Journal of Applied Leadership and Management 8, 72 – 89

Critical analysis of carbon dioxide emissions in a comparison of e-commerce and traditional retail

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Summary

Research questions:	What impact has the transportation flow before the last mile on the comparison of carbon dioxide emissions between traditional and online retail?
Methods:	Hypotheses are tested by a mixed-method approach, which included a critical literature review and the collection of new primary data via interviews and secondary data from a collaborative company that was then used to reconstruct transportation flows. The emissions were then calculated with the use of DIN EN 16258.
Results:	This study has identified that traditional retail only produces fewer emissions when goods are directly sent from the producer to a store without any obstructions. In all other cases, online shopping produces considerably fewer emissions than traditional retail. The second major finding was that customer behavior does not influence the overall emissions.
Structure of the article:	Introduction; Literature review; Theoretical framework & methods; Empirical results; Conclusions; About the author; Bibliography

Introduction

From ‘Fridays for Future’ to automobile companies that use software to fake good emission results for their products, news about climate change fills each day’s newspapers. The consequences are that customers become more conscious about their daily decisions and their impact on the climate and they are more willing to pay higher prices for environmentally friendly products (Adaman et al., 2011). With retailers advertising their environmentally friendly business, customers struggle to decide whether going to the store is better than ordering products online and having them delivered to the front door (Schneider, 2017). Looking at already existing studies does not give a clear picture of which of the two options is better for the climate, indeed even provides conflicting results. Most studies concentrate on the last mile, which is the final route from either the shop that the customer visits to their home or the transportation from the last logistic distribution center to the customer’s home.

The question this study aims to address is: What impact does the transportation flow before the last mile have on the comparison of carbon dioxide emissions between traditional and online retail? The goal is to provide a critical analysis of the existing studies regarding carbon dioxide emission in e-commerce and traditional retail. The findings of this study could help urban planners, retailers and customers to take more environmentally friendly approaches.

Literature Review

The following section defines the background of this study by explaining the history of the topic and taking a closer look at existing international and German studies.

Carbon dioxide and its effects on climate change

The effects of carbon dioxide on the climate were first mentioned in 1861 by John Tyndall. Through experiments with different gases, he showed that carbonic acid and oxide absorb more heat than usual air; therefore with more carbon dioxide in the atmosphere, the climate becomes warmer and absorbs more of the sun’s rays (known as CO_2 radiated heating) (Tyndall, 1861). Nevertheless, this theory was dismissed by several scientists. However, from the 1950s onwards, more and more studies regarding the link between carbon dioxide emissions and climate change have been conducted, showing how human behavior can interrupt the balance between human-made climate change, such as pollution or carbon dioxide emissions, and natural reasons for climate change (Benton, 1970; Plass, 1953). Research into climate change is still ongoing, and new findings can influence customer behavior. It influences daily life, politics, law-making, and, in its consequences, all aspects of a retail business. This leads to the following chapter explaining the difference between traditional retail and e-commerce.

Background information on traditional retail and e-commerce

Traditional retail nowadays means mainly brick-and-mortar shops as well as stalls in markets that are intended to sell products or services to a private customer. In the shops, customers have the chance to try and feel the products before buying them and taking them home immediately. However, in the last few years, shopping behavior has changed, as online shopping has become a strong competitor for traditional stores. The most significant visible difference between the two is that an e-commerce business has no physical store. E-commerce gives the customer the chance to compare prices and visit an assortment of different shops without leaving the house. Several online shops use algorithms to provide recommendations for customers. Most shops also offer overnight delivery, with customers expecting speedy delivery and free return shipping. These services can make online shopping more attractive, as it is quite comfortable to shop from the couch, and impulse buys are completed much faster.

The knowledge of remote shopping via catalogues, which started in Germany in the 1870s, led to an already prominent and informed customer base by the time the first webshops were introduced in Germany, leading to a fast-growing market of online shopping, which continues to grow (Aoyama & Schwarz, 2004). The sales volume of German e-commerce in 2019 reached nearly 60 billion Euros (HDE, 2019). Recent studies show that the amount of users who order a product online is growing and has now reached more than 80% of German inhabitants aged 14 years and above (Statista, 2019b). Prices, rather than eco-friendliness or delivery speed, are the main factor for deciding which online shop to order from. The optimization and digitalization of the last mile, which means bringing more technology like tracking devices and the use of algorithms into the logistic process, are one of the most crucial success points for customer satisfaction but also one of the costliest, accounting for around 65% of the distribution costs (Heinemann, 2019).

The following two problems show which problems retailers face on the last mile that can also influence how much emissions are ejected, as the solutions to these problems influence amongst other things distances travelled and energy consumption. The e-commerce delivery problem concerns the fact that the delivery from the depot to the customer needs to be cost- and punctuality-driven and as far as possible environmentally friendly. The problem consists of three major components: parcels, vehicles and depots. Emissions can be significantly reduced if retailers use a good algorithm that takes into account whether the delivery or e-commerce business has a heterogeneous fleet, which includes traditional cars and trucks, electric vehicles, and bikes. Changing home delivery to general pick-up points decreases emissions and costs for the business. The same applies to bundled shipments when one customer orders several products. (Heshmati, Verstichel, Esprit, & Vanden Berghe, 2019).

The travelling salesman problem addresses another problem in the last mile, where a route needs to be found with the minimal distance required to visit each customer at least once so as to be fast and efficient. This problem can be solved by using an algorithm to assign parcel lockers for customers to pick up their orders instead of delivering to every single person. This leads to a significant reduction in costs and emissions(Jiang, Chang, Zhao, Dong, & Lu, 2019).

The following section critically reviews previous comparative studies of traditional retail and e-commerce. It also highlights the main influences and limitations of these studies. The review is conducted in chronological order and sorted according to international and German studies.

Analysis of existing studies

During the literature research, it became apparent that the number of studies available on carbon dioxide emissions or greenhouse gases (GHG) for retail and e-commerce transportation flow is limited. Most international studies concentrate on a single country. Only one study could be found that compared different countries and their product transportation flows with its emissions (Rizet, Browne, Cornelis, & Leonardi, 2012). It is especially notable that since March 2013, a European norm (DIN EN 16258) has existed for calculating GHG and energy consumption for logistics companies, but only a small number of studies have used this norm.

International studies

One of the earliest studies comparing online shopping and traditional retail took place in 2001 in the USA. Matthews, Hendrickson, and Soh (2001) examined the emissions of selling books worth one million U.S. dollars (~ 286.000 books) in a generic scenario, simulating the transportation flow from the publisher to the customer. The results showed minimally better environmental benefits for e-commerce. However, the authors admitted that playing with some of the variables in the study could quickly lead to a better outcome for traditional retail.

In the intervening years, little research was conducted until 2010, when the “last mile” became the focus of a group of researchers for comparing online and traditional retail emissions. They recognized that no data exists about the amount of bought products per customer per shopping trip. J. B. Edwards, McKinnon, and Cullinane (2010) used statistics and primary data from UK online retailers to construct several last-mile scenarios. The results showed that a customer has to buy 24 non-food items per trip to produce less carbon dioxide than having up to 23 products delivered from an online shop. These results indicate that the behavior of the consumer determines whether online or traditional shopping is more environmentally friendly. The overall results were that the emissions for one product are 0.18 kg CO_2 when purchased online, 4.27 kg CO_2 when the customer drives a car to the store, and 1.27 kg CO_2 when the customer uses the bus.

The study of Rizet et al. (2012) used four different products and their supply chains from the producer to the customer to compare the emissions produced in France, Belgium, and the UK. It used the well-to-wheel emissions to calculate the CO_2 emissions from on-road transportation with conversion factors provided for logistics companies by the French Ministry of Ecology, Sustainable Development, and Energy in 2010. Whilst taking the emissions for storage and retail into account and comparing different kinds of retailers, it did not consider return shipping or recycling emissions. Web Surveys further analyzed the shopping trips of the customer. The results show that it depends on the product and the supply chain whether e-commerce or traditional retail produces fewer emissions.

Several studies (Carling, Håkansson, & Jia, 2013; Määttä-Juntunen, Antikainen, Kotavaara, & Rusanen, 2011) have examined the impact and trends of large shopping centers in rural areas, which require the customer to drive further, but usually result in a customer purchasing more products per visit. Other studies concentrated on the ideal location for retail in order to reduce carbon dioxide emissions by up to 22% (Carling, Håkansson, & Rudholm, 2013).

One Canadian study by Vigder (2013) examined the critical impact of consumer behavior on emissions when shopping, like return shipments. The study’s results of emissions per product, which are 0.5-1.4 kg CO_2 for online shops, 0.5-1.0 kg CO_2 for downtown stores, and 0.7-1.3 kg CO_2 for out-of-town shopping centers, showed that traditional retail produces less carbon dioxide emissions than online retail when comparing only the last mile. Finally, due to so many influences, it is hard to say which retail form should be preferred with regard to environmental friendliness. However, out-of-town shopping can lead to an increase in last-mile emissions of up to 60% compared to downtown or edge-of-town shopping. These results should lead to different thinking when planning cities and infrastructure (Carling, Håkansson, & Jia, 2013).

A case study in Sweden found that purchasing a standard electronic product via e-commerce produces 84% fewer emissions than buying one in a brick-and-mortar shop. However, the products were delivered to a pick-up point.

Travel to this pick-up point was also taken into account, and the significant difference in emissions stems from delivering in one truck and ideally picking up the parcel within walking distance. In comparison, the average distance to a brick-and-mortar store was 49 km. The study does not consider warehouse stops for either the traditional retail stores or the online shop. The algorithm, based only on existing data, took into account the shortest routes to the stores and their locations within the Dalecarlia region. No new data had been gathered. However, the algorithm was also used to calculate the emissions if the locations of the stores and delivery points were optimized. Using the optimal location, the emissions difference was 77%, but e-commerce still had a lower emission rate. The study also simulated what happens if the capacity level of the used trucks were to be 30% instead of 80%. In the last calculation, it would only lead to an average difference of 13 g CO_2 per parcel for brick-and-mortar shopping, but a difference of 27 g CO_2 for online shopping (Carling et al., 2015). These findings highlight the importance of utilization, making effective use of the trucks, warehouses, and available space, during the transportation flow, and how locations can influence CO_2 emissions.

A recent study in China comparing emissions of transportation, packaging, buildings, and returns has shown that e-commerce is better for the environment despite the higher additional packaging. The critical point is that the same return rate for both retail types was used. It identified packaging as the largest emissions producer overall. The researchers also used the stochastic Monte Carlo simulation to deal with the uncertainties regarding the variables in the calculation (Zhao, Wu, Gong, Yang, & Ni, 2019). This approach to the calculation of emissions will be further considered in this thesis.

The review shows that the methodologies, as well as results, differ greatly between the studies. The following chapter analyses the existing German studies on the topic.

German studies

Regarding the German studies, all of them differ in their outcomes and the used methods and data. They also considered different parts of the logistics chain when calculating emissions. Some are financed by companies and cannot be rated objectively.

One of the first German studies by Wiese, Toporowski, and Zielke (2012) analyzed the CO_2 emissions of a multi-channel clothing retailer for its online shop and its brick-and-mortar stores. They started the analyzed distribution from the central warehouse. The German census bureau provided the necessary data. The study showed that fewer emissions are produced via online shopping when the distances to the stores are greater. For short distances, traditional retail is more environmentally friendly. But the results ultimately depend on customers' behavior, including the return rate and the use of public or alternative transportation.

In 2015, the German CleanTech Institut, an independent, private-sector economic research institute, conducted a study financed by the Otto Group and Hermes, who provided the data as one of the largest logistics companies in Germany. First, the study defined five types of customers using an online survey. In the end, it is unclear how these definitions help calculate emissions for both kinds of shopping. The study looked at all product groups except for fresh products. The products were divided into two categories according to parcel distribution: up to 30 kg and bulk deliveries such as furniture. For calculating the CO_2 emissions, the study used a draft from 2011 for the now-released European norm DIN EN 16258. For the distance that a product covers during its logistic cycle, the study only considered the way from the main central warehouse to the customer. Notably, this is one of the rare studies that does not concentrate only on the last mile. It also examines the number of return shipments, which were significantly higher in e-commerce than in traditional retail. For calculating emission production, the study used the average km driven between distribution points. In the end, the study showed that e-commerce generates fewer emissions than traditional retail with 0.31-0.35 kg CO_2 per product for online shopping and 0.48-0.69 kg CO_2 for traditional retail. However, the study's findings suggest that the results depend on customers' behavior. The last mile to and from the shop that the customer drives by car produces significantly greater emissions than distribution via mail. (Deutsches CleanTech Institut, 2015).

The Öko-Institut, an independent research and consultancy institution, released a study comparing the emissions of e-commerce and traditional retail in 2015. Unfortunately, the full data of the study was not presented, and it only concentrated on buying a pair of shoes. The results showed that the emissions of warehouses for e-commerce are much lower than those produced by a brick-and-mortar shop.

The transportation of the shoes with a customer using a car to visit the store produced 3,270 g CO_2. Even when compared with the last shopping mile by the customer via bike (1,270 g CO_2) or public transport (1,710 g CO_2), online shopping still produces fewer emissions (660 g CO_2). It is not clear which data and methodology were used to calculate the emissions, as the findings were mainly presented in a diagram (Öko-Institut e.V., 2015).

The Wuppertal Institut for Climate, Environment, and Energy, a private non-profit research organization, released a study in 2016 on the impact of traffic emissions for shopping via e-commerce compared with driving to a brick-and-mortar shop (Pastowski, 2016). It also critically analyses existing studies and factors that influence the number of emissions. The study takes into account trends related to mail-order business, parcel delivering, consumer behavior, and transportation of goods. The reviews did not consider the number of bought products, how often the customers go shopping, or if one trip by car consists of multiple shop visits. The study does not calculate any emissions or simulate logistics chains and only used existing data.

A smaller study in 2019 compared only the last mile for online grocery shopping and supermarket visits in Germany without taking return shipments into account. It did consider packaging and that two paper bags will be used when visiting a supermarket. It used data from the German census bureau for a two-person household. It also considered acoustic emissions without any apparent justification; the calculation method for CO_2 emissions was not made clear, and no numerical results were presented. The study concludes that e-commerce is neither ecologically nor economically better for the customer (Koutsomitis & Lochmahr, 2019).

All the above findings have the same methodological issue in common, which is mentioned while comparing online and traditional retailers by J. Edwards, McKinnon, and Cullinane (2011). Setting appropriate systems boundaries is key when setting up such a study, as the related assumptions can highly influence the findings. An essential part of this research is to choose the right approach for calculating carbon dioxide emissions. It is vital to make the thesis comparable and reliable. The following section provides insight into this subject.

Analysis of methods for carbon emission calculation

Browsing the Internet produces several carbon dioxide calculators for customers and logistics companies, and there are also apps available. It is difficult to determine if the data from online calculators is necessarily reliable, as not all show the method and data resources.

The German Federal Environmental Agency financed a study in 2007 to develop an online-based tool to calculate personal carbon dioxide emissions. The researchers performed a critical analysis of 18 existing calculators. This study was then used to create an online calculator that is now widely in use. It includes the categories living, mobility/travelling, nutrition and consumption, and information about spending behavior, but not the shopping methods. Therefore, it is not suitable for the purpose of this thesis (Schächtele & Hertle, 2007).

Until 2013, there was no universal standard for calculating emissions in logistics (Kranke, Schmied, & Schön, 2011). Companies and studies therefore used different methods and data to calculate their emissions. France decided to obligate each logistics company to disclose the emissions of its transports starting on 1 October 2013. As there was no standard, France applied in 2008 for a European norm and released its decree with its data and values published by the French Ministry of Transport. In 2013, the European Union inaugurated the European norm DIN EN 16258 for calculating GHG in transport (DSLV-Deutscher Speditions- und Logistikverband e.V., 2013). The norm was mainly designed by COFRET, a consortium of 14 European (primarily research) institutions from eight European countries, to develop and test a methodological framework for accurately calculating GHG emissions in the context of supply chains. The DIN does not take into account emissions of buildings, warehouses or handling, but is planned for future adaptations of the norm. It takes into account the emissions produced by the fuel or electricity used by the vehicles. It provides the opportunity to calculate the emissions not only for transport but every single parcel.

The Deutsche Post AG and ARKTIK, a young company offering climate-saving solutions for other businesses, both provide an online carbon dioxide calculator for single deliveries based on DIN EN 16258. The calculator from ARKTIK is based on the guidelines of the DSLV Bundesverband Spedition und Logistik e. V. (DSLV), a representative central and federal association of around 3,000 freight forwarding and logistics service providers, regarding DIN EN 16258. ARKTIK is open about the basis for their calculations and where and why they deviate from the data provided by the DSLV (ARKTIK, 2020; Deutsche Post AG, 2017).

Together, these studies and methods provide important insights into the comparison between carbon dioxide emissions of transportation flows. The following section will discuss the ideas and concepts that are the benchmark of this thesis.

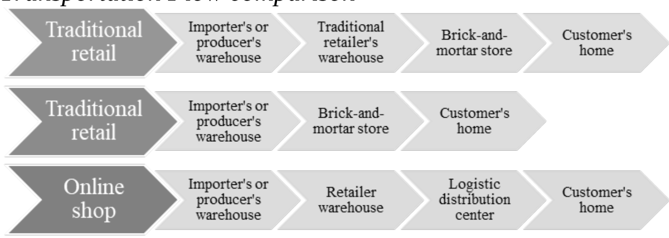
Theoretical framework & methods

The introduced and reviewed studies, calculators, and methods are all diverse. No approved and established theoretical models or methods exist for this kind of research. As discussed previously, most studies concentrated on the "last mile." The results greatly depended on the behavior of the customer. Nevertheless, these results can be influenced by researchers, who have found solutions to the travelling salesman problem and the e-commerce delivery problem. Much uncertainty still exists about the connection between the emissions released when it travels along with the complete transportation flow. This study aims to contribute to closing this gap in research. It will take a step back from the customer and will concentrate instead on the transportation routes the products take on their way to the customer and hereby compare traditional retail with e-commerce. The goal is to analyze the whole transportation flow of a company's stock until single products end up with the consumer.

The distance a product is transported before it reaches the store or the distribution center are noticeably longer than the last mile. However, more products can be transported via truck than a passenger car, although more fuel is used. This study will focus on the transportation stages inside the German border. The transportation flow starts either from the importer's or producer's warehouse, assuming that, until the border of Germany, products that are not produced in Germany have the same transportation route, regardless of whether they are sold online or in a brick-and-mortar store. The vertical distribution structure and its transportation train are of particular interest. This paper argues that research into whether e-commerce or traditional retail produces more carbon dioxide is reliable if it only focuses on the last mile, as it misses a substantial part of the transportation flow that each product has to follow. Figure 1 shows the transportation flows that will be further researched.

Figure 1

Transportation Flow comparison



In several cases, the step of the traditional retailer's warehouse is skipped, and goods are directly transported to the store. With the use of real data from a logistics service provider, the calculations for the flows become more realistic. For calculating the emissions, two locations of a customer's house will be assumed: Flensburg in the far north and Kempten in the south of Germany. This assumption will provide the chance to determine whether the customer's location influences the emissions produced, especially if the researched retailer has only one warehouse to ship or distribute goods from to its stores. The results will further broaden the question of the optimal location of warehouses and stores to produce fewer emissions.

To calculate the carbon dioxide emissions produced during the transportation of the products and to remain comprehensible, this study will use the inaugurated European Norm DIN EN 16258. Through its standardization, the study can easily be repeated, but can also be updated accordingly to the norm. DSLV released a manual to help companies calculate GHG according to DIN EN 16258. That manual will be used in this thesis as well (DSLV-Deutscher Speditions- und

Logistikverband e.V., 2013). As the sample size is not optimal and only data from one logistics company is available, a Monte Carlo simulation is used. The Monte Carlo simulation is a stochastic method based on a considerable number of similar random experiments; it is an option to deal with only having limited data, especially when only small samples are available. It allows for the simulation of other transportation flows to find the average production of carbon dioxide in e-commerce and traditional retail. This provides a universal result that most studies lack. Three simulations will be conducted: carbon dioxide emissions for direct delivery to the store, the emissions produced when goods have an additional stop at a traditional retailer's warehouse, and the case with an extra stop at the online shop distribution center.

Hypotheses

Based on the literature review and theoretical framework, the following hypotheses are introduced.

The first hypothesis: E-commerce produces fewer carbon dioxide emissions than traditional retail on the way from the producer to the customer because of a more efficient logistics chain. This can be proven by the following results:

1) A product that follows the same number of steps in the transportation flow produces fewer emissions when bought online.

2) When a product in traditional retail follows fewer steps than e-commerce, e-commerce produces fewer or the same amount of emissions.

The second hypothesis: The emissions of customers on the last mile have a significant influence on the overall CO_2 emissions when comparing online shopping and traditional retail. The following results will be expected to support the hypothesis:

1) When adding the customer's last-mile emissions to the results of traditional retail, e-commerce retail produces fewer emissions than if the customer uses a car.

2) When the customer uses alternative transportation modes on the last mile, such as public transport or a bike, traditional retail produces fewer emissions than e-commerce.

The third hypothesis: The location of an online customer does not influence the emissions produced due to a better distribution network. For proving this hypothesis, the following results are expected:

1) The emissions for products ordered online in Kempten and Flensburg are the same.

2) Products bought from traditional retail in Kempten and Flensburg show a tremendous difference from each other in the emissions produced.

The main objective of this study is to deepen the understanding of the relationship between the type of retail and transportation emissions. The following chapter will present the methods and calculations used, including presenting and interpreting the results, and end with a summary and conclusion.

Methodology

The literature review presented a range of methodologies used to understand how retail influences transportation and its emissions. The use of qualitative case studies is a well-established approach for comparing the emissions produced by transportation and consumer behavior. Therefore, a possible method that could have been used is comparing case studies. However, as all available case studies are not conducted within Germany and do not make assumptions, there is an issue with transferability and generalization. Conducting a case study for this study is also not an option, as there are not enough resources available to conduct, for example, real-time GPS tracking of parcels. Developing and justifying a model would require a large amount of detailed data from logistics companies, retailers, and consumers, which is not available for this study.

Given the available resources, it was decided that the study would use a mixed-method approach that included a literature review and research to gather new primary data via interviews and secondary data from a collaborative logistics company. The benefits of this approach are that it uses and combines the existing data and knowledge and a more quantitative approach will make the study better comparable.

One of the most successful logistics companies in Germany, which also operates worldwide, was only willing to share data on a restricted basis. Thus access to its database was not possible. A list of major companies in the sectors of DIY, electronics, clothing, food, and cosmetics was sorted based on sales in the years 2018 and 2019 in Germany (Statista, 2019a, 2019b, 2020a, 2020b). Unfortunately, only the data for the logistics operations for food companies and the DIY sector could be provided. Additionally, oral and written interviews were conducted with logistics service companies. This helped to gain a better insight into the received data and the last-mile transportation.

Ethics

Preparations were made to keep access to the data used in this study as restricted as possible so as to protect the data provider. These provisions allow the sharer to feel comfortable and be honest and open when providing access to the data. The amount of data that can be used depended on the willingness of the companies to share their data. The same ethics and procedures were applied to the interviews. The interviewees will be kept anonymous to provide a safe environment and emphasize more detailed answers.

Data

Around 1.3 million Microsoft Office Excel data points in two datasets (one for the DIY Sector, one for the food sector) were issued. The data provided showed the transportation flow from producers and importers inside Germany to online and traditional retailers' warehouses and brick-and-mortar stores from the beginning of April 2019 until the end of June 2019. The names of the companies sending the goods and the kind of goods were not available in the datasets. Each sender has a unique number, and the postcode and place were cited. The data did not show the whole transportation flow, the type of vehicle used, nor the amount of fuel consumed. However, after reaching back with detailed questions on the datasets, it was learned that a truck with a maximum load of 24 tons was used.

Another office at the logistics company was contacted in May 2020 via email with detailed questions about utilization and the vehicles used, responding that if a transportation goes to a company's central warehouse, the truck can also be a trailer truck up to 40 tons, but usually they use smaller trucks between 7.5-12 tons. The contradictions between these two statements can be explained by the fact that they came from two different offices inside the company. In both correspondences, the various specified and possible truck weight classes cited in DIN EN 16258 were made known. For the calculations, the study used a 24-ton truck for the distance between the importer's and company's warehouse, as this information comes from the source of the data. The transportation between the company's warehouse and its store is usually performed by a truck smaller than 7.5 tons with up to 17 stops on its way. The number of stops was not included in the calculations, as this cannot be ascertained from the provided data. The transportation from an online shop's warehouse to a parcel distribution center is performed by a 7.5-12-ton truck. This information was gathered from the written interview. The possibility of actively cooled transportation with its emissions cannot be taken into account, as there is no data available.

The dataset was cleaned of companies not on the original list provided. For the food sector, only two traditional retailers and two online shops were left. The DIY sector included three traditional retailers and two smaller online shops. Finally, the data was cleaned to remove zero values for transported weight or distance sections, which are required input variables. In the end, 35,000 data points from the DIY sector and 25,000 data points from the food sector remained, which were then used to identify the following explanations of transportation flows.

Transportation flow e-commerce – traditional retail

This study will consider not only the last mile, but the entire route from the importers' or producers' warehouses inside Germany. The data showed that traditional retailers transport their goods from producers or importers to their own regional warehouse and from there to their brick-and-mortar shops. With a less coded dataset, it would have been possible to follow the route of goods precisely from warehouse to warehouse to the shop. Therefore, datasets had to be combined to simulate a full transportation flow. The data also showed that large online shops use several regional warehouses. In contrast, small online shops only have one warehouse from which they ship their products. From there, the package is usually transported to at least one distribution center of the logistics company that ships the goods. From the distribution center, only small vehicles are used to bring the parcel to the customer's home. The following section will present the methods and equations used to calculate the carbon dioxide emissions released in the transportation flow.

Calculation of carbon dioxide for different transportation flows

Because no data on the amount of energy consumption was provided, it was necessary to first calculate the amount of fuel used with given average amounts for the size of the trucks. For the calculation, the following equation from DIN EN 16258 was used to analyze the energy consumption:

F [liter] = **W** [t] x **D** [km] x **E** [l/tkm], whereby

F = energy consumption (in liters).

W = real load weight in tons (from provided data).

D = real transportation distance in km (from provided data).

E = specific energy consumption (in l/tkm).

The specific energy consumption is determined by using the specific factors from Hausberger, Rexeis, Zallinger, and Luz (2009) and Rexeis, Hausberger, Kühlwein, Luz, and Ligterink (2013). These studies calculated the consumption for specific vehicle types from the handbook of emission factors, which were also taken into consideration when developing DIN EN 16258.

To calculate the carbon dioxide emissions, the following equation from DIN EN 16258 was used:

$\mathbf{G_w}$ (in CO_2e) = **F** (in liters) x $\mathbf{g_w}$ (in kg CO_2e/kg) whereby,

$\mathbf{G_w}$ = well-to-wheel-THG-emissions in kg CO_2-equivalent (CO_2e),

F = energy consumption (in liters),

$\mathbf{g_w}$ = well-to-wheel-THG-emission factor of measured data in kg CO_2e/kg.

For g_w, the THG-emission factor of “Diesel Germany” 3.77 kg CO_2e/kg was applied, since the trucks were all driving inside Germany. For the calculation, the well-to-wheel emission factor was used, which includes the whole lifespan of diesel and, subsequently, the emissions produced.

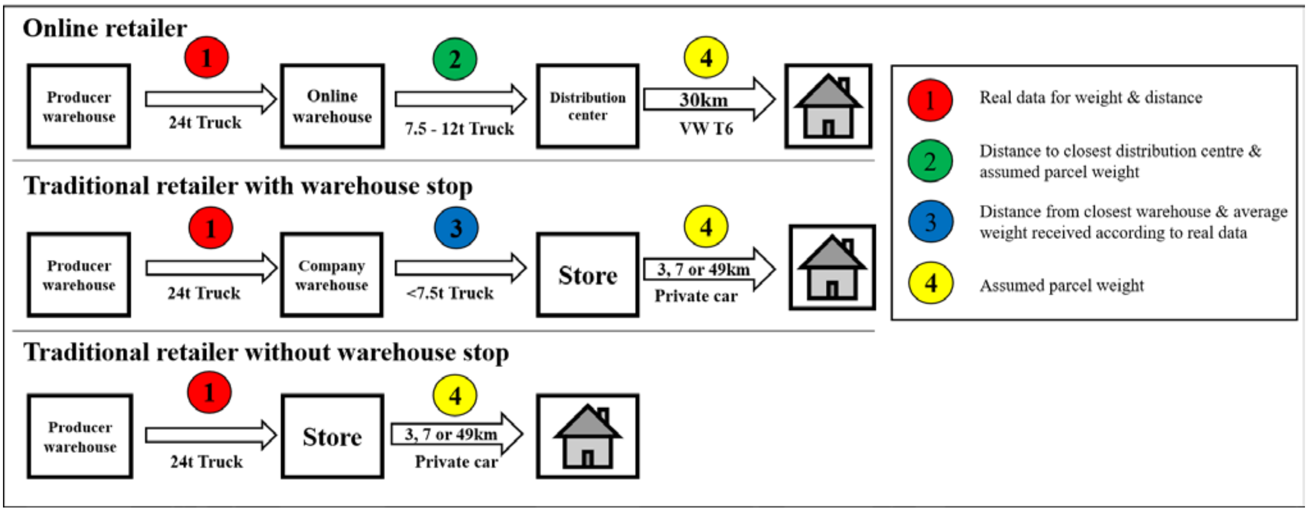
The online shop’s logistics were always considered from the closest warehouse to the closest parcel distribution center to the customer’s location. It was calculated as a transportation by another logistics partner with a diesel truck. For this transportation, no official data was available, so it was unknown if there were any additional stops or how much weight the truck was carrying in total. Therefore, only the assumed parcel weight was used for the calculation. The calculations were made with a truck of 7.5-12 tons using the previously presented equations and the specific energy consumption of 0.061 diesel use in l/tkm from DIN EN 16258, using average cargo as the shipped goods and the average longitudinal inclination profile. The same equations and assumptions were used to simulate a transportation from a company’s warehouse to its brick-and-mortar store. It was always assumed that the goods were shipped from the closest warehouse but using here the factors for a truck smaller than 7.5 tons. The weight used was the average of all transportations that the store usually receives.

The distance from the last parcel delivery base to the household was calculated at 30 km, an assumption based on a short interview with a German parcel delivery service indicating that the delivery car drives to more than one customer’s household. For the last mile for online shops, the emissions for transportation in electric vehicles and conventional diesel cars were calculated. The data provided by the automobile manufacturer for CO_2 emissions per km were used, which meant the emissions could not be calculated for the specific parcel.

The following assumptions were made for the last-mile emission: First, the consumer drives one of the four newest registered cars in Germany in 2019 (KBA, 2020) in different motor settings, cycles, or walks, making the trip solely to pick up either groceries or tools from a hardware store before returning to his or her residence. The automobile manufacturer’s stated CO_2 emissions per km were used for calculations. Second, for the DIY sector, it was assumed that the customer buys a new portable electric drill that weighs around 1.5 kg, including packaging. The average weight of groceries purchased was assumed to be 10 kg, including packaging. The same weight was used as the parcel weight from an online shop. Third, three different distances (3 km, 7 km, and 49 km) for one-way trips were assumed using the data from previous studies from Carling, Håkansson, and Jia (2013) and Carling et al. (2015). They had measured the distances using GPS in consumers’ cars. For the calculations within the different settings, the results of the different automobile types with the same motor settings were compared, and the average mean was used. The return rates used in this study were 25-35% for e-commerce and 5-10% for traditional retail (Vigder, 2013). Figure 2 gives an overview of the researched transportation flows and the assumptions and data used for the calculations.

Figure 2

Overview of researched transportation flows



The following section presents the results of emissions for the average transportation of a parcel in the DIY sector and the food sector.

Empirical Results

Several different settings were compared, including the shipping of goods from the same producer or importer. To condense the chart display, the following abbreviations are used: KE for Kempten and FL for Flensburg.

For electrical cars using energy from the public network, DIN EN 16258 calculates emissions of 0.583 CO_2e per kg in Germany. While the electric car does not produce emissions itself, the generation of the electricity does (DSLV-Deutscher Speditions- und Logistikverband e.V., 2013), which means that the last-mile transportation of a parcel by an electric vehicle is 0.87 kg CO_2e for a parcel in the DIY sector and 5.83 kg CO_2e in the food sector, no matter how far the parcel is transported. The calculated emission in the food sector means that an electrical car emits more CO_2e than transportation with a VW T6 on a 30 km roundtrip (4.8 kg CO_2) as Volkswagen only reveals the amount of CO_2 per km. The emissions for producing and transporting the diesel that the VW T6 used were not considered. Table 1 shows the different amounts of CO_2 emissions per car type that are released on the three different customers' last-mile trips. Here, the manufacturers also only reveal the amount of CO_2 per km.

Table 1

CO_2 emissions for vehicles used for the last mile by customers

	3 km	7 km	49 km
	CO_2e in kg	CO_2e in kg	CO_2e in kg
Hybrid	.588	1.372	9.604
Gas	.546	1.274	8.918
Diesel	.678	1.582	11.074
Fuel	.766	1.788	12.52

Notably, the data shows only small differences between the different kinds of motor engines and their ejected carbon dioxide emissions.

In the following section, the results for the two sectors, food and DIY, are represented and an overall analysis per sector conducted. Next, comparisons of transportation flows starting from the same producer or importer were performed to demonstrate the differences between the different types of transportation flows, highlighting how much of an influence an additional stop in a distribution center or warehouse can make.

Food sector results

In this section, the emissions for the transportation of a 10 kg parcel or grocery purchase were calculated, and three different transportation flows were compared. These included one for online shopping with a stop at the warehouse and two for traditional retail, where the product is either transported directly to the store or previously stopped at the company's warehouse.

Table 2 below shows the differences between carbon dioxide emissions in the food sector for online shopping and retail shopping using all the available data. It should be noted that because online food shop 1's warehouse is in Munich, the distance from there to the distribution center in KE is shorter and the emissions are fewer than for the other online shopping parcels. The results show the influences of warehouses in the supply chain and the effects of having several warehouses all over the country or just having one. These findings indicate that distance can influence the emissions produced.

Table 2

Carbon dioxide emissions of the food sector

	FL	KE
	CO_2e in kg	CO_2e in kg
No warehouse 3 km	89.44	55.44
No warehouse 7 km	90.3	56.3
No warehouse 49 km	99.32	65.33
With warehouse 3 km	1384.42	1092.34
With warehouse 7 km	1349.3	1093.2
With warehouse 49 km	1358.33	1102.22
Online food shop 1	329.61	67.13
Online food shop 2	231.02	238.93

The data above shows that the carbon dioxide emissions for traditional shopping are reduced by 93% in FL and 95% in KE when goods are shipped to a store directly without the diversion to a warehouse. The difference between the longest trip to a store without a warehouse stop in the transportation flow and the online delivery transportation flow to FL is 71% for online food shop 1 and only 59% for online food shop 2. The difference in KE is even lower, with just 9% for online food shop 1 and 74% for online food shop 2. The data also shows that the customer's last-mile emissions do not impact the overall emissions.

A comparison of carbon dioxide emissions for goods that were shipped from Hamburg, a city in the north of Germany, was conducted. The data shows that online food shop 1 could produce fewer emissions when shipping goods to FL (0.82 kg CO_2e) than someone from a rural area around FL who went shopping (17.55 kg CO_2e), even though no warehouse was involved. There was no data available to calculate a traditional retail shopping tour in FL with a warehouse involved. However, the findings in KE show that a warehouse significantly increases the amount of emissions, with 116.22 kg CO_2e for the 3 km last mile. The same is visible for the transportation flows starting in Trochtelfingen, where enough data was available to compare the different supermarket chains with their warehouses, but only with small sample sizes.

In the third comparison, the deliveries started from Nuremberg, a city in Bavaria not too far from KE. However, the emissions for the traditional food retailer 2 and online food shop 2 are higher for KE than FL, as the goods were first shipped to a warehouse further away. Unfortunately, only small sample sizes were available. It should also be noted that the weight of the goods was higher than in most of the other comparisons. The weight influenced the amount of emissions significantly, with online food shop 2 producing nearly ten times more emissions than the amount of emissions produced with products from a producer in Trochtelfingen.

DIY sector results

Both online shops chose a warehouse base in the south of Germany, which accounts for the minor differences between FL and KE in delivery emissions. The dataset for the DIY sector also showed that traditional retailers rarely use company warehouses. Traditional DIY retailers 1 and 2 each operate only one central warehouse, both of which, according to the data, were barely used. Comparing the differences between the emissions in Table 3 shows that a customer living in a rural area only reduces emissions by 5% when buying in a store and not ordering online at DIY online shop 1. If they order from DIY online shop 2, they would even produce 55% fewer emissions compared with going to the store.

Table 3

Carbon dioxide emissions of the DIY sector

	FL	KE
	CO_2e in kg	CO_2e in kg
No warehouse 3 km	14.43	28.6
No warehouse 7 km	14.87	29.04
No warehouse 49 km	19.39	33.56
With warehouse 3 km	199.92	318.82
With warehouse 7 km	200.36	319.26
With warehouse 49 km	204.88	323.78
Online DIY shop 1	14.91	14.55
Online DIY shop 2	36.36	36.06

A comparison of three companies that receive goods from either Ratingen or Herzeberg-Clarholz was performed. In all cases, the goods were directly transported to the stores. Starting from Ratingen, the parcel from online DIY shop 1 to the customer's home in KE produced more than double the emissions, at 46.33 kg CO_2e, than the brick-and-mortar stores traditional DIY retailer 1 (14.32 kg CO_2e) and traditional DIY retailer 3 (21.03 kg CO_2e), with a customer travelling 49 km to the store and back. The difference in emissions between traditional and online retail with transportation from Herzeberg-Clarholz is not as large as for Ratingen, with an average difference of only 11.24 kg CO_2e, even though it was the same setting just with a different producer.

In the third comparison, goods were shipped directly from Bodnegg to traditional DIY retailer 2's store in FL, producing 26.47 kg CO_2e, and traditional DIY retailer 3's stores all over Germany, producing 13.85 kg CO_2e, both calculated for a customer just 3 km away. On average, DIY online shop 1 (16.39 kg CO_2e) produced about half the emissions of transportations to FL, even without the use of a warehouse. No matter how far the traditional retail store was away and the average shipped weight, this was nearly the same for all companies.

Monte Carlo simulation results

The Monte Carlo simulations were conducted with all the available data on the previously chosen companies. Each simulation was calculated with 10,000 repeated random samplings (N = 10,000). For the online shop, KE was used as the final location. First, the results for the food and DIY sector will be presented separately, and then all incorporated data and results will be shown. The simulation data was also used to execute a one-way ANOVA with ά =.05 to see if the different kinds of transportation flows differ significantly from each other. The data for the last-mile emissions need to be added.

The results shown in Table 4 indicate that even with a higher sample size traditional retail only produces fewer emissions than e-commerce when no company warehouse is involved. Goods in the food sector that were transported directly to the store produced 94.80% fewer emissions than transported via a warehouse. The warehouse produces more than 80% greater emissions than the online shop for a 10 kg parcel. In the DIY sector, the figure is even higher, at around 84% more emissions.

Table 4

Monte-Carlo simulation of CO_2e for the food sector

	Mean	SD	Max
	CO_2e in kg	CO_2e in kg	CO_2e in kg
Trad. retail with warehouse	1216.83	990.96	5039.19
Trad. retail	63.27	358.91	1634.93
Online shopping	235.27	376.9	1539.31

The normal distribution was proved with a histogram. Levene's test was used to prove the variance homogeneity, which was only given between the online retail and the transportation flow of traditional retail without the warehouse stop. The test showed a variance heterogeneity between the two traditional retail transportation flows. However, due to the large and same sample size for each group, the one-way ANOVA is robust enough to use in this case (Bortz & Schuster, 2010).

The one-way ANOVA proves that there is a significant difference in average emissions between the three different transport flows ($F (2, 29997) = 9450.32$; $p =.000$), which means the null hypothesis is rejected.

The figures in Table 5 show that although the simulation was run with a high number of samples, the standard deviation is still high. In comparison to the food sector, the emissions are lower, and the maximum does not exceed 600 kg. The difference between traditional retail and online shopping is closer. The one-way ANOVA also proved that the difference in carbon dioxide emissions was statistically significant for the different kinds of retail transportation flows, $F(2, 29997) = 13982.55$ $p <.000$. The normal distribution was given, but the F-test showed variance heterogeneities between all three groups.

Table 5

Monte Carlo simulation of CO_2e for the DIY sector

	Mean	SD	Max
	CO_2e in kg	CO_2e in kg	CO_2e in kg
Trad. retail with warehouse	163.98	114.57	587.17
Trad. retail	16.3	30.32	138.85
Online shopping	25.25	19.83	103.26

The overall simulation with all available and suitable datasets in Table 6 shows that the standard deviation is smaller than in the previous calculations, which means that the simulation helped to simulate a better statistical normal distribution and therefore better comparable results. This table is quite revealing as, unlike the other tables, it shows that the customer's emissions play an important role when comparing the results. Adding the emissions of a customer from a rural area, the difference in emissions between online shopping and store-bought products is only 2.3 kg. Therefore, if the customer uses an older car or one that ejects more CO_2, the online shop will become more environmentally friendly. This result is significant, as it is contrary to the findings of the other two simulations. The reason could be that by combining the available data in the simulation, the datasets that were used to conduct the simulation are N = 58,162, while the DIY sector used only N = 33,146 and the food sector N = 25,015.

Table 6

Monte Carlo simulation of CO_2e complete

	Mean	SD	Max
	CO_2e in kg	CO_2e in kg	CO_2e in kg
Trad. retail with warehouse	115.21	62.9	386.69
Trad. retail	9	18.33	73.39
Online shopping	22.64	19.93	97.94

Finally, using the numbers from the complete Monte Carlo simulation in Table 6, the return rates are added, assuming that the companies sent the products back to the producer for quality checks. The results are as follows: 123.85 kg CO_2e for traditional retail with a warehouse stop, 9.68 kg CO_2e for traditional retail with direct transportation to the producer, and 29.43 kg CO_2e for e-commerce. Table 7 below illustrates the one-way ANOVA for the complete dataset without separating the two sectors.

Table 7

One-way analysis of variance of combined carbon dioxide emissions in different transportation flows

Source	*SS*	*f*	*MS*
Between groups	68335724.45	*2*	34167862.23
Within groups	46302189.34	*29997*	1543.56
Total	114637913.8	*29997*	

The data is normally distributed, but again showed variance heterogeneities through all three groups. The one-way ANOVA proves that the difference between the carbon dioxide emissions, was therefore significant $F(2,29997) = 22135.74$, $p=.000$.

Overall, the results show a trend that a transportation flow with an additional warehouse significantly increases the ejected emissions. However, the reader should bear in mind that the studies use many assumptions and show several limitations which are outlined in the following section.

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Limitations

The limitation that affects this research is a non-ideal data set which also only comes from one logistics company, leading to a small sample size.

A non-ideal dataset is a constraint that affects many scientific studies, especially in the field of freight traffic. The major limitation of this study is that no data is available for a complete transportation flow including all the necessary data such as energy consumption, vehicles used, and transported weight. In particular, data for the transportation flow between the companies' warehouses to the store or the parcel distribution center are missing. Additionally, the data used for the last mile was not measured, only assumed. It also does not provide information on the utilization of each truck and whether more goods were shipped with detours. The effect of space utilization in the trucks could not be further investigated due to missing data. Because of the lack of some information, data from other studies had to be used that are not entirely comparable with the situation in Germany. The generalizability of these results is therefore subject to certain limitations. In the next section, with these limitations in mind, the principal findings of the research are discussed.

Discussion

Despite the limitations, the data suggests that the transportation flow before the last mile has a significant impact on the comparison of carbon dioxide emissions between traditional and online retail. The results indicate that customer behavior does not significantly influence the final emissions of a parcel. These findings do not reflect the findings of earlier studies mainly because they only concentrated on the last mile, which is heavily dependent on customer behavior.

The Monte-Carlo simulation results indicate clearly, even with last-mile emissions added to the goods transported directly to the store, that buying in a store is still better for the environment than ordering online when a product does not have an additional warehouse stop. The results indicate that each extra stop of a good until a customer buys it results in a significant amount of extra carbon dioxide emissions. The customer emissions are only a small fraction of the mean emissions for traditional retail. These findings could have a significant influence on how, for example, web calculators estimate a customer's carbon dioxide footprint. The results also show that the return rate, even though it is three times higher for online shopping, does not significantly influence the end result, either.

The findings regarding the comparisons between rural shopping trips without a goods warehouse stop and online shop deliveries are contrary to the findings of Carling et al. (2015). Their results showed that online retail produced lower emissions. These results must be interpreted with caution because the missing number of goods transported from the warehouse to the distribution center or retail store have a strong influence on the calculations. It also shows that kg CO_2e emitted per parcel has a broad potential spectrum due to the possible variations in the main variables, which are distance travelled, weight, or transportation flow. The sector the company works in is irrelevant, as the results were nearly the same, regardless of whether food or DIY products were shipped. The logistic approach that a company chooses affects the overall carbon dioxide emissions, which could have been further investigated with more expert interviews.

The data gathered via the interviews was substantial to make precise calculations, although they could have been executed in a better and more detailed way by finding suitable interview partner earlier in the research process. With a structured approach and more interview partners, a comparison of different companies or just product groups would have been possible, giving the research more in-depth knowledge.

Regarding the hypotheses, the findings suggest that the first hypothesis can only be partially confirmed. The e-commerce transportation flow produces fewer emissions than a traditional retail transportation flow with the same number of steps. However, it produces several more kg CO_2 than a traditional retailer that sends goods directly to stores from the producer's or importer's warehouse. These findings are important when a retailer reviews its transportation flow and tries to make adjustments to reduce carbon dioxide.

The second hypothesis is rejected. The impact of the customer's last-mile emissions on the results is insignificant. The outcome in the comparison of the different amounts of ejected emissions per retail type stays the same. These results indicate that future research should shift its focus from the last mile to further up the transportation flow.

The last hypothesis is rejected. For traditional retail, as well as for the global online player online food shop 1, the emissions produced vary greatly, with up to 100 kg CO_2 more, mostly for FL. Only the online shops with one warehouse in Germany show a slight difference in the ejected emissions. These findings can make an impact when deciding on the locations for online retailers' warehouses.

Overall, the findings indicate that the transportation flow before the last mile has a significant influence on the emissions produced per parcel and should always be taken into consideration when trying to make environmentally friendly decisions, whether on the part of the customer or the retailer.

Conclusions

In this investigation, the aim was to assess how different retail types influence transportation emissions and if online shopping or traditional retail produces fewer carbon dioxide emissions. The second aim of this study was to investigate the effects of different transportation flows and customer behaviors on the final emissions per parcel.

The critical analysis of the existing literature revealed several existing methods to calculate carbon dioxide emissions in a transportation flow and to compare the emissions of different retail types. The result is that there is no precise answer to the question of which retail type is better for the environment, and studies' results contradict each other.

This study used a mixed-method approach, which included a critical literature review and the collection of new primary data via interviews and secondary data from a collaborative company that was then used to reconstruct transportation flows. The emissions were then calculated with the use of DIN EN 16258. The advantage of this approach is that it could pick the best solutions from the literature and combine it with new knowledge while trying to use as much real data as possible, which made the study more reliable. However, one of the most significant limitations was the fact that several assumptions had to be made due to the lack of data, especially in the lack of a full transportation flow, which needed to be reconstructed.

The present study is one of the first attempts to thoroughly examine full transportation flows of traditional and online retail and their emissions from the first warehouse in a country to the customer's home. This study has identified that traditional retail only produces fewer emissions when goods are sent directly from the producer to a store without any obstructions. In all other cases, online shopping produces considerably fewer emissions than traditional retail. The second major finding was that customer behavior does not influence the overall emissions in a way that changes which retail type is more environmentally friendly. This study indicates that an efficient and well-planned transportation flow with as little as possible obstruction and detour can lead to a better environmental balance.

Due to the use of real data from a prominent German logistics company combined with existing and approved data from previous studies, the external validity is given, and the results can at least be generalized for Germany. The internal validity is also given.

Taking into account previous studies, Germany is lacking extensive research in this area and has only just started to explore how essential that field of science might be for the future. Previous studies outside Germany have already shown that investing in environmentally friendly logistic chains and city planning can have a considerable impact on the ejected carbon dioxide in as simple a process as going shopping. Analyzing carbon dioxide emissions critically in a comparison of online shops and traditional retail is vital for the future of every retail business, as more and more customers are encouraged to ask if their behavior is environmentally friendly. Even though this thesis is limited to the data that could be gathered, it is still essential for the customer, who can now more easily decide how to buy products and how they can help to prevent climate change.

This study determines that online shopping is an excellent possibility to reduce carbon dioxide emissions when used conscientiously. A business that knows how to improve carbon dioxide emissions can answer the demands of the customers, but this is only possible if more research in this area is conducted. It is therefore recommended that in the future a more prominent study with more data and more companies interviewed should be conducted to finalize a comprehensive result and to make the data more comparable. With more details available, the customer can make a conscientious decision on how to shop in an environmentally friendly manner.

About the author

Tanja Schmitz studied Adult Education at the Helmut-Schmidt-University in Hamburg and graduated as Master of Arts in 2012. She then proceeded to serve as a Navy officer until 2019. In 2017, she commenced a part-time MBA program at the Professional School of Business and Technology in Kempten. She currently works as an Integration Engineer for Damen Naval Schelde Shipbuilding in Vlissingen.

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