motives from surrounding countries [22]. Inbound shopping-motivated travel rose rapidly during the situation, mostly from nearby eurozone member countries. Notably, demand from Slovakia, a recent eurozone member, increased significantly. However, the people of Romania and Ukraine, who have poorer living levels, have seen a significant drop in demand in some regions. Despite these swings, shoppers' average per capita expenditure remained steady during the crisis[22]. Surprisingly, the crisis increased customers' price sensitivity, pushing them to seek bargains in Hungary through shopping tourism. Eurozone residents took advantage of the advantageous EUR-HUF exchange rate, whilst non-eurozone residents reduced their expenditure in Hungarian retail outlets. The crisis did not raise total spending by shopping tourists from eurozone member countries but increased their involvement. In the case of non-eurozone nations, the problem increased per capita expenditure. Motivations varied, with one group drawn to Hungary for everyday shopping and the other by attractive prices and the odd opportunity for profitable transactions in the grey zone [22]. The study also emphasised that price advantages resulting from the HUF devaluation could influence shopping tourism behaviour. However, such exchange rate fluctuations had short-term impacts, with the psychological appeal of finding a good deal playing a significant role. The devaluation of the national currency brought about temporary and unpredictable competitive advantages, especially in Hungary, given its small size and high import dependency [22].

In Hungary, the term 'fuel tourism' refers to the fact that, despite high fuel prices, there is little demand for this form of tourist each year. This discovery highlights the complicated interplay between fuel costs and travel habits, underlining the importance of a thorough understanding of the factors influencing tourist trends, particularly in the context of fuel-related travel decisions.

The findings add to the more extensive debate on how economic factors, such as gasoline prices, can influence travel preferences and tourist dynamics in a specific geographical setting [22].

2.8 Fuel Tank Capacity and Fuel Efficiency in Heavy Trucks

Efficient fuel management in heavy trucks is a critical aspect of the transportation industry, impacting operational costs and environmental sustainability [23]. In the United States, the fuel tank capacity of big rigs varies between 454 and 568 Liters, with fleet considerations influencing the choice between single or dual tanks. Single-tank configurations are preferred for weight-conscious fleets engaged in short-haul operations, allowing for increased payload capacity. On the other hand, longer-distance fleets often opt for dual 568-Liters tanks, maximising mileage range and taking advantage of lower retail fuel prices [23].

However, the usable capacity of a fuel tank is less than its listed capacity. Drivers are advised to fill tanks only to around 95% capacity to account for temperature fluctuations, over-filling risks, and contaminants at the tank bottom. These contaminants include metal fragments, rubber from engine components, dirt, and microorganisms, emphasising the importance of maintaining air space in the tank [23].

Fuel costs for big rigs in the U.S., based on current retail diesel prices of around $3.00 per gallon, can range from $360 to $900 for trucks with one 454-Liters tank or two 568-Liters tanks, respectively. The distance a big rig can travel on a full tank varies depending on factors like fuel efficiency. A truck with one 454-litre tank might cover approximately 966 kilometres at 39 L/100km, while those with two 568-litre tanks could reach up to 3219 km with advanced aerodynamic technology [23].

In Europe, where overall length regulations are stricter, trucks often feature a combination of tank sizes (e.g., 454 Liters and 757 Liters), resulting in a total capacity of around 1211 Liters. Despite carrying more weight, European trucks achieve better fuel efficiency (27 L/100km) than the U.S. average (38 L/100km) [23].

2.9 Comparison of Fuel Sales with Domestic Consumption

Institut für Energie- und Umweltforschung Heidelberg gGmbH (IFEU) recognises differences between the Working Group on Energy Balances (AG Energiebilanzen) sales volumes and energy consumption calculated in TREMOD for road transport (cars and trucks) [24]. As the energy and greenhouse gas inventory for emissions reporting is determined according to the sales figures of the energy balance, the domestic results of TREMOD must be adjusted to the sales figures of the energy balance [24]. The difference between domestic consumption and fuel sales over time is sometimes subject to strong fluctuations. These can only be partially explained so far. A significant problem is the need to document the energy balance that explains the procedure for determining the sales figures and the breakdown by sector. The domestic consumption calculated with TREMOD is associated with uncertainties, as the underlying vital statistics (mileage, fleet composition, specific energy consumption) are not exact values but are, in part, based on simplified extrapolations and modelling [24].

Table 2 Comparison of domestic consumption and sales of petrol and diesel in road transport 2010-2018 [22]

	Gasoline Consumption in the country (PJ)	Domestic gasoline sales (PJ)	Difference in sales/ consumption	Diesel Consumption in the country (PJ)	Domestic diesel sales (PJ)	Difference in sales/ consumption
2010	958	822	-14,2%	1423	1257	-11,7%
2011	946	820	-13,3%	1455	1280	-12,0%
2012	916	775	-15,4%	1462	1309	-10,4%
2013	891	773	-13,3%	1494	1359	-9,0%
2014	879	777	-11,6%	1534	1376	-10,3%
2015	839	739	-11,9%	1574	1422	-9,6%
2016	827	740	-10,6%	1612	1467	-9,0%
2017	824	750	-9,0%	1637	1501	-8,3%
2018	823	724	-12,1%	1644	1457	-11,4%

A study conducted on behalf of the Federal Environment Agency (Umweltbundesamt) found that the fuel consumption calculated with the TREMOD model and the differences in the sales figures are plausible. In ViZ for 2017, the DLR arrives at similar differences for domestic petrol consumption, which hardly differs from domestic consumption (domestic and national car mileage are almost identical) and assumes that the cause is almost exclusively grey imports [25].

In the case of diesel fuel, domestic consumption (ViZ) and domestic consumption (TREMOD) are not directly comparable due to the driving performance balance in freight transport (more freight mileage by foreigners in Germany than by residents abroad). For example, the DLR calculates a total consumption for domestic mileage in 2017 that is almost identical to the sales figures in the energy balance, while TREMOD calculates an additional consumption of domestic transport of around 9 % with a higher mileage in freight transport by foreigners in Germany (see Table 1). Given that foreign trucks, lorries and articulated lorries account for 20% of the mileage on German territory [26], this order of magnitude is plausible, as is the assumption that a large part of this difference is also attributable to grey imports.

In addition, there are further uncertainties, for example, in the allocation of fuels to the individual sectors or changes in the distribution of fuels in the 2018 mineral oil sales statistics of BAFA, which the DLR took into account in the 2019/2020 edition of ViZ published at the end of 2019.

It was no longer possible to consider and reconcile the calculation results from TREMOD, which were only available at the end of the “Aktualisierung der Modelle TREMOD/TREMOD-MM für die Emissionsberichterstattung 2020” project, the amended data from the mineral oil statistics BAFA published in 2019, and the work to consider the energy statistics adjustment in ViZ 2019/2020. However, such a comparison should be carried out in 2020 and would be a reasonable basis for further developing the method for determining grey imports and exports.

2.10 Average Fuel Consumption

The truck's fuel consumption and emissions are influenced by the vehicle's specific energy consumption per kilometre, escalating with heavier load weights. Consequently, the energy consumption per kilometre is intricately tied to the degree of capacity utilisation. The ensuing figure illustrates an instance of energy consumption per vehicle kilometre, portraying its relationship with load weight and featuring values associated with various freight types [27].

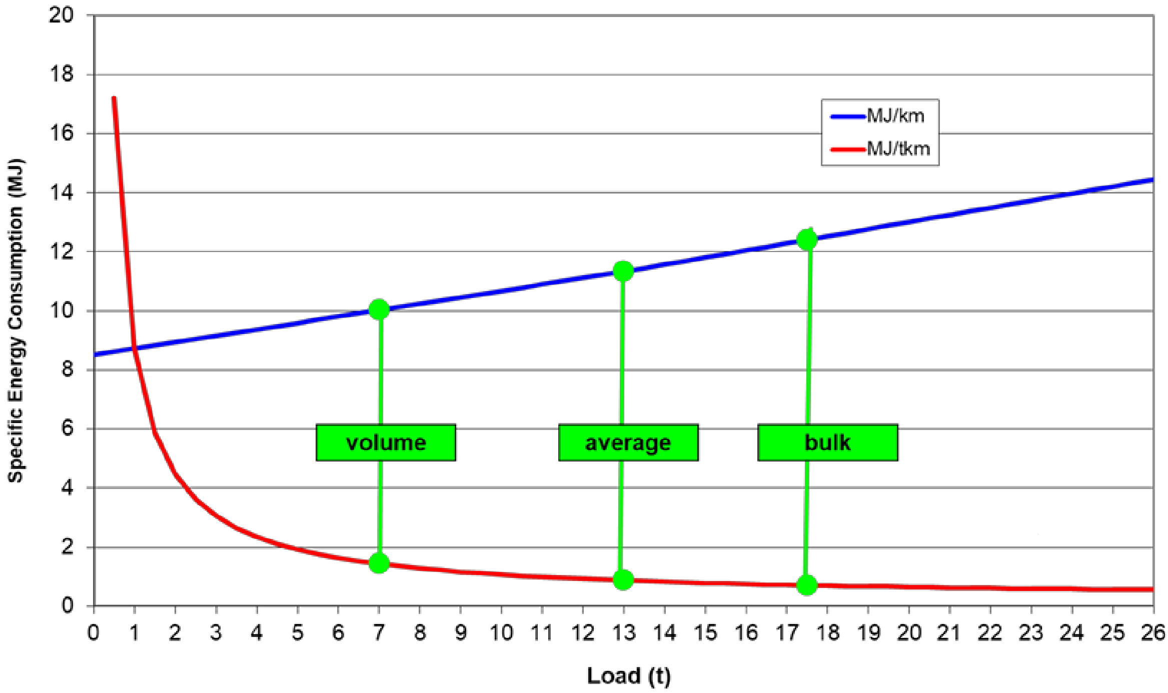

Figure 4 Energy consumption for heavy-duty trucks (40 t vehicle gross weight, Euro-VI a-c, motorway, hilly) as a function of load weight [27]

Table 3 shows energy consumption values for Euro 6 Trucks between 3.5 and 60 tonnes in three different load weights: empty, average and complete, with moderate usage, not including empty trips. Rigid lorries and articulated trucks in the same gross weight class can have different empty weights, depending on the body type (e.g. curtain sider vs. box).

Table 3 Energy consumption of selected diesel trucks with different load factors in Europe [27]

Truck GVW	**Empty 0%**	**Average 60%**	**Full 100%**
Energy Consumption (MJ/km)			
>7.5-12t	6.3	7.1	7.6
>12-18t	7	8.5	9.5
>18-26t	7.8	9.8	11.2

3 Methodology

As mentioned in Chapter 2, section 2, there is a gap in the calculation model of ViZ, which only calculates national fuel consumption instead of domestic fuel consumption. National fuel consumption is the subtraction of components A and B in Figure 2, leading to the fuel consumption of German trucks inside German borders.

Our main objective in this thesis is the non-resident trucks, which represent component C in Figure 2, research on the different public data to fill the gap by a new calculation or data set after research on the internet and the various resources on the internet. There is no available data for the fuel consumption volume for the foreign trucks in Germany, so we are conducting a new calculation to get the foreign trucks' fuel consumption.

The calculation formula is similar to the one for the national fuel consumption, which depends on the average fuel consumption for the various weights and axes classes for the trucks, the average mileage, and the number of targeted trucks.

3.1 The Calculation of Average Fuel Consumption

As mentioned in Chapter 2, fuel consumption depends on the truck's gross vehicle weight, as various trucks weigh 7.5 tonnes with less than three axes and over 18 tonnes with more than three axes. The weight for each weight and axe class between the trucks over the years was calculated using Table J9 in the BALM toll data [28].

As shown in Figure 5, it is evident that a majority of more than 18 tonnes with more than three axes have most of the truck's GVWs; therefore, based on the GVWs, the average fuel consumption will be calculated.

Section 10 of the literature review presents findings on diesel energy consumption per kilometre, revealing variations based on the load carried by the truck, the assumption of truckloads with 100% will be taken due to the majority of the cross borders trips being fully loaded with the EU regulations, which allow up to 40 tonnes gross weight for each truck [29] and the cabotage rules which provides up to 3 visits inside Germany for the non-resident trucks [30] which make an explicit assumption that non-resident trucks will try to make their utilisation roughly complete. In Table 4, the average consumption was calculated assuming that burning one litre of diesel results in 38.6 megajoules per litre [31]; average diesel consumption for the various truck weights is listed in Table 4 based on data provided in Table J9 in the BALM toll data [28].

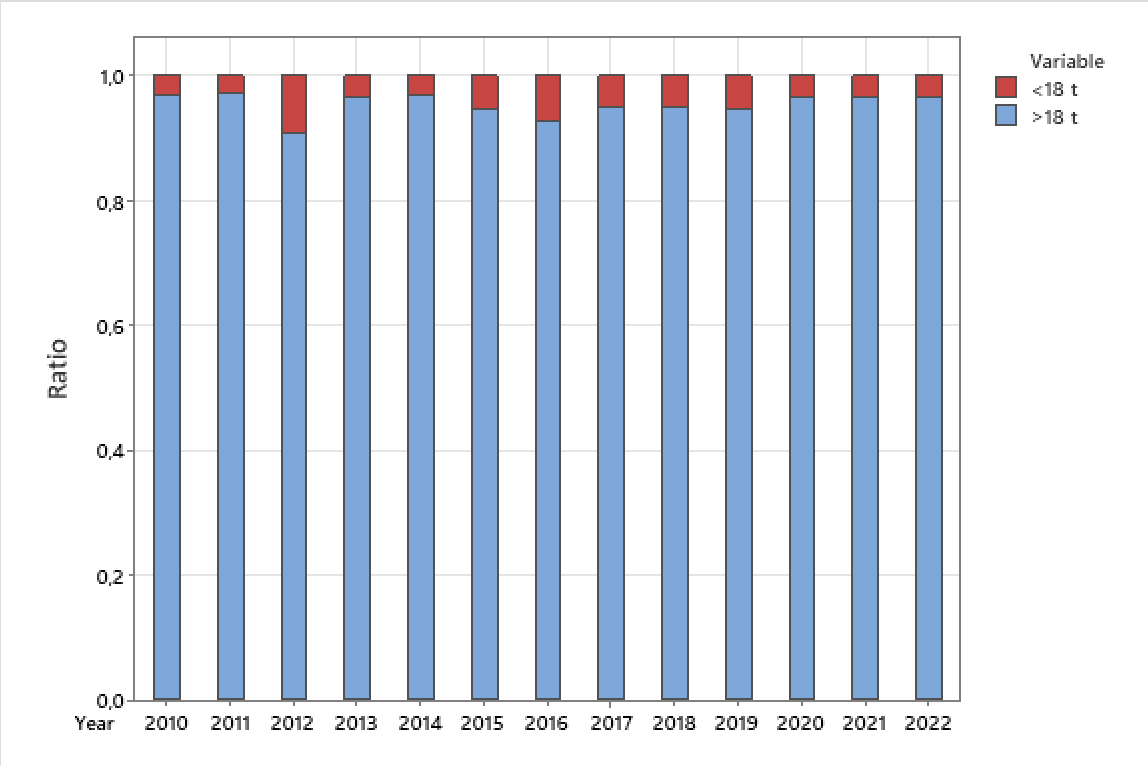

Figure 5 Chart of Weight and Axes Classes

Table 4 Average fuel consumption of selected diesel trucks with different weights [28]

Truck Weight	**Average Diesel Consumption (L/100 km)**
>7.5-12t	19.69
>12-18t	24.61
>18-26t	29.02

After taking the ratio of the GVW and axe classes of the trucks and the weighted averages of the average fuel consumption of the trucks with different GVW and axes, there is a slight difference between each year between 2010 and 2022, as in Table 5.

Table 5 Weights of the trucks with different weights and axe class

Year	**Under 18 tonnes with less than 3 Axes**	**Over 18 tonnes with more than 3 Axes**	$W_{Year}*X_{Year}$
2010	0.0297	0.9703	28.81
2011	0.0281	0.9719	28.82
2012	0.0916	0.9084	28.39
2013	0.0335	0.9665	28.79
2014	0.0319	0.9681	28.80
2015	0.0553	0.9447	28.64
2016	0.0737	0.9263	28.51
2017	0.0518	0.9482	28.66
2018	0.0502	0.9498	28.67
2019	0.0544	0.9456	28.70
2020	0.0335	0.9665	28.80
2021	0.0334	0.9666	28.80
2022	0.0331	0.9669	28.81

3.2 Average Mileage and Number of Trucks

After some research and inquiries regarding finding data related to average mileage and the number of trucks crossing the borders, Toll tables by the BALM and Road freight transport database by the statistical office of the European Union (Eurostat) and after some research in both sources, it got with a conclusion that Toll tables make more relevant and accurate for the thesis scope as it is more precise and detailed due it is electronically collected on borders. It covers all the federal ways; meanwhile, Eurostat data is based on sample surveys to collect information. Toll tables have been published monthly and annually since 2008 with 11 tables [28]; each has different data based on toll mileage. J10 [28], which is the average distances travelled on toll roads for each vehicle licence plate by every nationality, was considered in the calculation as it is more relevant since it takes every foreign truck as an individual based on the nationality behaviour which the geography proximity, fuel prices, taxes and CO_2 tax for each nation affects its behaviour towards fuel consumption.

3.3 The Calculation of Non-Resident Trucks Fuel Consumption

Data between 2009 and 2022 were collected for average fuel consumption, average mileage, and the number of crossing border trucks with the calculation model presented in Figure 6. This model is an adaptation of the model found in Figure 3.

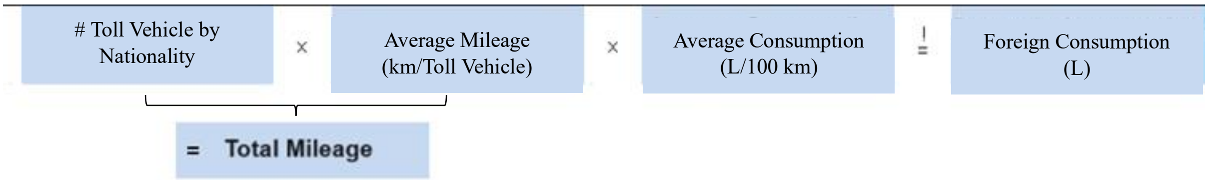

Figure 6 Calculation concept of Non-Resident Fuel Consumption

Calculations took the period since 2009 since the J10 table [28] was not presented before, and it just gave the number of entries for each federal way without respect to the truck nationality. Table 6 is an example of the 2022 calculations for 2009-2021 listed in the appendices.

Table 6 Average kilometres travelled, toll vehicle numbers, and fuel consumption by nationality.

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	24550	5860	41.4451
Bulgaria	28611	18232	150.2829
Denmark	7728	8017	17.8494
Estonia	3890	20115	22.5431
Finland	1077	17747	5.5067
Finland France	36237	2331	24.3355
Greece	2041	14850	8.7318
Great Britain	Brexit	Brexit	Brexit
Ireland	2681	7233	5.5866
Italy	16655	12105	58.0832
Croatia	8129	24693	57.8298
Latvia	8411	22306	54.0531
Lithuania	56507	23282	379.0197
Luxembourg	6962	14725	29.5348
Malta	58	9749	0.1629
Netherlands	80182	12835	296.4966
Austria	33700	10832	105.1711

Poland	230322	33303	2209.8142
Portugal	15448	7247	32.2551
Romania	65531	20002	377.6331
Sweden	2187	13987	8.8130
Slovakia	19337	25198	140.3781
Slovenia	18126	30114	157.2561
Spain	38500	7450	82.6302
Czech Republic	44300	30401	387.9971
Hungary	25834	24618	183.2237
Cyprus	198	22676	1.2935
Non-EU	94960	8445	231.0497
Total	872162	448354	5068.9761

3.4 The Validation of the Calculation

To validate the new fuel consumption calculation concerning toll statistics, comparison with other related work would be a great reference to prove the precision of the latest numbers, as Section 2.9 highlights a discernible gap between fuel sales and domestic consumption over the years based on TREMOD model, primarily attributed to non-domestic fuel factors., then comparing the variance between domestic consumption in ViZ and the combined domestic consumption in ViZ with non-resident trucks' fuel consumption in Germany is analogous to the distinction observed between fuel sales and domestic consumption.

These differences are demonstrated in Table 7 and illustrated in Figure 7. The gap between the two differences, at the beginning, can be noticed until it gets more correlated over time; that is obvious due to the toll collection system’s development, which reduced the toll obligation to a minimum permissible gross weight of 7.5 tonnes in 2015 and the expansions to cover all the federal roads till reached all national roads in 2018.

Table 7 New Approach Comparison with TREMOD

Year	National Diesel fuel consumption form ViZ (A)	Non-resident truck's fuel consumption in Germany (B)	Domestic Consumption (A+B)	Difference in (A+B)/ (B)	Difference in sales/domestic consumption
2009	36441.2753	2411.773	38853.0483	6.21%	13%
2010	37861.7061	2642.691	40504.3971	6.52%	11.70%
2011	38606.3802	2845.693	41452.0732	6.87%	12%
2012	39249.3592	2803.348	42052.7072	6.67%	10.40%
2013	41576.0445	2965.762	44541.8065	6.66%	9%
2014	41799.7592	3170.72	44970.4792	7.05%	10.30%
2015	43834.7300	3423.828	47258.558	7.24%	9.60%
2016	42518.6278	3794.307	46312.9348	8.19%	9%
2017	41229.2186	4098.488	45327.7066	9.04%	8.30%
2018	40415.5223	4507.483	44923.0053	10.03%	11.40%

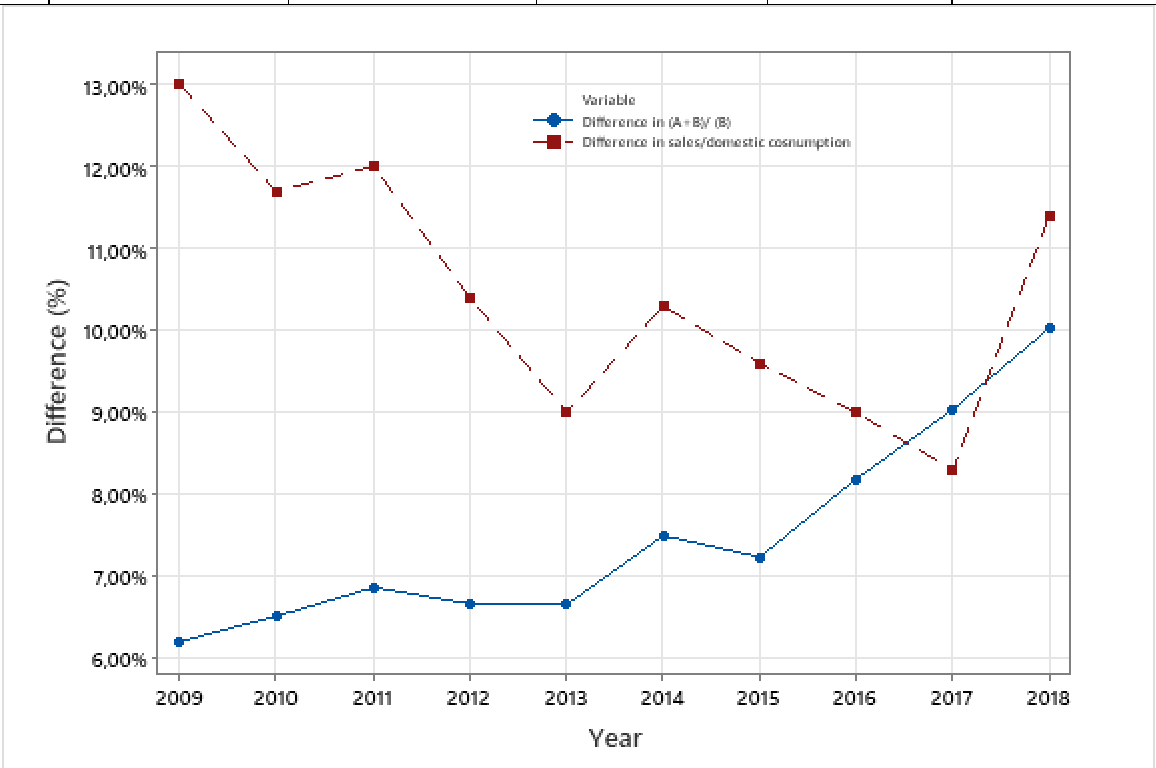

Figure 7 Time Series Plot of New Approach vs TREMOD

3.5 Foreign Consumption Analysis per Country

In order to estimate the fuel quantities imported by non-resident trucks, the behaviour of the non-resident trucks is a key factor related to the fuel quantities imported with the crossing border trips.

The behaviour analysis requires data for prices and fuel demand for each country. Some countries do not have a significant effect on the total numbers. Notably, most cross-border trucks are from Poland (Table 9). Thus, the focus is on this one country.

3.6 Correlation Analysis

Correlation analysis was employed to examine the relationship between the different variables by non-resident trucks in Germany. This analysis aimed to identify potential patterns and quantify the strength and direction of the association between these variables.

Pearson is a widely used statistical measure when measuring the relationship between variables; in this thesis, Person correlation is used to evaluate the linear relationship between two continuous variables. A relationship is linear when a change in one variable is associated with a proportional change in another [32]. The Pearson correlation coefficients can range in value from −1 to +1. The Pearson correlation coefficient is +1 when one variable increases and the other increases consistently. This relationship forms a perfect line, but if the amount is inconsistent, the correlation coefficient is positive but less than +1. In a random relationship, the correlation coefficient is nearly zero. Suppose the relationship is a perfect line for a decreasing relationship. In that case, both correlation coefficients are −1. If the relationship is that one variable decreases when the other increases, but the amount is not consistent, then the Pearson correlation coefficient is negative but more significant than −1.

3.7 Regression Analysis

Regression analysis [33] investigates the relationship between fuel consumption by non-resident trucks in Germany and relevant predictor variables. The goal is to identify significant factors contributing to fuel consumption variations and develop a predictive regression model. Simple linear and multiple linear regression were considered by the nature of the relationship between the dependent variable (Foreign Diesel Consumption) and the independent variables (predictors), which constantly increase.

3.8 Time Series Analysis

Time series analysis was implemented to model and forecast the trends and patterns in the fuel consumption data for non-resident trucks in Germany. As the data is non-stationary and few data points were collected, the ARIMA model [34], which is more suitable for medium- and long-term forecasts, could not be used. Double exponential smoothing was chosen over single exponential smoothing for its effectiveness in capturing both level and trend components in time series data. It was selected from over triple exponential smoothing or, as it is called, Winter's method, as the data does not have seasonality [35].

The weights adjust the smoothing amount to define how each component reacts to current conditions. Usually, the data is enough to reduce the noise (irregular fluctuations) to make the pattern more apparent. Minitab Statistical Software chose weights for level and trend [36], which minimises the sum of the squared residuals in an ARIMA (0,2,2) model, zero of autoregressive terms, two nonseasonal differences needed for stationarity and two lagged forecast errors in the prediction equation.

Double exponential smoothing uses the level and trend components to generate forecasts. The forecast for m periods ahead from a point at time t is $L_t + mT_t$, where L_t is level, and T_t is the trend at time t.

4 Results and Discussion

4.1 Descriptive Statistics

Descriptive statistics are statistical measures that summarise and describe a dataset. These measures help to understand and analyse the essential characteristics and patterns of the data. Descriptive statistics are often used to organise, present, and interpret data meaningfully.

Descriptive Statistics provide a summary of the data and allow the gain of insights, identifying patterns, and making comparisons; they were a critical factor in building further analysis as they gave a better perspective to the data. Through analysis of the descriptive statistics of the new fuel consumption calculations through 2009-2022 over different nationalities. It was easier to notice patterns and trends over the years. Table 8 shows some of the descriptive statistics used throughout the thesis.

Table 8 Descriptive Statistics for Foreign Consumption between 2009-2022

Year	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
2009	28	86.1	24.4	128.9	0.3	15.4	35.8	97.7	609.8
2010	28	94.4	27.2	144.1	0.3	12.2	40.2	112.9	691.7
2011	29	98.1	29.7	159.9	0.4	12.5	33.5	127.3	802.5
2012	29	96.7	29.2	157.4	0.3	12.3	33.0	125.4	790.3
2013	29	102.3	32.3	173.7	0.4	11.1	34.4	134.0	884.3
2014	29	109.3	36.3	195.3	0.4	10.4	36.3	142.7	1008.8
2015	29	118.1	41.1	221.3	0.4	10.2	37.4	150.6	1155.8
2016	29	130.8	48.1	259.0	0.2	9.9	35.3	167.3	1366.0
2017	29	141.3	54.1	291.3	0.2	8.6	37.0	185.1	1545.2
2018	29	155.4	61.0	328.5	0.0	8.8	40.1	186.9	1749.9
2019	28	169.5	67.6	357.5	0.2	11.9	48.8	188.1	1882.2
2020	27	172.8	70.0	363.6	0.2	16.7	53.3	181.4	1891.8
2021	27	186.9	77.6	403.3	0.2	17.3	55.1	186.8	2103.1
2022	27	187.7	81.3	422.6	0.2	17.8	57.8	183.2	2209.8

Through analysing descriptive statistics, it is clear that the linear increase of the foreign fuel consumption quantities over the 14 data points was investigated made a reasonable assumption that a linear relationship between the fuel consumption and the other variables related to it can be noticed in the increase in the foreign fuel consumption during these years is shown in Figure 8.

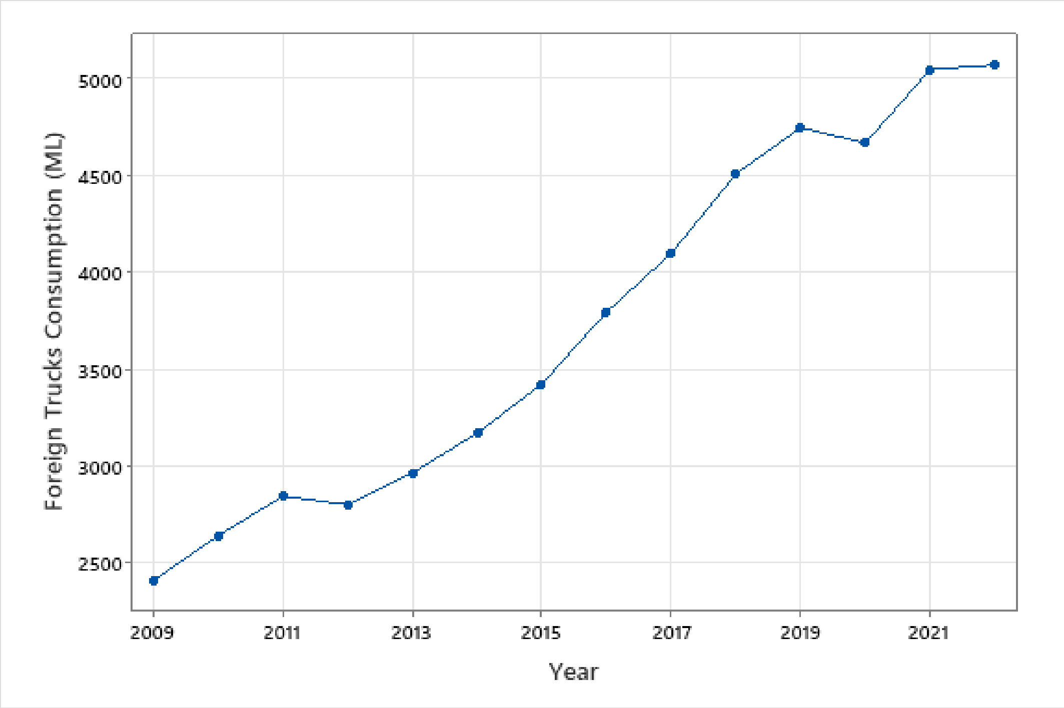

Figure 8 Time Series Plot of Total Foreign Trucks Consumption

4.1.1 Descriptive Statistics per Nationality

Through analysing descriptive statistics per nationality, the substantial fuel consumption across the 27 EU nations, particularly in East European countries, as they have cheaper diesel fuel prices, as shown in Figure 9 for some selected countries between West and East Europe, suggests a correlation with variables related to fuel price differences and demand, Table 9 shows some of the descriptive statistics used throughout the thesis.

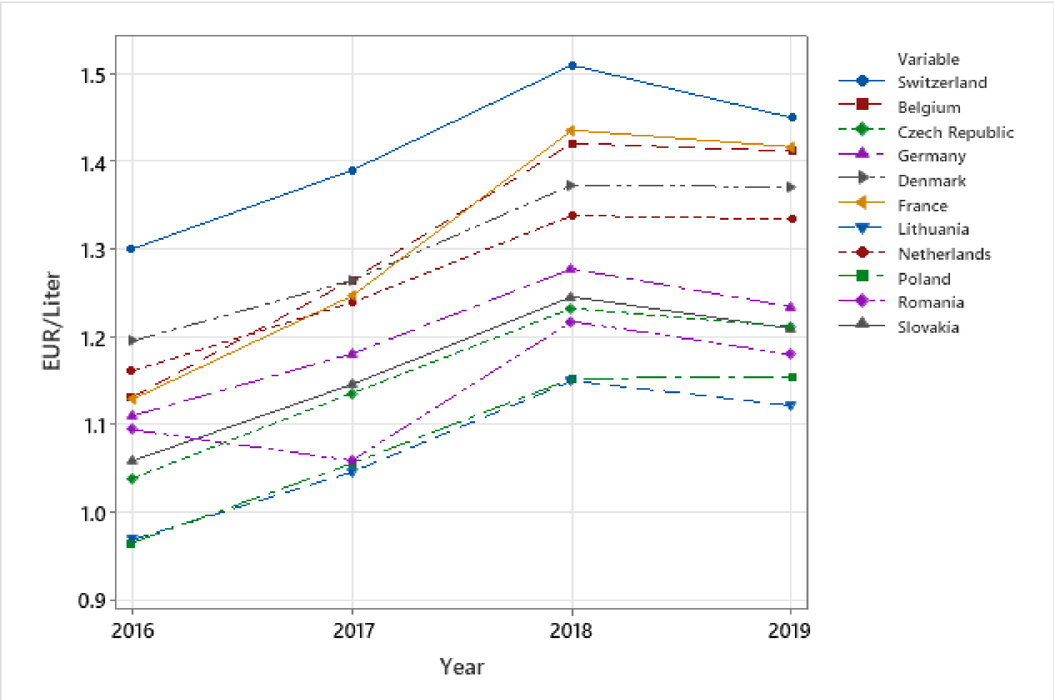

Figure 9 Time Series Plot of Diesel Prices for Selected European Countries

Table 9 Descriptive Statistics for Foreign Consumption between 2009-2022 per Nationality

Nationality	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Poland	14	1335	149	558	610	799	1261	1885	2210
Czech Republic	14	354.4	12.9	48.4	267.8	307.7	372.2	392.9	413.1
Netherlands	14	297.99	3.28	12.28	281	288.27	297.52	303.95	327.27
Romania	14	256.9	31.1	116.2	77.8	142	268.6	376.3	387.8
Non EU	14	217.39	7.64	28.59	192.83	195.05	204.8	237.34	287.14
Lithuania	14	197.5	29.1	108.9	77.1	110.2	149.1	317.8	379
Hungary	14	181.83	6.52	24.39	120.75	171.47	185.03	199.41	207.28
Slovakia	14	149.47	5.45	20.4	102.77	140.83	149.07	166.71	172.11
Bulgaria	14	112.8	12.1	45.3	36.8	69.9	119.5	158.2	163.1
Slovenia	14	111.64	9.29	34.76	70.38	79.72	101.28	153.5	161.61
Austria	14	106.87	2.78	10.39	93.39	99.43	104.77	110.86	129.21
Spain	14	66.51	2.45	9.16	56.27	59.16	62.44	74.97	82.63
Italy	14	61.45	2.86	10.72	53.24	54.28	55.35	69.63	83.84
Belgium	14	42.4	1.92	7.18	34.9	37.38	40.36	46.89	57.78
Latvia	14	41.8	2.93	10.97	25.06	33.36	39.61	54.35	57.75
Croatia	12	35.12	4.04	14.01	16.77	20.83	35.83	45.24	57.83
Luxembourg	14	27.483	0.799	2.991	23.571	24.76	27.234	29.594	32.658
Portugal	14	27.04	1.21	4.54	19.78	23.08	26.47	31.82	32.99
Denmark	14	22.76	1.68	6.28	16.74	17.82	19.74	27.28	34.75
France	14	21.565	0.338	1.263	19.873	20.413	21.602	22.393	24.336
Estonia	14	20.078	0.812	3.037	16.384	16.734	20.133	23.208	23.981
Sweden	14	12.408	0.992	3.711	8.813	9.734	10.615	15.726	19.824
Great Britain	11	8.196	0.312	1.035	6.806	7.115	8.806	9.118	9.366
Greece	14	7.639	0.247	0.924	6.73	7.034	7.257	8.675	9.582
Finland	14	6.547	0.263	0.986	5.343	5.85	6.333	6.946	8.962
Unknown	10	6.16	1.5	4.74	0.02	2.6	4.7	9.75	14.99
Ireland	14	4.399	0.118	0.44	3.999	4.071	4.21	4.608	5.587
Cyprus	14	2.84	0.203	0.758	1.294	2.412	2.816	3.529	3.783
Malta	14	0.2615	0.0241	0.0902	0.1522	0.1651	0.2472	0.3567	0.3908
Total	14	3728	254	950	2412	2835	3609	4686	5069

Figure 10 illustrates the increasing foreign fuel consumption over the years for the top ten countries with the highest mean; Poland has the highest growing slope for all other nationalities between 2009 and 2022, indicating that Poland has the highest effect on the cross-border trip market, as mentioned in Chapter 2. Due to Poland's particular importance, such contrasting developments significantly impact the presentation of overall traffic; therefore, taking Poland as a single case would clarify the situation.

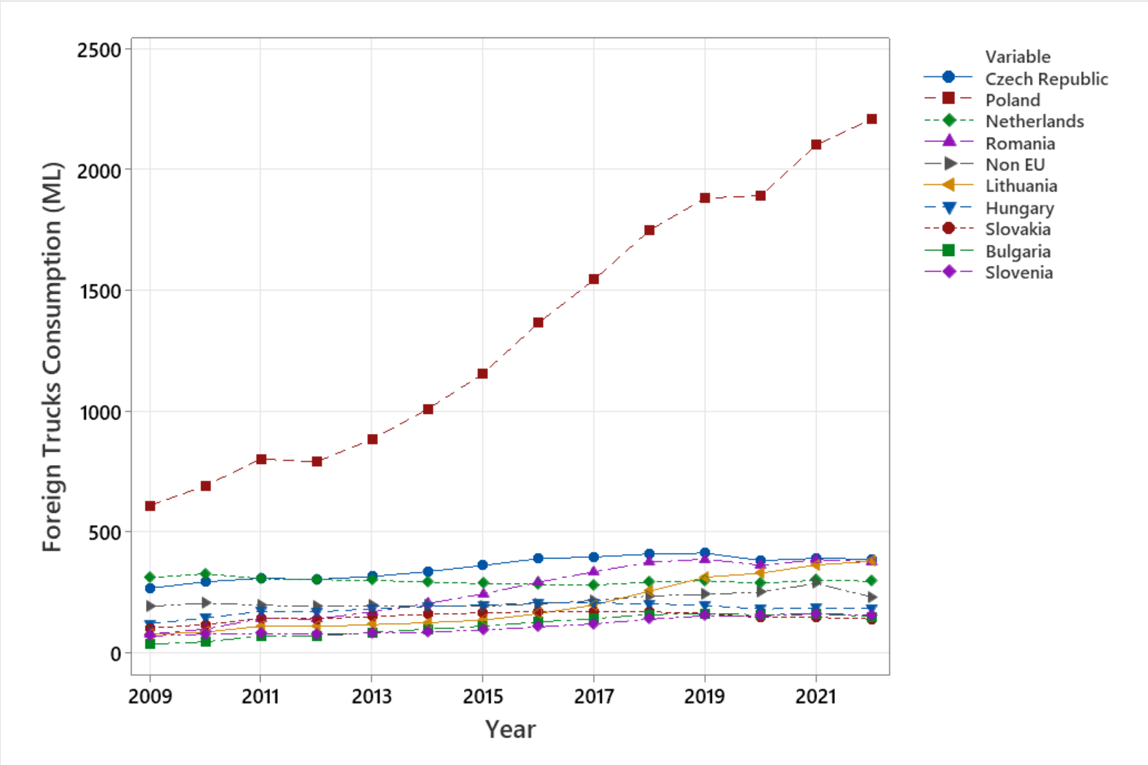

Figure 10 Time Series Plot of Foreign Consumption

4.2 Fuel Prices Differences

It can be assumed the high effect of fuel prices on the behaviour of the non-resident trucks, as they have options to fuel in the origin, transit or destination country; the cheapest option would be chosen. Trucks can fill the tank for their trip, including the cabotage trips, which HGVs can go farther than on a full tank. Trucks could use this strategy mainly with geographical proximity to Germany, such as Poland. Figure 11 shows the similarity of the fuel prices between Germany and Poland without considering taxes between 2009 and 2019.

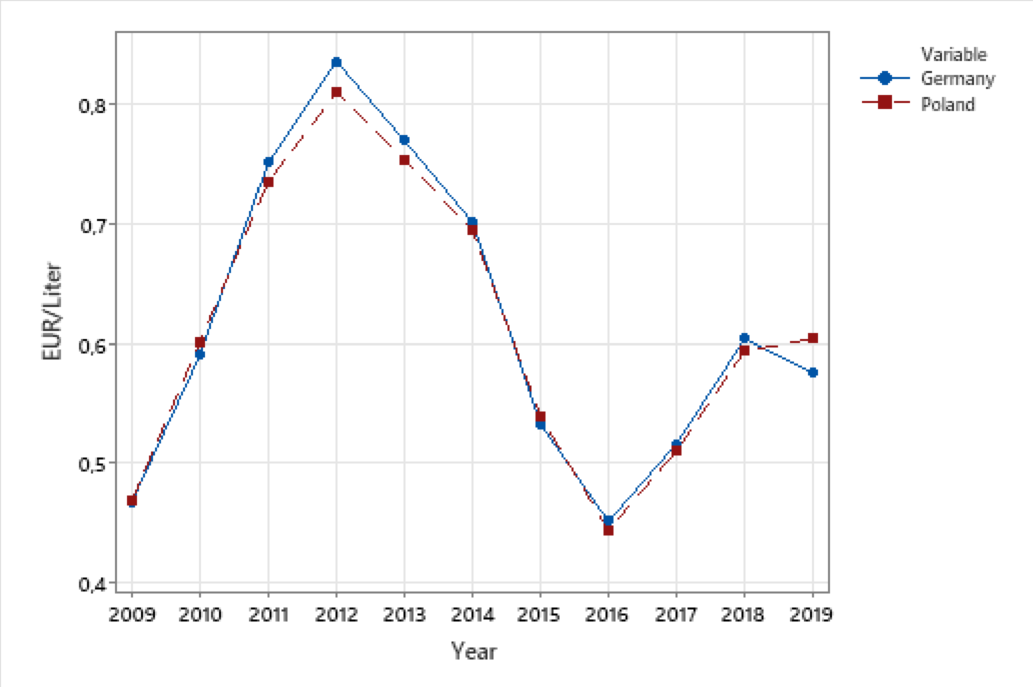

Figure 11 Diesel Retail Prices without Tax [37]

The different fuel tax policies between the EU countries lead to the other final prices for the retail customers (Chapter 2); as of July 2023, Germany is ranked 8 with the highest excise duty on diesel at 0.49 euro in the EU; meanwhile, Poland is ranked 24 at 1.44 PLN (0.33 euro), as shown in Figure 12 the fuel prices after adding tax for each country.

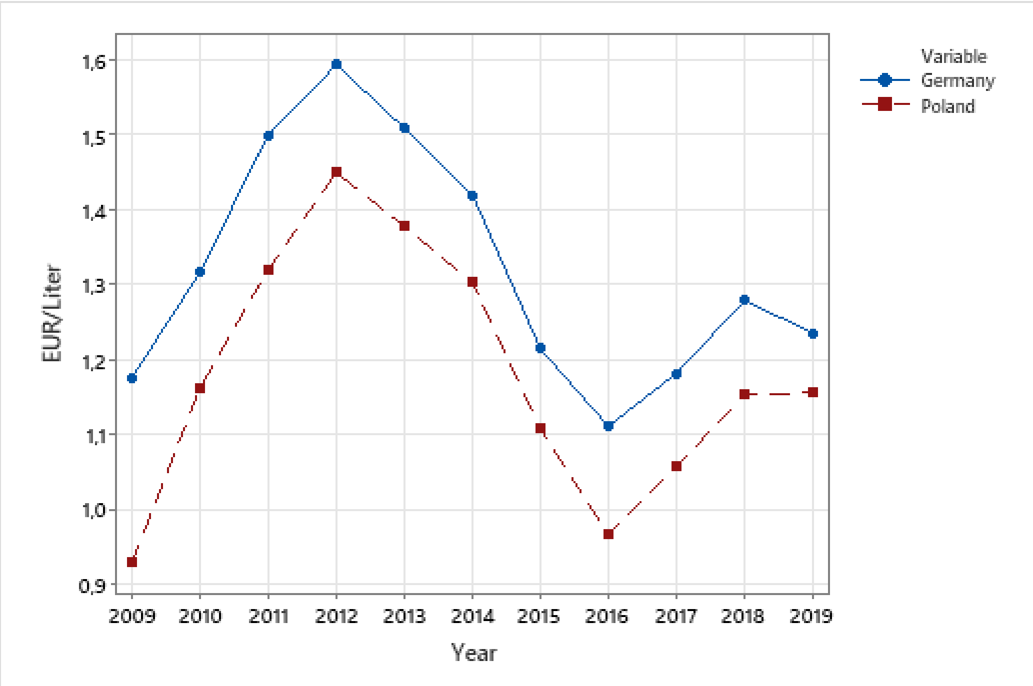

Figure 12 Diesel Retail Prices with Tax [37]

4.3 Domestic Fuel Consumption in Poland

After gathering the annual reports of The Polish Organization of Oil Industry and Trade (POPiHN) between 2010-2022. The members of POPiHN are the energy companies in Poland, and the report goes on with the domestic fuel consumption in the country. Figure 13 shows the increase of the domestic fuel consumption. In 2020, the decrease in fuel consumption was extraordinary because of challenging pandemic circumstances.

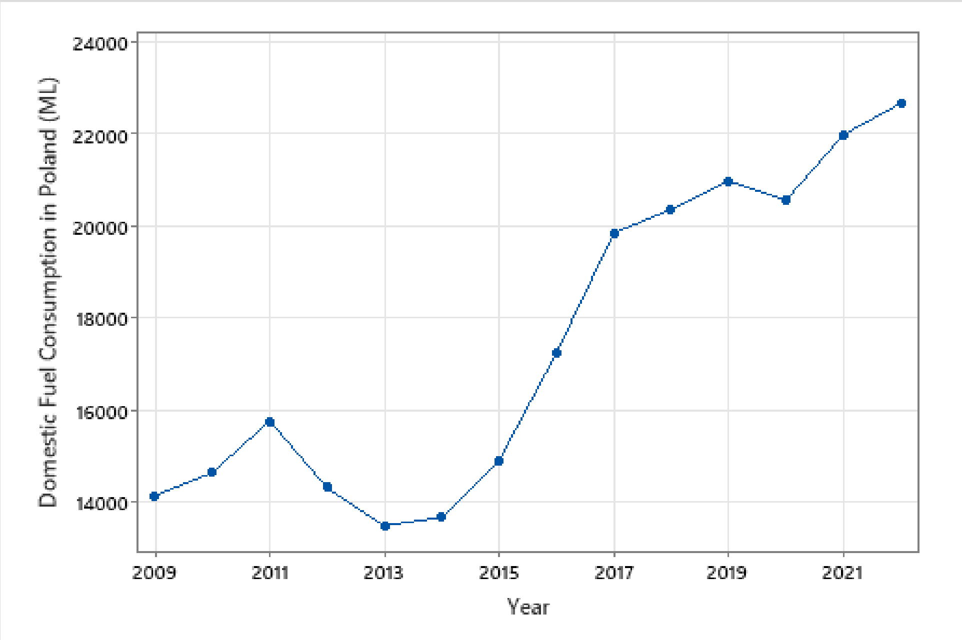

Figure 13 Time Series Plot of Domestic Fuel Consumption in Poland

4.4 Correlation Analysis

A significant portion of this thesis was dedicated to analysing the correlation between the variables influencing the fuel consumption behaviour of Polish trucks in Germany, addressing the research questions and objectives outlined in the introduction.

4.4.1 Polish Trucks Fuel Consumption in Germany vs Domestic Diesel Fuel Consumption in Poland

Pearson correlation analysis showed the relationship between Polish trucks' fuel consumption in Germany and domestic diesel fuel consumption in Poland, which is essential to establish as there are few predictors in the available sources. The 0.999 r value means that there is a perfect correlation between the fuel consumption in Poland and Germany by Polish Trucks; this strong relationship means that we can build a strong assumption that the increase in domestic fuel consumption in Poland will influence the increase in Polish trucks fuel consumption and fuelling in Germany. Figure 14 illustrates the correlation between the fuel consumption of Polish trucks in Germany and domestic diesel fuel consumption in Poland.

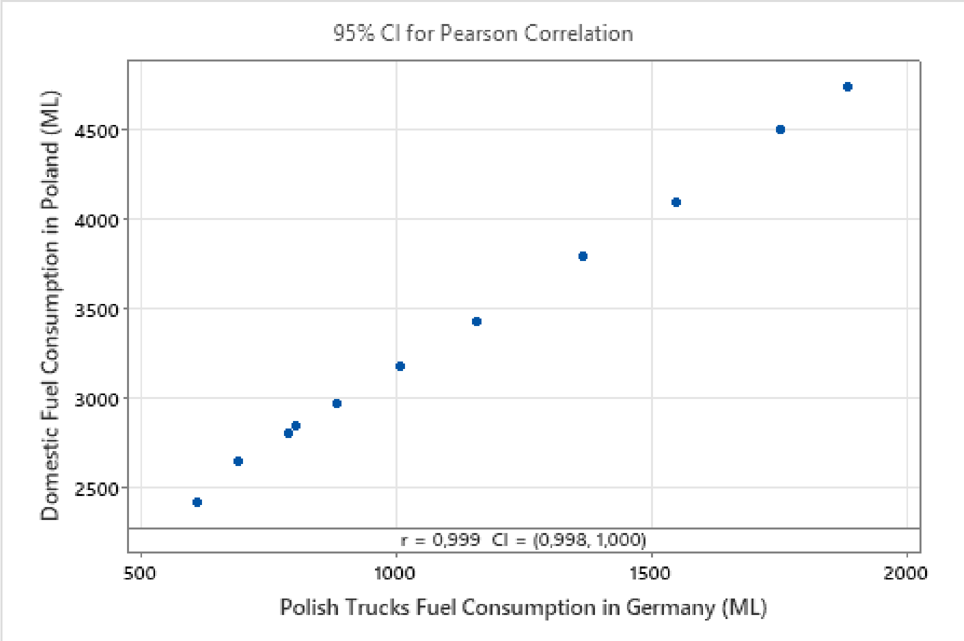

Figure 14 Matrix Plot of Polish Trucks Fuel Consumption in Germany vs Domestic Diesel Fuel Consumption in Poland

4.4.2 Polish Trucks Fuel Consumption in Germany vs Diesel Fuel Prices Difference

The same correlation analysis examined the potential relationship between Polish fuel consumption in Germany and the diesel Fuel price difference between Poland and Germany. However, the obtained r value of 0.689 indicates a positive relationship between the two variables. This positive correlation proves the effect of differences in fuel prices on the behaviour of the non-resident trucks from Poland and other East European countries, which have constant long-term lower prices than Germany. Figure 15 illustrates the correlation between Polish trucks' fuel consumption in Germany and the difference in diesel fuel prices between Poland and Germany.

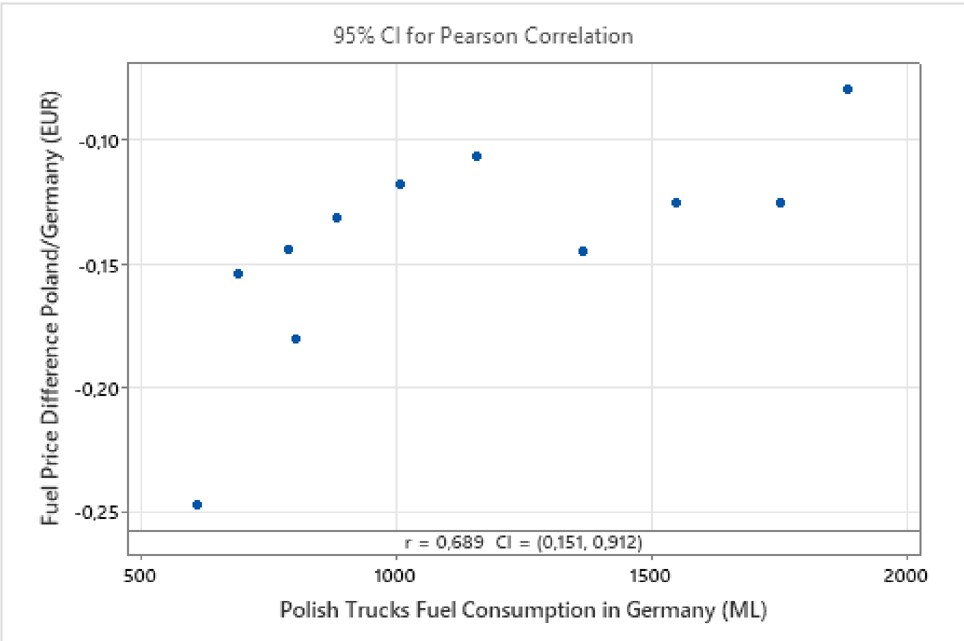

Figure 15 Matrix Plot of Polish Trucks Fuel Consumption in Germany vs Diesel Fuel Prices Difference

4.5 Regression Analysis

A part of this thesis was dedicated to analysing the relationship between the variables that influence the fuel consumption behaviour of Polish trucks in Germany and previous works to predict some needed answers for the research questions and objectives outlined in the introduction.

4.5.1 Dependent Variables Prediction

A dependent variable is needed for a prediction model, as data points for the percentage of foreign diesel are not available to estimate the fuel quantity imported by non-resident trucks. Some research was done to find other reliable works that estimated these data points in the past.

In 2011, the Federal Statistical Office of Germany (Destatis) published "Further development of the calculations on energy consumption and CO_2 emissions from road traffic as part of the NAMEA calculation approach: Methodological report" [38]. The report estimates the consumed foreign diesel percentage based on the KBA data since 2005 [39] for 2004, 2006, and 2008, which could help better evaluate the current situation reached till 2021, when the last KBA report was published. Table 10 shows the estimated percentages for foreign diesel trucks.

Table 10 Mileage and fuel consumption of German and non-resident trucks in Germany

Year	**KBA - Foreign Truck Mileage - All Journeys (1000. km)**[39]	**With Foreign Diesel (%)**[38]
2004	7681540	51
2006	8624880	54
2008	9435327	58

Figure 16 shows the fitted equation between KBA data and foreign diesel percentage is Y = 20.7 + 0.000004 X. The 96.84% R-Square value means a strong relationship that a reliable model can be built using the Foreign Diesel Percentage as a primary dependent variable.

Table 11 shows the data points for foreign diesel percentages between 2004 and 2021 after applying the KBA data between 2004 and 2021 to the fitted equation.

After applying the fitted equation to predict the foreign diesel percentage, it was noticed in Table 12 that the percentage reached 76.37 % in 2021, proving the assumptions of the rising consumption of foreign diesel in Germany. These data points will be used as a primary response for the final prediction model.

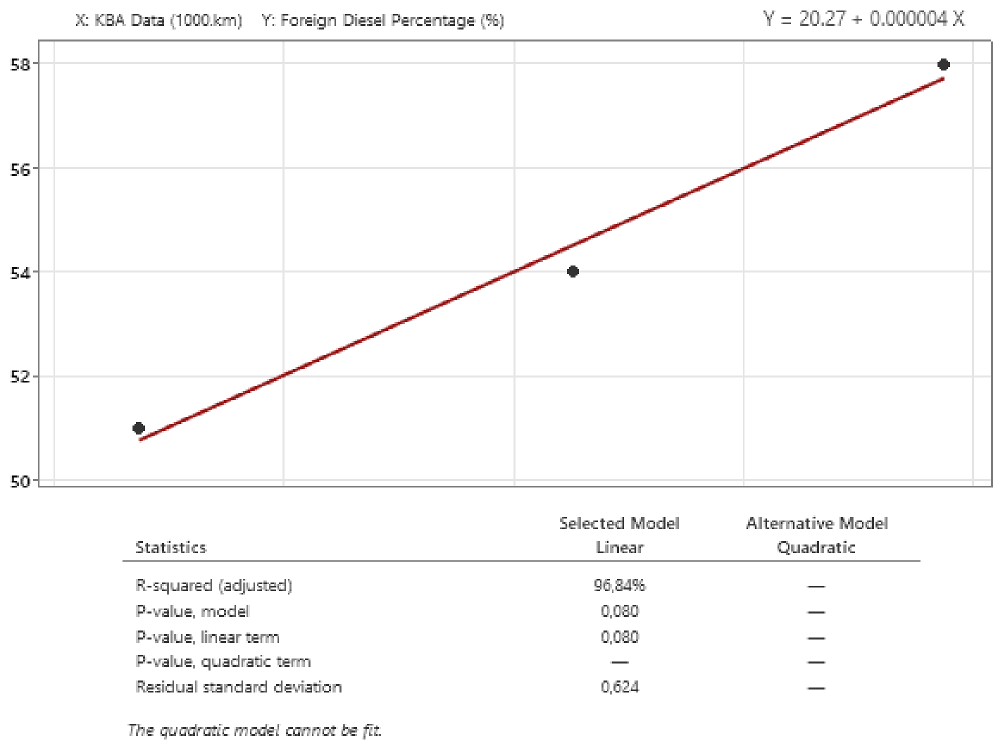

Figure 16 Regression Report for KBA Data vs Foreign Diesel Percentage

Table 11 Mileage and fuel consumption of German and non-resident trucks in Germany based on Regression

Year	**KBA - Foreign Truck Mileage - All Journeys (1000. km)**[39]	**With Foreign Diesel based on Regression (%)**
2004	7681540	51.00
2005	7719030	51.15
2006	8624880	54.77
2007	8840492	55.63
2008	9435327	58.01
2009	10223093	61.16
2010	10433176	62.00
2011	10566641	62.54
2012	10536734	62.42
2013	11717751	67.14
2014	12074399	68.57
2015	10859470	63.71
2016	11769397	67.35
2017	12872632	71.76
2018	11957363	68.10
2019	13070854	72.55
2020	13184354	73.01
2021	14026108	76.37

4.5.2 Foreign Fuel Consumption by Polish Trucks in Germany Prediction

After generating dependent variables for 2004-2021, the predictors will be the fuel price difference between Poland and Germany, total fuel consumption by Polish trucks in Germany (Section 3.3) and domestic fuel consumption in Poland. Data points between 2009 and 2019 are used as there are missing values for each dataset in several years. Figure 17 shows the generated regression report by Minitab Statical Software.

Regression Equation

Foreign Diesel Percentage = 63.51 + 13.1 Fuel Price Difference
+ 0.00878 Fuel Consumption by Polish
- 0.000338 Domestic fuel consumption in Pl

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	63.51	6.79	9.35	0.000	
Fuel Price Difference	13.1	30.7	0.43	0.682	3.19
Fuel Consumption by Polish	0.00878	0.00676	1.30	0.235	15.62
Domestic fuel consumption in Pl	-0.000338	0.000848	-0.40	0.702	10.21

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.38149	75.12%	64.46%	47.29%

Figure 17 Regression Report for Foreign Diesel Percentage at selected values

A statistical model was built using foreign fuel percentage as the dependent variable and the corresponding predictors' corresponding values. A significant regression equation was derived as the basis for the statistical predictive model. This model equation enables forecasting foreign fuel consumption percentages by Polish trucks in Germany based on specific prices and fuel volume inputs. The integrated approach provides a powerful tool for predicting future percentages.

4.6 Time Series Analysis

A part of this thesis was dedicated to forecasting analysis, including smoothing plots for the double exponential smoothing method. Notable estimations for what may come soon could provide some answers and recommendations.

4.6.1 Non-Resident Trucks Fuel Consumption Forecasting

The double Exponential Method showed the time series for the non-resident truck's fuel consumption after using smoothing constants 0.925588 for level and 0.162909 for trend as they had the minimum sum of the squared residuals in an ARIMA (0,2,2) model. It is evident in Figure

18 that the generated smoothed line fits the actual data line with low accuracy measures, which proves more accuracy for the forecasted data. Table 12 shows the forecasted values and the 95% prediction interval (PI), representing a range of values within which the actual value is expected to fall with 95% confidence for 2023 and 2027.

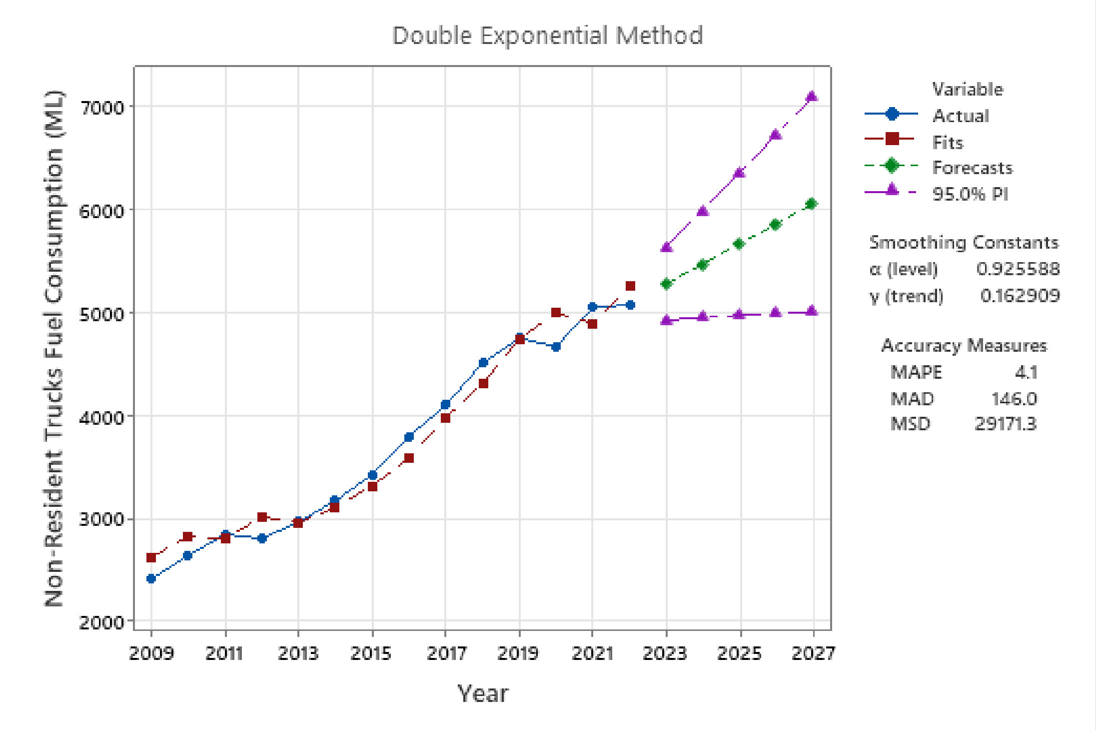

Figure 18 Smoothing Plot for Non-Resident Trucks Fuel Consumption

Table 12 Non-Resident Trucks Fuel Consumption Forecasting 2023-2027

Year	Forecasted Non-Resident Trucks Fuel Consumption (ML)	Lower 95.0% PI	Upper 95.0% PI
2023	5277.11	4919.47	5634.75
2024	5471.21	4951.14	5991.29
2025	5665.32	4973.20	6357.43
2026	5859.42	4991.34	6727.50
2027	6053.52	5007.54	7099.50

4.6.2 Consumed Foreign Fuel Percentage Forecasting

The double Exponential Method showed the time series for the KBA - foreign truck mileage - all journeys [39] after using smoothing constants 0.387995 for level and 0.162117 for trend as they had the minimum sum of the squared residuals in an ARIMA (0,2,2) model, it is evident in Figure 19, the generated smoothed line fits the actual data line with low accuracy measures which proves more accuracy for the forecasted data. Table 13 shows the predicted values for the periods between 2022 and 2026.

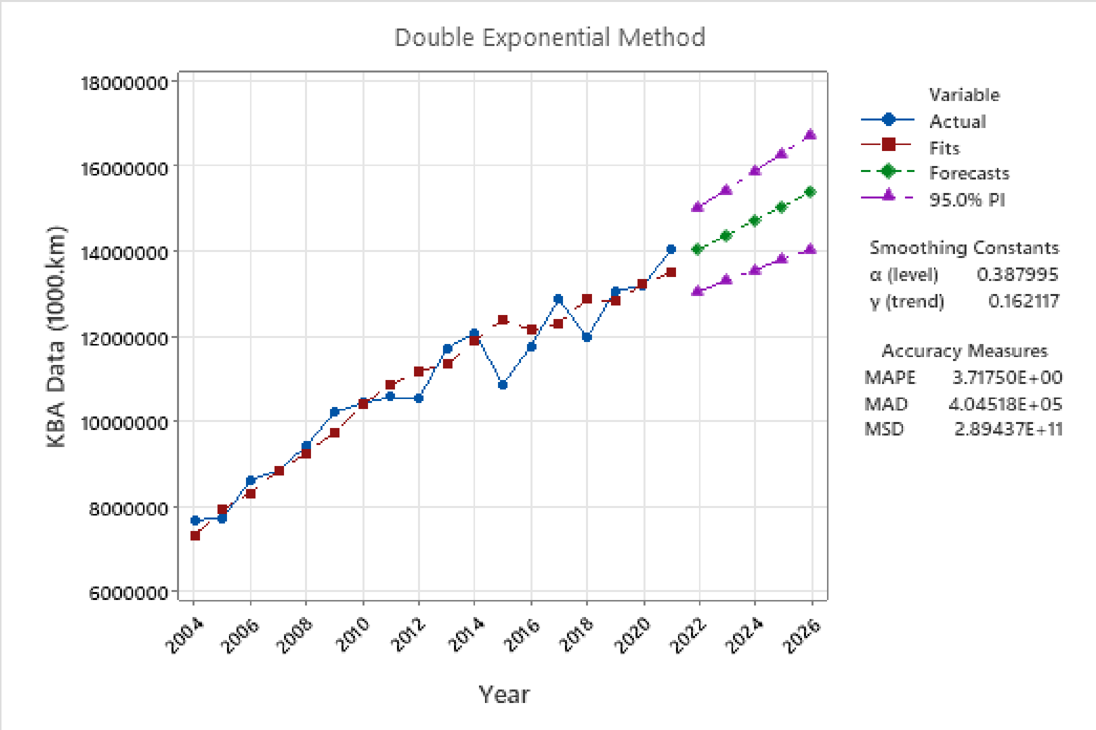

Figure 19 Smoothing Plot for KBA Data

Table 13 KBA - Foreign Truck Mileage - All Journeys Forecasting 2022-2026

Year	**Forecasted KBA - Foreign Truck Mileage (ML)**	**Lower 95.0% PI**	**Upper 95.0% PI**
2022	14046045	13054995	15037095
2023	14382961	13312485	15453437
2024	14719877	13561678	15878075
2025	15056792	13804317	16309267
2026	15393708	14041773	16745643

Table 14 shows the percentage of consumed foreign fuel after applying the forecasted values on the fitted equation of Section 5.4.1 to predict the percentage based on the KBA data.

Table 14 Consumed Foreign Fuel Percentage Forecasting 2022-2026

Year	**Forecasted Consumed Foreign Fuel Percentages based on Regression (%)**
2022	76.45
2023	77.80
2024	79.15
2025	80.50
2026	81.84

5 Conclusion and Recommendations

5.1 Consclusion

In conclusion, this thesis has thoroughly explored diesel fuel consumption dynamics, focusing on non-resident trucks, particularly Heavy Goods Vehicles (HGVs), in the European context, with a specific emphasis on Germany. Employing a multidimensional approach encompassing time series analysis, correlation, and regression analysis, the study aimed to understand comprehensively the factors influencing fuel consumption behaviours.

One significant revelation was the strong correlation observed between the increase in fuel consumption by non-resident trucks in Germany, the corresponding rise in domestic fuel consumption in their home countries, and the fuel price difference gap from the opposite side. To enhance data accuracy for future research, new calculations for non-resident trucks in Germany were initiated based on toll data.

The primary focus of the thesis was to establish a calculation methodology for a more precise estimation of the foreign diesel consumed by non-resident trucks in Germany. Leveraging regression modelling, the study delved into the intricate relationships among various variables influencing the fuel consumption behaviour of non-resident trucks.

Additionally, the research employed forecasting methods based on new estimations to project outcomes for the subsequent five periods. It is acknowledged, however, that forecasting in the transportation sector is subject to various external factors, particularly political conditions, such as significant events in 1993 and 2003 related to the EU establishment and evaluations by specific countries.

These findings seamlessly align with the overarching theme of sustainability, as they contribute to understanding environmentally friendly and sustainable transport practices. By acknowledging the inherent complexity of predicting cross-border fuel consumption and developing a robust data methodology for accurate quantitative analysis, the study lays a foundation for promoting sustainability in the road freight transportation sector. Moreover, the investigation explores pathways for transitioning to zero-emission vehicles, utilising regenerative fuels, and considers policy and decision support as potential avenues for reducing CO2 emissions and fostering a more sustainable transportation landscape.

5.2 Recommendations

- Enhance fuel consumption measures: The thesis suggests improvements in methods for measuring fuel consumption.
- Establish an integrated strategy: Encourage collaboration among all relevant entities in Germany to consolidate efforts and engage more stakeholders in ViZ Publish.
- Utilize automated and electronic devices: Shift towards data collection methods that rely on automated devices instead of surveys and rough estimations. This would contribute to a more accurate and transparent data collection process.
- Develop a data-driven toll system: Enhance the toll system to capture data related to fuel capacities in heavy goods vehicles (HGVs) more efficiently. This can be achieved by implementing systems similar to those used to determine the fuel capacity in the tanks of trucks, preventing fuel smuggling between countries.

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Appendix A

A.1

Table 15 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2009

Nationality	Toll vehicles [number]	Average mileage per vehicle [km]	Consumption (ML)
Belgium	27553	7060	56.0487
Bulgaria	18488	6911	36.8108
Denmark	9555	12602	34.6921
Estonia	5429	10579	16.5475
Finland	1697	16418	8.0273
Finland France	32734	2375	22.3983
Greece	2588	12850	9.5815
Great Britain	11052	2766	8.8063
Ireland	3929	4077	4.6147
Italy	27861	10260	82.3607
Croatia	Joined 2011		
Latvia	9700	8967	25.0615
Lithuania	24321	11008	77.1359
Luxembourg	8039	14100	32.6580
Malta	207	4202	0.2506
Netherlands	73104	14826	312.2725
Austria	30159	14870	129.2096
Poland	139045	15221	609.7787
Portugal	16187	4242	19.7832
Romania	34323	7867	77.7964
Sweden	3949	16641	18.9333
Slovakia	27668	12892	102.7722
Slovenia	12792	19096	70.3797
Spain	40993	4764	56.2654
Czech Republic	52321	17762	267.7563
Hungary	21740	19277	120.7455
Cyprus	522	21704	3.2642
Non-EU	99882	6701	192.8301
Unknown	98853	526	14.9918
Total	834691	300566	2411.7728

A.2

Table 16 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2010

Nationality	Toll vehicles [number]	Average mileage per vehicle [km]	Consumption (ML)
Belgium	28334	7077	57.7756
Bulgaria	21807	7273	45.6947
Denmark	9845	12252	34.7513
Estonia	5270	11722	17.7987
Finland	1929	16125	8.9617
Finland France	35745	2218	22.8467
Greece	2510	12372	8.9468
Great Britain	11580	2807	9.3661
Ireland	4506	3768	4.8914
Italy	28574	10184	83.8397
Croatia	Joined 2011		
Latvia	9012	10645	27.6400
Lithuania	23876	12562	86.4148
Luxembourg	7970	14214	32.6381
Malta	184	5594	0.2965
Netherlands	73088	15542	327.2730
Austria	31347	14000	126.4443
Poland	140889	17040	691.7033
Portugal	18110	4426	23.0914
Romania	39111	8739	98.4792
Sweden	4006	17175	19.8236
Slovakia	28617	14278	117.7206
Slovenia	12794	21140	77.9252
Spain	43196	4771	59.3728
Czech Republic	52018	19653	294.5419
Hungary	22806	21986	144.4630
Cyprus	657	18298	3.4636
Non-EU	95576	7488	206.1909
Unknown	83604	429	10.3362
Total	836961	313777	2642.6910

A.3

Table 17 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2011

Nationality	Toll vehicles [number]	Average mileage per vehicle [km]	Consumption (ML)
Belgium	26938	6108	47.4239
Bulgaria	27537	8841	70.1673
Denmark	8464	11309	27.5888
Estonia	4606	12651	16.7956
Finland	1369	17805	7.0257
Finland France	35262	2203	22.3911
Greece	2303	11029	7.3207
Great Britain	10820	2924	9.1177
Ireland	3964	4031	4.6054
Italy	25176	9705	70.4244
Croatia	4027	14674	17.0313
Latvia	9818	11835	33.4908
Lithuania	26557	14453	110.6310
Luxembourg	7473	13268	28.5774
Malta	186	6593	0.3535
Netherlands	71922	14831	307.4355
Austria	28891	13465	112.1274
Poland	147633	18859	802.4811
Portugal	17761	4570	23.3960
Romania	47279	10459	142.5297
Sweden	3496	15786	15.9069
Slovakia	29104	17064	143.1409
Slovenia	11890	23351	80.0225
Spain	42127	5004	60.7559
Czech Republic	49840	21501	308.8677
Hungary	24649	24227	172.1214
Cyprus	585	22437	3.7831
Non-EU	87857	7780	197.0076
Unknown	19820	555	3.1728
Total	777354	347317	2845.6929

A.4

Table 18 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2012

Nationality	Toll vehicles [number]	Average mileage per vehicle [km]	Consumption (ML)
Belgium	26938	6108	46.7064
Bulgaria	27537	8841	69.1057
Denmark	8464	11309	27.1714
Estonia	4606	12651	16.5415
Finland	1369	17805	6.9194
Finland France	35262	2203	22.0523
Greece	2303	11029	7.2100
Great Britain	10820	2924	8.9797
Ireland	3964	4031	4.5358
Italy	25176	9705	69.3589
Croatia	4027	14674	16.7737
Latvia	9818	11835	32.9841
Lithuania	26557	14453	108.9572
Luxembourg	7473	13268	28.1450
Malta	186	6593	0.3481
Netherlands	71922	14831	302.7842
Austria	28891	13465	110.4309
Poland	147633	18859	790.3399
Portugal	17761	4570	23.0420
Romania	47279	10459	140.3733
Sweden	3496	15786	15.6663
Slovakia	29104	17064	140.9752
Slovenia	11890	23351	78.8118
Spain	42127	5004	59.8367
Czech Republic	49840	21501	304.1947
Hungary	24649	24227	169.5173
Cyprus	585	22437	3.7259
Non-EU	87857	7780	194.0270
Unknown	20829	648	3.8335
Total	778363	347410	2803.3475

A.5

Table 19 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2013

Nationality	Toll vehicles [number]	Average mileage per vehicle [km]	Consumption (ML)
Belgium	24335	5995	41.9946
Bulgaria	29531	9977	84.8099
Denmark	7888	11130	25.2714
Estonia	4119	13818	16.3836
Finland	1244	18932	6.7794
Finland France	33734	2221	21.5711
Greece	2392	10527	7.2480
Great Britain	9902	3139	8.9480
Ireland	3491	4068	4.0878
Italy	22384	9438	60.8096
Croatia	4776	14246	19.5858
Latvia	9588	12453	34.3692
Lithuania	26301	15465	117.0815
Luxembourg	6669	13815	26.5208
Malta	166	7672	0.3666
Netherlands	71077	14694	300.6376
Austria	27759	13061	104.3680
Poland	152701	20118	884.2926
Portugal	17034	4623	22.6680
Romania	53075	11115	169.8126
Sweden	3159	14535	13.2173
Slovakia	28631	18324	151.0158
Slovenia	12054	23648	82.0531
Spain	39342	5168	58.5242
Czech Republic	49175	22345	316.3047
Hungary	26451	23980	182.5842
Cyprus	574	22793	3.7660
Non-EU	82819	8232	196.2399
Unknown	23744	651	4.4502
Total	774115	356183	2965.7619

A.6

Table 20 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2014

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	23027	5665	37.3548
Bulgaria	33944	11419	110.9915
Denmark	8043	9063	20.8734
Estonia	4356	15705	19.5903
Finland	1290	17648	6.5192
Finland France	32402	2207	20.4797
Greece	2319	11030	7.3248
Great Britain	8084	3190	7.3844
Ireland	3150	4596	4.1453
Italy	19575	9614	53.8912
Croatia	6444	16280	30.0409
Latvia	9612	13744	37.8316
Lithuania	28870	16403	135.6039
Luxembourg	6337	13001	23.5927
Malta	209	6177	0.3697
Netherlands	71777	13952	286.7750
Austria	28697	11831	97.2218
Poland	179439	22493	1155.8000
Portugal	17938	5090	26.1482
Romania	68022	12544	244.3447
Sweden	2723	14065	10.9677
Slovakia	29953	19301	165.5496
Slovenia	14084	23611	95.2247
Spain	41731	5047	60.3143
Czech Republic	53319	23729	362.3124
Hungary	31865	21700	198.0094
Cyprus	421	22167	2.6724
Non-EU	80199	8406	193.0434
Unknown	45619	724	9.4516
Total	853449	360400	3423.8284

A.7

Table 21 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2015

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	23129	5358	35.3301
Bulgaria	35399	12680	127.9659
Denmark	8051	8103	18.5996
Estonia	4421	16404	20.6761
Finland	1160	18585	6.1462
Finland France	32851	2191	20.5168
Greece	2254	11262	7.2370
Great Britain	8270	3018	7.1147
Ireland	3041	4670	4.0489
Italy	20061	9309	53.2396
Croatia	7064	17209	34.6563
Latvia	10027	14475	41.3795
Lithuania	34053	16758	162.6929
Luxembourg	6143	13459	23.5706
Malta	100	8553	0.2438
Netherlands	74392	13348	283.0901
Austria	30562	10968	95.5608
Poland	195420	24518	1365.9622
Portugal	18189	5168	26.7977
Romania	75860	13543	292.8924
Sweden	2521	14219	10.2198
Slovakia	29029	20769	171.8847
Slovenia	15978	23565	107.3435
Spain	43030	5227	64.1229
Czech Republic	53477	25590	390.1437
Hungary	29472	24670	207.2835
Cyprus	475	19459	2.6352
Non-EU	80486	8864	203.4000
Unknown	36589	916	9.5530
Total	881504	372858	3794.3072

A.8

Table 22 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2016

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	23180	5253	34.8958
Bulgaria	35552	14007	142.7175
Denmark	8124	7957	18.5256
Estonia	4411	17403	22.0011
Finland	1133	18760	6.0919
Finland France	31842	2178	19.8734
Greece	2055	11459	6.7489
Great Britain	9177	2663	7.0044
Ireland	3033	4658	4.0492
Italy	20238	9382	54.4151
Croatia	7163	18027	37.0085
Latvia	9658	16001	44.2906
Lithuania	38268	18066	198.1411
Luxembourg	6189	13443	23.8454
Malta	104	6767	0.2017
Netherlands	75068	13061	280.9966
Austria	32624	9988	93.3860
Poland	202277	26654	1545.2004
Portugal	18584	5407	28.7996
Romania	76490	15326	335.9886
Sweden	2565	13784	10.1330
Slovakia	28194	21299	172.1088
Slovenia	17528	24008	120.6056
Spain	42027	5552	66.8744
Czech Republic	52549	26366	397.0807
Hungary	29149	24744	206.7155
Cyprus	559	17779	2.8484
Non-EU	81434	9301	217.0744
Unknown	5356	564	0.8663
Total	864531	379857	4098.4884

A.9

Table 23 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2018

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	24821	5255	37.3944
Bulgaria	36168	15279	158.4344
Denmark	8379	7474	17.9561
Estonia	4333	19033	23.6448
Finland	1211	17584	6.1052
Finland France	34188	2162	21.1910
Greece	2266	10531	6.8416
Great Britain	10298	2500	7.3803
Ireland	3118	4473	3.9988
Italy	23162	8379	55.6437
Croatia	7428	18852	40.1486
Latvia	9651	17820	49.3092
Lithuania	43232	20702	256.6026
Luxembourg	6592	13952	26.3684
Malta	72	9728	0.2008
Netherlands	79088	12947	293.5667
Austria	35597	10067	102.7474
Poland	206992	29486	1749.8862
Portugal	19366	5616	31.1815
Romania	78692	16660	375.8728
Sweden	2339	15304	10.2627
Slovakia	27613	21496	170.1827
Slovenia	19125	25417	139.3705
Spain	41790	5929	71.0348
Czech Republic	52271	27352	409.9040
Hungary	29446	24116	203.5937
Cyprus	487	19943	2.7845
Non-EU	87816	9368	235.8598
Unknown	359	155	0.0160
Total	895900	397581	4507.4833

A.10

Table 24 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2019

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	23512	5578	38
Bulgaria	32405	17544	163
Denmark	7464	8273	18
Estonia	3951	21152	24
Finland	1001	19976	6
Finland France	33508	2250	22
Greece	1943	12070	7
Great Britain	9514	2493	7
Ireland	2518	5828	4
Italy	19639	9743	55
Croatia	6957	21425	43
Latvia	8808	21975	56
Lithuania	44737	24441	314
Luxembourg	6725	14138	27
Malta	61	9471	0
Netherlands	79331	13114	299
Austria	35399	10502	107
Poland	204027	32148	1882
Portugal	17451	6588	33
Romania	72277	18696	388
Sweden	2148	16063	10
Slovakia	23676	24017	163
Slovenia	18693	28629	154
Spain	39730	6660	76
Czech Republic	48184	29879	413
Hungary	26638	25697	196
Cyprus	375	23496	3
Non-EU	78533	10728	242
Total	849205	442573	4746.6873

A.11

Table 25 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2020

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	23024	5855	38.8244
Bulgaria	30106	18239	158.1517
Denmark	6826	8517	16.7446
Estonia	3848	20809	23.0624
Finland	807	22986	5.3426
Finland France	31604	2221	20.2138
Greece	2010	12261	7.0982
Great Britain	Brexit		
Ireland	2408	5881	4.0785
Italy	16390	11290	53.2979
Croatia	7122	22454	46.0599
Latvia	8303	23097	55.2341
Lithuania	47905	23904	329.8177
Luxembourg	6752	13979	27.1850
Malta	54	10174	0.1582
Netherlands	75625	13257	288.7661
Austria	33880	10696	104.3731
Poland	200448	32768	1891.7684
Portugal	16420	6698	31.6770
Romania	66554	18929	362.8461
Sweden	1831	17120	9.0283
Slovakia	20813	24408	146.3164
Slovenia	18675	28534	153.4762
Spain	37749	6866	74.6489
Czech Republic	45349	29255	382.1104
Hungary	25753	24451	181.3580
Cyprus	380	18861	2.0643
Non-EU	85467	10254	252.4161
Total	816103	443763	4666.1182

A.12

Table 26 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2021

Nationality	**Toll vehicles [number]**	**Average mileage per vehicle [km]**	**Consumption (ML)**
Belgium	24156	5972	41.5541
Bulgaria	30502	18449	162.0876
Denmark	6727	8920	17.2848
Estonia	4144	19849	23.6933
Finland	926	22072	5.8874
Finland France	33700	2298	22.3052
Greece	2097	14329	8.6554
Great Britain	Brexit		
Ireland	2368	6622	4.5168
Italy	16042	11917	55.0659
Croatia	7931	24051	54.9437
Latvia	9094	22046	57.7501
Lithuania	56477	22395	364.3241
Luxembourg	6971	14828	29.7731
Malta	61	8663	0.1522
Netherlands	77726	13432	300.7273
Austria	35255	10660	108.2507
Poland	226220	32276	2103.1383
Portugal	15496	7390	32.9861
Romania	67087	19982	386.1410
Sweden	2043	15690	9.2330
Slovakia	20082	25433	147.1177
Slovenia	18892	29698	161.6095
Spain	38069	7504	82.2864
Czech Republic	45710	29732	391.4606
Hungary	26091	24862	186.8456
Cyprus	271	22915	1.7887
Non-EU	93894	10617	287.1439
Total	868032	452603	5046.7227

A.13

Table 27 Average kilometres travelled and toll vehicle numbers and fuel consumption by nationality in 2022

Nationality	Toll vehicles [number]	Average mileage per vehicle [km]	Consumption (ML)
Belgium	24550	5860	41.4451
Bulgaria	28611	18232	150.2829
Denmark	7728	8017	17.8494
Estonia	3890	20115	22.5431
Finland	1077	17747	5.5067
Finland France	36237	2331	24.3355
Greece	2041	14850	8.7318
Great Britain	Brexit		
Ireland	2681	7233	5.5866
Italy	16655	12105	58.0832
Croatia	8129	24693	57.8298
Latvia	8411	22306	54.0531
Lithuania	56507	23282	379.0197
Luxembourg	6962	14725	29.5348
Malta	58	9749	0.1629
Netherlands	80182	12835	296.4966
Austria	33700	10832	105.1711
Poland	230322	33303	2209.8142
Portugal	15448	7247	32.2551
Romania	65531	20002	377.6331
Sweden	2187	13987	8.8130
Slovakia	19337	25198	140.3781
Slovenia	18126	30114	157.2561
Spain	38500	7450	82.6302
Czech Republic	44300	30401	387.9971
Hungary	25834	24618	183.2237
Cyprus	198	22676	1.2935
Non-EU	94960	8445	231.0497
Total	872162	448354	5068.9761