E-grocery of tomorrow: home delivery of food between profitability, customer acceptance and ecological footprint

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Abstract: In this article, we present simulation results on the environmental impact of stationary grocery shopping and home delivery in terms of CO_2 emissions in four representative city districts in Hanover. Input parameters and comparison variables are based on a comprehensive literature review on grocery shopping behaviour, e-grocery delivery terms and framework conditions in Germany, while several usage scenarios aid in reproducing a realistic system set-up, ultimately allowing to quantify the CO_2 emission reduction potential through the implementation/amplification of e-grocery home delivery strategies. In order to assess and quantify the respective ecological impact of different grocery shopping activities, we developed a sophisticated agent-based simulation model. Depending on the individual behavioural scenario, multiple simulation runs employing centralised shipping of e-grocery orders from a food fulfilment centre into a metropolitan area like Hanover have yielded that e-grocery can cause up to 11% less CO_2 emissions. Nevertheless, to be able to achieve significant reductions in greenhouse gas emissions in different behavioural settings, system-level innovations and more efficient delivery concepts are required.

Keywords: e-grocery; home delivery of food; customer acceptance; simulation model; urban logistics; city logistics; urban transportation planning; stationary grocery retail; food fulfilment centre.

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1 Introduction

As result of the digitalisation, the food retail industry has experienced a fundamental transformation. Even though initial development impulses in online food retailing (referred to as e-grocery) were already evident in the 1990s, it was – despite of steadily increasing growth rates in general online trade – very uncommon to buy groceries online for a long time (Saskia et al., 2016). Especially fresh groceries were excluded from this distribution channel due to high logistical efforts and costs (Hays et al., 2005). However, in recent years, the market activity in e-grocery has significantly increased, resulting from a change in various influencing factors and external conditions compared to the 1990s. In this context, both technological progress as well as societal changes play a superordinate role (Dederichs and Dannenberg, 2017).

The consumer behaviour changes rapidly, promoting home delivery concepts for grocery and food products. Consequently, despite of the fact that the German e-grocery market is still in an early development stage, it features a very high growth potential (Seitz et al., 2015). Nowadays, more than one in every ten euros in the retail sector is spent online. Depending on the individual scenario, online-generated retail sales are even expected to make up for up to 25% of the total retail revenue by 2020 (Stüber et al., 2017). While the online grocery market is growing quickly, competitors in urban areas have to deal with profitability, market coverage and regulatory compliance, especially with regard to emissions and other ecological measures. In many cases, taking into account both behavioural patterns as well as conceptual characteristics, the impact of e-grocery in terms of reducing CO_2 emissions is not clear. While some studies indicate that e-grocery has a high potential to reduce emission outputs (e.g. Kämäräinen et al., 2001; Hardi and Wagner, 2019), other publications claim the opposite (e.g. Williams and Tagami, 2003). Hence, this paper provides a sophisticated approach to compare stationary food retail with a popular e-grocery concept, namely delivery from a food fulfilment centre. An agent-based city simulation model will be developed and employed to assess emissions in different scenarios, enabling to easily compare important performance indicators between e-grocery and stationary retail. Subsequently, the proposed approach and simulation model can be used in order to evaluate upcoming urban transport planning projects in Hanover (Germany) and other metropolitan areas.

1.1 USEfUL research project and study area

The cooperative research project USEfUL (Investigation, simulation and evaluation tool for urban logistics) started in September 2017 and is concerned with recording, simulating and evaluating future- and goal-oriented solutions for urban logistics (Landeshauptstadt Hannover, 2018a). Purpose of the USEfUL research project is the development and evaluation of inner-city logistics processes and concepts by employing simulation models. This approach is intended to create possibilities for predefining and varying influencing factors as well as options for controlling and optimising the simulated activities. Moreover, the simulative approach aims at minimising costs for the piloted applications of individual concepts, including e-grocery.

In accordance with the USEfUL research project, this paper focuses on e-grocery in the metropolitan area of Hanover. To assure a high degree of transferability concerning simulation results and associated insights, in the course of the research project, four districts have been selected based on their structural properties and individual capability of representing average urban quarter characteristics. Each of the chosen districts has different characteristics (Table 1) in terms of population density, traffic flow as well as housing and represents a specific district type (commercial, industry, residential, mixed). Consequently, the results gathered for the districts “Mitte”, “List”, “Oststadt” and “Groß-Buchholz” in Hanover (Landeshauptstadt Hannover, 2018b) can easily be transferred to other cities and urban contexts by matching the given characteristics and district types.

Table 1 Structural district characteristics (Landeshauptstadt Hannover, 2018b)

	“Mitte”	*“List”*	*“Oststadt”*	*“Groß-Buchholz”*
Inhabitants (amount)	11,576	47,078	14,794	27,405
Residential buildings (amount)	916	3105	1049	3595
Area of residential buildings (m^2)	261,758	746,776	233,217	589,770
Buildings (amount)	2317	6302	1605	8999
Total area (m^2)	2,420,000	5,010,000	850,000	7,840,000
Local supply area (m^2)	17,380	19,782	2380	7920
Land allocation – living (m^2)	201,269	2,570,185	648,551	3,302,762
Land allocation – commerce (m^2)	0	520,554	0	381,627
Land allocation – traffic (m^2)	248,912	237,742	81,410	536,207
Registered vehicles (amount)	7251	19,882	5505	13,027
• Private (amount)	3078	15,274	4355	9654
• Commercial (amount)	4173	4608	1150	3373

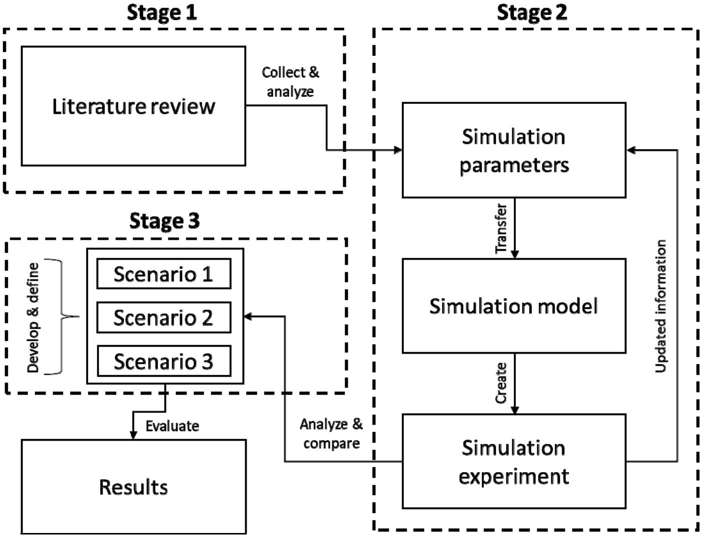
2 Problem statement

The impact of e-grocery in comparison to stationary retail in terms of kilometrage and CO_2 emissions is not clear, making it difficult to evaluate the ecological footprint and value of grocery shopping concepts. Hence, a framework is required, which is capable of checking stationary grocery shopping against central delivery by a food fulfilment centre in e-grocery. According to a rough estimation made for Bern, Switzerland, e-grocery does not have any major impact on emissions outputs (Jordan et al., 2018). By comparing distances and subsequently calculating emission outputs for stationary and online grocery shopping based on different behavioural scenarios, the individual CO_2 emission outputs can be assessed, which aids in judging the overall ecologic impact of various shopping scenarios. Ultimately, we want to investigate, if behavioural grocery shopping scenarios exist, where the given e-grocery concept is more favourable in terms of CO_2 emissions outputs than stationary retail.

3 Methodology

In order to examine the impact of e-grocery on CO_2 emissions in comparison to the effects caused by frame conditions of stationary retail, this paper utilises a research process consisting of three stages. The methodological approach has been adapted from Hamilton et al. (2005), who have utilised a similar research design to investigate the impact of tourism on climate changes. By employing the multi-stage process, a comprehensive level of analysis is ensured, as reliable and realistic input parameters can be gathered within the course of the research that subsequently form the basis of an integrated simulation model, ultimately resulting in more reliable outcomes.

Figure 1 Three-stage research process



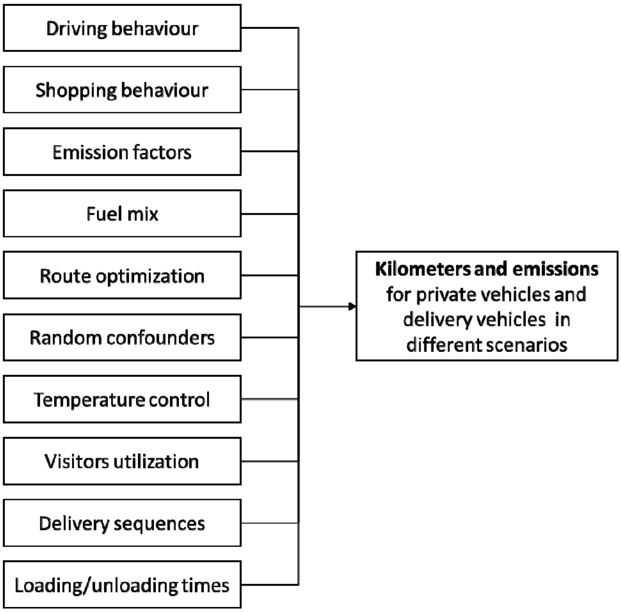
During the first stage, relevant information for the simulation model is retrieved. Secondary data from relevant literature sources is collected, analysed and reviewed to provide a thorough framework for the subsequent simulation experiment. Consecutively, based on the data and insights from stage one, a detailed simulation model is derived and developed in the second phase of the research process, providing information on the mileage and emissions caused by e-grocery as well as stationary retail. In stage three, different behavioural scenarios are defined and employed in order to analyse and compare simulation results in realistic settings. Finally, the individual simulation results of each scenario are compared and evaluated to provide insights into the previously outlined research problem. The three stage research process is presented in Figure 1 and will be expatiated further in the subsequent section.

Research process: Stage 1

For the first stage of the research process, information on the status quo of urban logistics in Hanover is retrieved from meta publications and relevant literature sources on comparable study areas in a similar context. Based on the findings of the literature review, Figure 2 delivers a synopsis on the information requirements to establish simulation parameters needed for consequently developing a simulation model capable of comparing distances and CO_2 emissions concerning e-grocery and stationary retail.

In order to collect reliable data on the required parameters, relevant publications as well as studies investigating delivery-, behaviour- and output-specific conditions in urban areas have to be analysed. In this context, a systematic literature review supplies secondary information on all necessary simulation parameters by employing a systematised approach to filter, analyse and condense data sets in terms of their respective informational content.

Figure 2 Simulation parameters for comparing of e-grocery and stationary retail



We have conducted the review in accordance with the guidelines of vom Brocke et al. (2009) and performed search queries in the library catalogues Google Scholar, AISeL and BASE in December 2018 and January as well as February 2019. Suitable references have been identified by their title, abstract and keywords using the following keyword combinations: *E-grocery*, *Germany*, *Home-Delivery*, *Online*, *Food Retailing*, *Shopping*, *Grocery and Provider*, whereby parameter categories presented in Figure 2 have been utilised as meta-characteristics for selecting relevant references. Finally, we considered 23 scientific sources (3 books, 4 book chapters, 11 journal publications and 5 working papers) for this publication.

In Germany, the share of e-grocery in comparison to stationary grocery shopping is highly inferior. About 3% of the entire population make use of e-grocery, regardless of the individual shop supplying the goods (Leyerer et al., 2018). Around 80% of German consumers have no experience at all with shopping for groceries online and less than 1% actually use e-grocery for their weekly grocery shopping activities (Plachetta and Röttig, 2012). In terms of stationary shopping, German consumers tend to use the nearest shopping facilities for 50–60% of all shopping activities, depending on the respective situation and urgency to receive the goods (Schulz 2012). Accordingly, almost half of all purchases regarding grocery shopping take place at retail locations that are not selected for proximity reasons. Pursuant to insights from a study conducted in 1978, accessibility/ distance is the primary factor influencing the destination choice for urban shopping trips (Recker and Kostyniuk, 1978). Hence, in our simulation model we assume that consumers take the shortest possible route in order to reach the desired supermarket. In terms of opening times, supermarkets generally are open from 7 am to 10 pm (Janssen, 2018).

In total, the contemplated pilot areas in Hanover feature about 8700 households that can be examined in terms of grocery shopping behaviour (Landeshauptstadt Hannover, 2017). Supermarkets can broadly be distinguished in local stores and hypermarkets, whereas 44 local stores and 11 hypermarkets are located in the study area (Google, 2019). Moreover, grocery shopping itself, depending on the shopping volume, can be sub-classified into small purchases and bulk shopping. We define bulk shopping as all orders and purchases with a total value of 50 euro (€) or more, whereas small purchases are classified by a total purchase value of less than 50 €. When it comes to bulk shopping, German consumers tend to use 1.87 supermarkets in order to satisfy their individual shopping needs (Bodkin and Lord, 1997).

Generally, about 63% of all grocery shopping trips within Europe are done for small purchases, while the remaining 37% represent bulk shopping (Nielsen, 2011). In the USA, the figures are similar, with a share of 61% small and 39% bulk purchases (Koupon Media, 2016). Regarding facilities, large-scale store formats are the preferred option when consumers are undertaking major trips and small ones when fill-in trips are carried out (Reutterer and Teller 2009). On average, consumers in Germany spend 21.01 € per trip when shopping for groceries in stationary retail stores (Bähr, 2016). In contrast, about 67.95 € are spend per order when it comes to e-grocery (Walter Fries, 2017). Here, it becomes obvious that e-grocery mainly is employed for bulk shopping, whereas the majority of stationary grocery shopping trips are carried out for small purchases. This assumption is accessorily supported by a representative study of Nobis and Kuhnimhof (2017), which proves that online shopping in metropolitan areas is generally used for small purchases in 8% and for bulk shopping in 30% of all shopping instances. The average shopping rate per day per household for both e-grocery as well as stationary retail equals 0.51 and the average duration of a grocery shopping trip in Germany corresponds to 71.16 minutes (Papastefanou and Zajchowski, 2016). Concerning shopping occupancy with regard to individual time slots, 23.8% of all consumers execute their grocery shopping activities between 10 am and 12 pm. Additionally, popular slots for grocery shopping are between 8 am and 10 am (14.2%), 2 pm and 4 pm (14.7%), 12 pm and 2 pm (16.5%) and 4 pm and 6 pm (17.2%). In contrast, the least favourable time slots are between 8 pm and 10 pm (1.5%) as well as 7 am and 8 am (2.6%) (Adlwarth and Kecskes, 2013).

In the area that is subject to this research, 54.8% of all inhabitants aged 18 or older possess a car (Landeshauptstadt Hannover, 2017). Contingent on the shopping type, the car utilisation differs. Generally, about 40% of the population in metropolitan areas employ a car for small shopping trips, while 48% use it for bulk grocery shopping. While, in contrast to purchases by bike (23%) or by foot (38%), public transport is often used for bulk purchases (53%), the majority of inhabitants prefers to do small purchases on foot (72%) rather than by public transport (24%) or bike (33%) (Nobis and Kuhnimhof, 2017). In this context, it is important to note that the given percentages are not absolutes, as interviewees were allowed to provide multiple answers, consequently providing a tendency on the modal split rather than a definite share. Additionally, more than 50% of all grocery shopping tours are instances of chained trips, meaning that shopping activities are combined with other activities like commuting to work or visiting friends, not resulting in extra distances caused by the shopping trip itself (Schulz 2012). While only 21% of the population combine tours when it comes to bulk purchases, the majority (79%) employs combined trips for small purchases (Lademann 2007).

On the basis of the e-grocery activities of a large retail grocery chain in Germany, we assume that a supplier carries out three tours per day on six days a week, namely from Monday to Saturday, with a vehicle fleet of five delivery vans and the vehicle specifications indicated in Table 2 (Heinemann et al,. 2019). A delivery vehicle generally has different temperature zones for different product categories (van der Laan, 2017). In line with the multiple-depot vehicle routing problem, delivery routes are optimised based on the tour itself, the individual route and the available capacity of the delivery vehicle (Hays et al., 2005). According to the priory mentioned retail chain, we assume a capacity of 18 deliveries per vehicle as well as average unloading times of 15 minutes per order at the customer site and loading times of 35 minutes per vehicle for all orders at the fulfilment centre. Moreover, with a likelihood of 5%, we take into account the probability of failed delivery attempts, which occur when customers are not at home during the delivery activity. In this case, a second delivery attempt is made at the following day. In line with the real-world operations of the industry partner, all delivery activities are carried out from a dedicated fulfilment centre and executed by the retailer itself.

Table 2 Specifications of delivery vehicles

Vehicle: Renault Master L2H1 + Kiesling Flat Runner							
Engine	*Fuel type*	*Pollutant category*	*kW/PS*	*Built*	*Tare weight*	*Payload*	*Size*
ENERGY dCi 145	Diesel	Euro 6b	96/130	2018	2286 kg	1214 kg	5.4 m x 2 m x 2.5 m

Compared to other metropolises, Hanover can be considered reasonably unprogressive concerning sustainable mobility. Both particulate pollution as well as CO_2 emissions per capita are very high, even though, despite of the car-friendly infrastructure, the modal split within the city is to be regarded positively. Regardless of the activity type, the city's general modal share for cars equals 38%, while it corresponds to 19% for bikes, 25% for pedestrians and 19% for public transport (Bouchain et al., 2017). In interdependence with the respective distances that need to be covered, the citizens of Hanover prefer different transport modes. Short distances usually are covered by foot or bike, whereas distances greater than two kilometres are traversed by public transport or car (Gruschwitz and Follmer, 2013). The main travel reasons in 2011 in Hanover were leisure activities (30%), shopping trips (26%), commuting to and from work (24%) as well as private errands (16%), which is particularly interesting as, on a local scale, shopping trips are responsible for more mileage than commuting to work, indicating the importance of establishing a model for grocery shopping that ensures reduced CO_2 emissions in an urban context (Gruschwitz and Follmer, 2013).

In terms of emissions, we have developed a model capable of converting distance values into CO_2 emission outputs. Based on data of various emissions categories and classes from the European Environment Agency (2016) and structural vehicle data for the four research district in Hanover (Landeshauptstadt Hannover, 2017), both the overall emission output for a specified area as well as the emissions caused by individual vehicles can be calculated. The corresponding algorithm for the described method is $E_{ij} = \sum(N_{j,kk} \times M_{j,k} \times EF_{i,j,k})$, with $N_{j,k}$ representing the number of vehicles in a nation's fleet of category j and technology k, $M_{j,k}$ illustrating the average annual distance driven per vehicle of category j and technology k in km per vehicle and $EF_{i,j,k}$ being the technology-specific emission factor of pollutant i for vehicle category j (Auf der Landwehr et al., 2019). Ultimately, we descried an average CO_2 emission output of 172 g/km for private vehicles and 230 g/km for commercial delivery vehicles as specified in Table 2.

Due to the fact that the literature review did not yield all information required as modelling inputs for Hanover, Germany, we have based the remaining parameter inputs on secondary data for other German metropolises and information provided by our industry partner. In order to provide reliable simulation results, general input data from the literature review regarding Germany or other nations have been compared to the information from our partner and adjusted accordingly. Figure 3 provides an indication about the respective data sources as well as a synopsis on the collected information and all parameters employed as modelling inputs for the simulation.

Research process: Stage 2

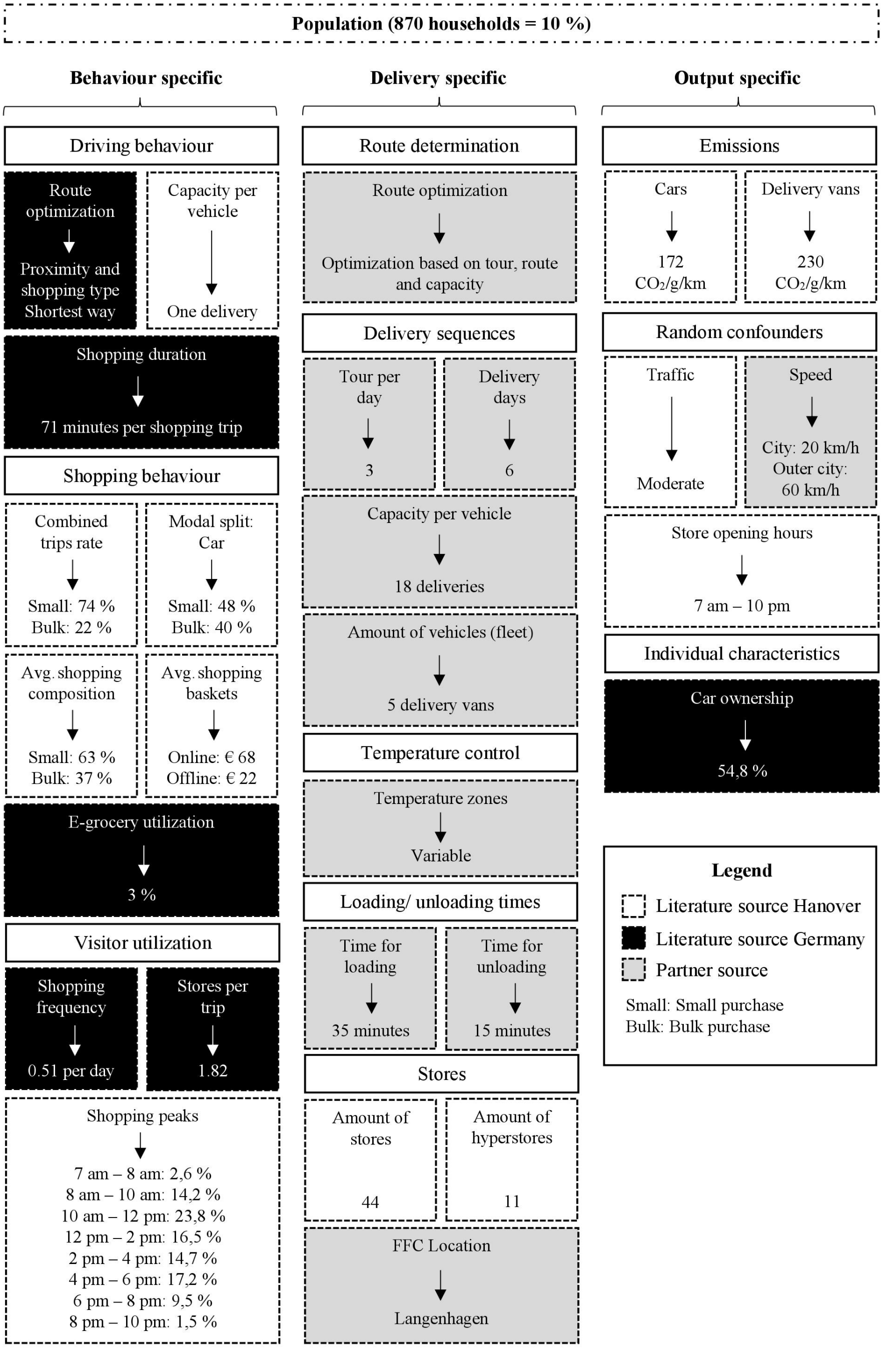
While the priory defined parameters are fundamental to the results and the validity of the simulation model, the following section will provide a comprehensive overview about the model development itself.

As a simulation incorporating the entire population (8700 households) requires long computing times, which would make it difficult to compare different scenarios based on minor changes and parameter adjustments, a sample size has been determined that is used within the simulation framework to represent the entire population. In this context, a common formula for sample size calculation has been employed (Isreal 1992):

$$((z^2 \times p(1-p))/e^2) / (1+(z^2 \times p(1-p)/e^2 \times N)),$$

where N is the size of the entire population (8700 households), z has the value 2.48 (based on a chosen confidence interval of 98.68%), e is the margin for error (0.4%) and p is the standard deviation (0.5), resulting in a sample size of 865.4, which we have rounded up to 870 to eventually represent 10% of the entire population. Moreover, in order to generate meaningful results, up to 500 orders for the given sample are simulated per simulation run, with an e-grocery tour bearing up to 96 orders per tour.

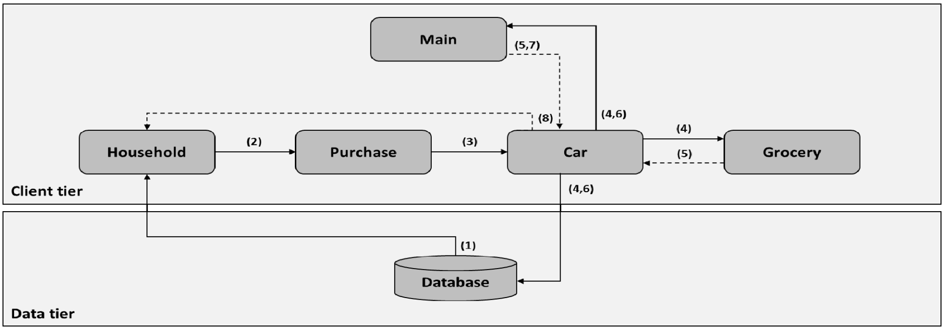
Figure 3 Parameter overview for simulation model



The simulation has been implemented and run with the software AnyLogic (Version 8.4), a multimethod simulation modelling tool supporting agent-based as well as discrete event and system dynamics modelling approaches. The software is based on Java and offers a high degree of flexibility by featuring pre-programmed model building blocks while also supporting individual development as well as GIS maps (based on Openstreetmap) including Point-to-Point navigation. For our simulation study, we have employed an integrated approach, combining agent-based modelling with discrete event-simulation. We use a time-advancing mechanism where the simulation system is represented as progress of events (discrete event simulation), which in turn are triggered by individual behaviour patterns of active objects within the model (agent-based simulation). The behaviour of individual agents as well as agent networks is controlled via statecharts, whereby each state transition represents an event progress responsible for the time-advancing mechanism. Navigation and routing procedures are based on a geospatial environment, where agents are placed in a tiled GIS-Map with pre-defined streets and routes are calculated based on distances between the given tiles. While AnyLogic provides a framework for simulation development in terms of a graphical interface and predefined functions, it does not offer integrated algorithms or simulation logics. Therefore, all dynamic functionalities such as agent objectives and networks, routing algorithms and behaviour events were coded individually by means of Java. Ultimately, two simulation models have been developed. While the first one simulates stationary retail, the second one models e-grocery deliveries from a specific fulfilment centre.

Figure 4 outlines the conceptual model for simulating stationary grocery shopping, describing the general system behaviour and its agents. Here, all elements in the client tier represent agents within the model, while the sequence of interaction events between agents during runtime is indicated by the respective numbers. Moreover, the solid lines indicate forward interactions (e.g. households make a purchase and hence trigger the purchase agent) and the dotted lines denote backward interactions (e.g. cars return to households without interacting with the purchase agent). The main agent serves as interface and graphic environment for the simulation.

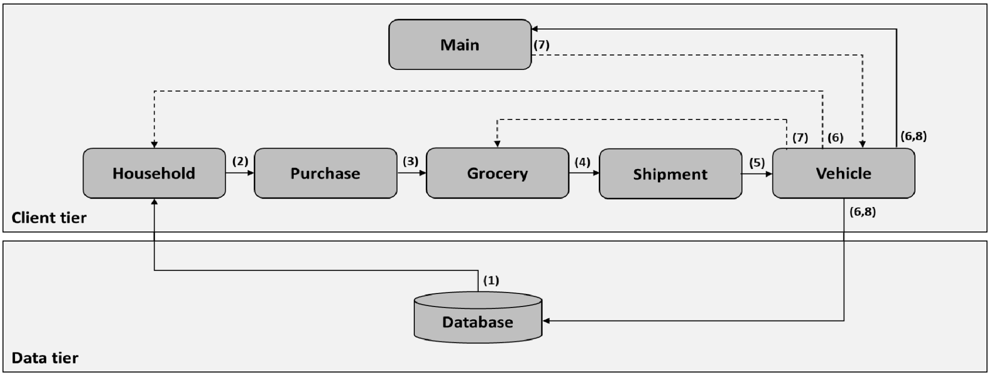
Figure 4 Conceptual model of stationary shopping



The data tier (1) is responsible for storing required information, including input data as well as results (mileage). Based on the collected information from the first step of the research, initially the address data of the households and the individual shopping behaviour are implemented into the system. Subsequently, the households are placed on the GIS-Map. (2) On the basis of the respective distributions, on a daily basis, each household agent determines whether the current day is a “shopping day” and selects a preferred shopping time slot. When the appropriate time slot has arrived, the household draws up a list with a suitable grocery retailer, where the purchase should be made and decides on a mode of transport. Depending on the shopping trip type, the customer always drives to the closest super- or hypermarkets (3). The list is handed over to the vehicle (if chosen as transport mode for the shopping trip), which immediately drives to the food retailer and makes the purchases for the defined amount of loading time. (4) The distance that has been covered by the vehicle is recorded in the database. On the simulation interface (Main), the chronologically continuous distance diagram as well as the daily distance diagram are updated. (5) Afterwards, the vehicle returns to its point of departure. (6) The route is re-recorded in the database and the distance diagrams updated on the Main interface. (7) The vehicle informs its household that the purchase has been made and (8) is returned to the household, which now determines its next purchase time.

Figure 5 provides an overview about the conceptual model for the e-grocery simulation. Here too, (1) address data and information about shopping behaviour are transferred into the system and households are placed on the GIS-Map. (2) Households determine their shopping activities and automatically generate a basket if this condition is true. Accordingly, the order is submitted to the fulfilment centre, (4) which collects all orders, groups them according to districts and initiates the delivery process at a priory defined time. Here, the time slots for the customers are determined by means of the shopping peak distribution outlined in step 1 of the research process. If the respective time slot has been reached, all orders are aggregated into one delivery and (5) consigned to the delivery vehicle. (6) The delivery vehicle drives to the household and delivers the orders. The respective routing is based on three delivery time slots, namely 7 am to 12 pm, 12 pm to 6 pm as well as 6 pm to 10 pm, and is executed by means of the k Nearest Neighbour (kNN) principle (Dudani, 1976). Here, at first the nearest customer (i) with a given time slot is determined as starting point for each vehicle in its delivery area as well as a given range. Subsequently, the last customer (i) of each vehicle is set as starting point for determining the nearest customer (i) that is still to be delivered. This process is repeated until all consumers in a delivery area are compiled in one network and no orders are left to fulfil within a given time slot. Likewise, the distance is stored in the database. On the simulation interface (Main), the chronologically continuous distance diagram is updated. (7) Afterwards, the courier returns to the delivery vehicle and continues the tour until all orders of the delivery have been delivered or the vehicle runs out of stock. If the delivery has been finished, the vehicle returns to the fulfilment centre and either redelivers outstanding orders or finishes the delivery process. Again, the mileage is stored in the database and the distance diagram is updated.

Figure 5 Conceptual model of e-grocery

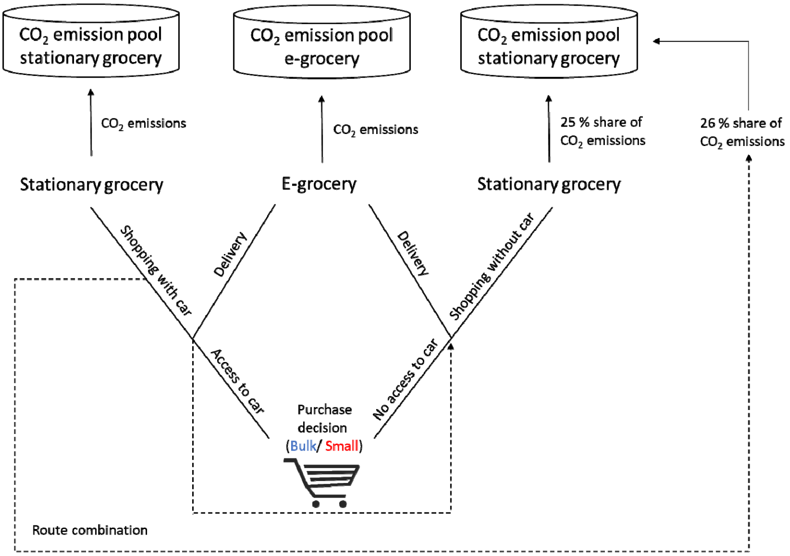


Research process: Stage 3

When comparing distances and consequently emission outputs according to the priory quantified values in order to assess the impact of e-grocery in comparison to stationary retail, several distinctions concerning different scenario cases have to be made. Hence, we defined a CO_2 emission pool for both grocery shopping types, reflecting the emission outputs of various scenarios and consequently facilitating a veritable comparison.

The general comparison approach in terms of the simulation experiment is presented in Figure 6. Based on the collected information sets on simulation parameters, first the general car availability of a consumer is analysed and evaluated. If access to a vehicle is given, three potential decision branches are available: grocery shopping by car, e-grocery or shopping without car. If the consumer decides to go shopping by car, CO_2 emissions are added to the emission pool for stationary grocery, unless the grocery shopping trip is executed in the course of a route combination. In this case, in accordance with the primary travel reasons in Hanover presented in stage 1 of the research process, a share of 26% CO_2 emissions is added, because in other instances consumers would have covered the respective distance in any case due to other primary trip reasons (e.g. leisure activities: 30%). In the case of e-grocery, additional CO_2 emissions caused by the delivery always incur and consequently are added to the emission pool for e-grocery. If consumers do not have access to a vehicle and therefore also arrange their grocery shopping tour without a car, only a limited share of CO_2 emissions will be added to the emission pool for stationary grocery, representing the shopping activities by cab and public transport. Here we have taken into account a combined data set regarding the modal split as well as the primary shopping purposes in Hanover, indicating an emission share of 2% caused by cabs and 24% caused by public transport (Nobis and Kuhnimhof, 2017). Consequently, we assume an average emission share of 25% caused by shopping activities by consumers not having access to a car. To determine the particular emission outputs for a single e-grocery delivery, we have divided the CO_2-emissions for an entire trip by the amount of orders fulfilled by a delivery van.

Figure 6 Comparison concept for CO_2 emissions in e-grocery and stationary grocery shopping



Based on the comparison concept and the given behaviour branches, we defined three behavioural scenarios, which have been used for compiling, analysing and comparing simulation results in order to assess the ecological value of e-grocery. Other scenarios that are, due to their individual characteristics and environmental constraints, unlikely to reflect the reality (e.g. "exclusively all consumers that own or have access to a car use e-grocery for all purchases instead of stationary retail"), are not implemented in the reflection process. While prior studies (e.g. Williams and Tagami, 2003) have shown that e-grocery has a negative environmental impact with low utilisation rates, we defined behavioural scenarios featuring high usage rates. Two main success factors of e-grocery as identified by Anckar et al. (2002) are increased convenience and a large product assortment. Accordingly, it is likely to assume that, if its growth continues, e-grocery will mainly be employed by customers that do not have access to a car and/or want to make a bulk purchase. This assumption is further supported by Seebauer et al. (2016), who have conducted a study indicating that e-grocery utilisation is directly motivated and influenced by car ownership.

Scenario 1: E-grocery in the given city districts is exclusively used for all purchases by all private consumers that do not have access to a car (45.2% of the population). In this scenario, e-grocery is not employed by the respective customer group to supplement stationary retail, but to entirely replace it.

Scenario 2: E-grocery in the given city districts is used for bulk purchases by all private consumers (37% of the population), while stationary retail is still used for all small purchases. These purchases are executed with the priory specified car utilisation rate (48%).

Scenario 3: E-grocery in the given city districts is exclusively used for bulk purchases by all private consumers that do not have access to a car (16.7%), while stationary retail is still used for small purchases.

4 Results

In order to produce meaningful and reliable results on the CO_2 emissions caused by e-grocery and stationary retail, 100 simulation runs per scenario (one run equals 1 day) have been executed, analysed and evaluated. While consumers generally cover about 3.7 kilometres when shopping for groceries in stationary retail stores regardless of any e-grocery scenario, on average 2.7 kilometres are covered for small and 4.6 kilometres for bulk purchases. Accordingly, our simulation for e-grocery has shown that an average distance of 2.8 kilometres in scenario 1, 2.9 kilometres in scenario 2 and 3.7 kilometres in scenario 3 is covered per order and van when deliveries are executed from the designated food fulfilment centre in Langenhagen. In line with the amount of orders and the respective capacity of the delivery vehicles, one vehicle is capable of performing 18 deliveries. Consequently, for every 19th order, a new delivery vehicle has to be used and all orders are split among the available vans, temporarily increasing the average amount of distances covered. The total number of orders has a direct influence on the distances, as it determines the utilised capacity. Overall, with the aim to equally spread orders among the delivery fleet and hence cope with the customer's flexibility requirements, the simulation has yielded a van utilisation rate of 74% (Scenario 1), 73% (Scenario 2) and 54% (Scenario 3).

Figure 7 Average total kilometrage (in km) and emissions (in kg) on 100 days in different grocery shopping scenarios

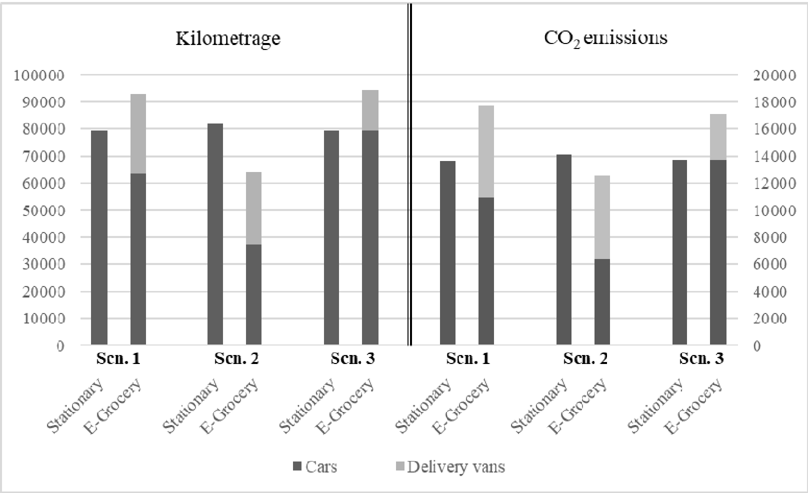


Figure 7 supplies a synopsis on the total emissions as well as distances covered in kilometres for the given scenarios in stationary grocery shopping as well as e-grocery. Typically, consumers tend to use local shops and supermarkets for small purchases, whereas hyperstores and large discounters are the preferred choice when it comes to bulk shopping. While most kilometres are covered in terms of e-grocery scenario 1 and 3, only scenario 2 results in reduced distance outputs compared to stationary grocery shopping activities. Taking into account the given van utilisation rate, in scenario 1, one delivery van covers 2.8 kilometres per order on average (2.9 in scenario 2 and 3.8 kilometres in scenario 3). In contrast, the average distance covered by private vehicles equals 3.7 kilometres per vehicle in all scenarios. As e-grocery is not employed to entirely replace stationary grocery in the given scenarios, the mileage covered by delivery vans is always supplemented by the additional mileage resulting from individual shopping activities completing the scenario. If we compare a parameter set-up exclusively comparing e-grocery to stationary retail, meaning that all customers engage in e-grocery and do not visit brick-and-mortar store anymore (100% case), the mileage caused by e-grocery is significantly lower than the mileage caused by stationary retail (50,194 kilometres vs. 91,966 kilometres).

Based on the distances replicated in the course of the simulation experiment, CO_2 emissions in grams per kilometre have been computed and added to the respective emission pool. Figure 7 shows the individual results, indicating that scenario 1 results in the highest amount of CO_2 emission outputs among all grocery shopping scenarios. The results on emission outputs, including the assumption from Setting X (Table 3), where a delivery van utilisation rate of 100% is assumed, are in accordance with our findings on the distances that are covered within the scope of the given scenarios, explicitly indicating that e-grocery can only aid in emission savings in scenario 2. However, in a best-case scenario, where e-grocery would entirely replace stationary shopping activities (Scenario 4 – Table 4), a significant amount of CO_2 emissions can be economised.

Table 3 Distances and emissions caused with 100% degree of van capacity utilisation in all scenarios

Setting X: 100% van utilisation rate	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Legend*
Kilometres per order and delivery van	2.06 ↓	2.15 ↓	2.03 ↓	123: Lowest value of all scenarios for one category ↑: Higher comparison value between both values of a category set within one scenario ↓: Lower comparison value between both values of a category set within one scenario
Kilometres per order and car	3.70 ↑	5.6 ↑	3.70 ↑	
Total distance e-grocery (km)	85.120 ↑	55.650 ↓	87.788 ↑	
Total distance stationary retail (km)	79.394 ↓	81.881 ↑	79.485 ↓	
Total emissions e-grocery (kg)	15.767 ↑	10.576 ↓	15.422 ↑	
Total emissions stationary retail (kg)	13.656 ↓	14.084 ↑	13.671 ↓	

In line with the compiled data on shopping behaviour, delivery traits and outcome characteristics, the emission pools for e-grocery often excel pools for stationary shopping activities. Concerning the given e-grocery scenarios, scenario 2 features the lowest emission outputs. While stationary retail can be expected to cause CO_2 emission outputs of about 13.700 kilograms for a total of 100 days, e-grocery induces about 17.700 kilograms CO_2 in scenario 1, 12.500 kilograms in scenario 2 and 17.100 kilograms in scenario 3.

Table 4 Distances and emissions caused with 100% e-grocery usage rate (entire population using e-grocery) and priory defined input parameters

Scenario 4: 100% e-grocery usage rate	*Result*
Kilometres per order and delivery van	2.04
Kilometres per order and car	4.29
Total distance e-grocery (km)	50.194
Total distance stationary retail (km)	91.966
Total emissions e-grocery (kg)	11.545
Total emissions stationary retail (kg)	15.818

Consequently, in a set-up taking into account our behavioural scenarios as well as the priory collected information and data sets, our simulation experiment has shown that stationary grocery shopping often results in less CO_2 emissions than e-grocery. In order to be environmentally beneficial, high e-grocery utilisation rates are required in order to efficiently utilise the delivery fleet and minimise the mileage resulting from delivery activities – especially due to the relatively long distance between the fulfilment centre and the delivery area. Moreover, home-delivery activities cause additional emissions for consumers usually pursuing their shopping activities on foot, by bike or by public transport. Consequently, even though the bundled delivery approach is more beneficial in terms of kilometrage, access distances, higher van emissions and behavioural patterns require a significant share of customers generally shopping by car to engage in e-grocery in order to considerably reduce the environmental footprint caused by grocery purchases.

5 Conclusion and discussion

We have proved that stationary retail and e-grocery distinctively differ in terms of CO_2 emissions caused by various factors interlinked with the individual concepts in the pilot are in Hanover. According to our simulation results, the simulated e-grocery concept can be regarded as inferior to stationary retail in terms of CO_2 emission output values when it is mainly used by customers that generally do not use a car for grocery shopping. Especially scenario 1, where home deliveries are exclusively used by consumers that do not have access to a car for grocery shopping, e-grocery induces a very high amount of emissions compared to other concepts. In contrast, scenario 2 yields a significant emission savings potential, adumbrating the environmental benefits of the home delivery approach when it is used universally among modal groups.

The results mainly depend on individual behavioural patterns and can distinctively differ in accordance with the employed input parameters and behaviour rules. Therefore, in order to increase the feasibility of our simulation model, in a subsequent research project we aim to develop a behavioural model capable of imitating decision making processes and customer interdependencies for grocery shopping activities. Due to the fact that recent data on modelling inputs was not always available, older information sources have been employed repeatedly, potentially reducing the overall validity of the simulation results. In this context, an additional field study regarding behaviour, delivery and output specific modelling parameters can aid in supplying valuable information and increase the overall quality of the simulation approach. Moreover, in our current model, we assume that combined routes (e.g. commuting) result in a share of additional distances contributing emissions to the emission pool of stationary retail. However, in practice, combined routes may still result in additional distances because the shopping activity requires (minor) detours. Therefore, in a follow-up project, the impact of combined routes needs to be analysed in further detail and included in the simulation model. Furthermore, additional e-grocery concepts like Click & Collect, store and central warehouse deliveries should be taken into account in future simulation experiments, as the delivery location is a major influencing factor regarding the distances resulting from home delivery. In addition, we also expect e-grocery concepts to be more favourable in terms of CO_2 emission outputs if an electric delivery fleet will be employed, which also needs to be investigated in an additional research project.

This paper and the underlying simulation model form a valuable basis for future research in terms of emission outputs caused by stationary retail and grocery delivery and support decision-making processes in urban transport planning. Apart from CO_2 emissions, also other emissions like NOx, SOx and PM can be evaluated and compared, supplying an even more profound information source for shaping future grocery concepts and make infrastructural adaptations.

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References

Adlwarth, W. and Kecskes, R. (2013) *Consumer Index: Total Grocery 08 | 2013*. Available online at: https://www.gfk-verein.org/sites/default/files/medien/1/dokumente/gfk_consumer_index_082013.pdf

Anckar, B., Walden, P. and Jelassi, T. (2002) ‘Creating customer value in online grocery shopping’, *International Journal of Retail & Distribution Management*, Vol. 30, No. 4, pp.211–220.

Auf der Landwehr, M., Trott, M., and von Viebahn, C. (2019) ‘E-grocery in terms of sustainability – simulating the environmental impact of grocery shopping for an urban area in Hanover’, in Putz, M. and Schlegel, A. (Eds): *Simulation in Produktion Und Logistik 2019*, Verlag Wissenschaftliche Scripten, Auerbach, pp.87–96.

Bähr, C. (2016*) Handelstelegramm: 04/16*. Available online at: https://www.tk-report.de/wp-content/uploads/2016/05/IRI_Handelstelegramm_04-2016_1.pdf

Barth, M., An, F., Younglove, T., Scora, G., Levine, C., Ross, M. and Wenzel, T. (2000) ‘The development of a comprehensive modal emissions model’, *NCHRP Web-only document*, No. 122, pp.25–11.

Bodkin, C.D. and Lord, J.D. (1997) ‘Attraction of power shopping centres’, *The International Review of Retail, Distribution and Consumer Research*, Vol. 7, pp.93–108. https://doi.org/10.1080/095939697343058

Bouchain, J., Große, S., Großmann, A., Runge, F. and Heinrich, C. (2017) *Städte Ranking zur nachhaltigen Mobilität*, Greenpeace e.V. Available online at: https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20170322_greenpeace_mobilitaetsranking_staedte.pdf

Dederichs, S. and Dannenberg, P. (2017) ‘Vom Nischenmarkt in die Expansion: Die aktuelle Dynamik des deutschen Online-Lebensmitteleinzelhandels im Kontext der Transitionsforschung’, *Einzelhandel in Deutschland–aktuelle Dynamiken im Kontext neuer Rahmenbedingungen*, Mannheim, pp.59–82.

Demir, E., Bektaş, T. and Laporte, G. (2011) ‘A comparative analysis of several vehicle emission models for road freight transportation’, *Transportation Research Part D: Transport and Environment*, Vol. 16, No. 5, pp.347–357. https://doi.org/10.1016/j.trd.2011.01.011

Dudani, S.A. (1976) ‘The distance-weighted k-nearest-neighbor rule’, *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. SMC-6, No. 4, pp.325–327.

European Environment Agency (2016) *EMEP/EEA air pollutant emission inventory guidebook 2016: Technical guidance to prepare national emission inventories*, Publications Office of the European Union, Luxembourg.

Google (Eds.) (2019) *Google Maps*, Map: Groß-Buchholz, Hannover; Mitte, Hannover; Oststadt, Hannover; List, Hannover. Available online at: http://maps.google.com/maps

Gruschwitz, D. and Follmer, R. (2013) *Mobilität in der Region Hannover 2011: Berichtslegung 2013*, infas Institut für angewandte Sozialwissenschaft GmbH. Bonn. Available online at: https://www.hannover.de/content/download/…/file/infas_Bericht_MiR+Hannover.pdf

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2005) ‘Climate change and international tourism: a simulation study’, *Global Environmental Change*, Vol. 15, No. 3, pp.253–266.

Hays, T., Keskinocak, P. and de López, V.M. (2005) 'Strategies and challenges of internet grocery retailing logistics', in Pardalos, P.M., Hearn, D.W., Geunes, J., Akçali, E., Romeijn, H.E. and Shen, Z.-J.M. (Eds): *Applied Optimization. Applications of Supply Chain Management and E-Commerce Research*, Vol. 92, Springer, Boston, MA, pp.217–252. https://doi.org/10.1007/0-387-23392-X_8

Hardi, L. and Wagner, U. (2019) 'Grocery delivery or customer pickup—influences on energy consumption and CO_2 emissions in Munich', *Sustainability*, Vol. 11, No. 3, p.641.

Heinemann, G., Gehrckens, H.M. and Täuber, T. (2019) *Handel mit Mehrwert*, Springer Fachmedien Wiesbaden, Wiesbaden.

Israel, G.D. (1992) *Determining Sample Size*, University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS, Florida.

Janssen, L. (2018) 'Filiallogistik im stationären LEH', in Janssen, L. (Ed.): *Abfallreduktion im Lebensmitteleinzelhandel*, Springer Fachmedien, Wiesbaden, pp.13–42. https://doi.org/10.1007/978-3-658-23012-8_2

Jordan, Y., Viebahn, C. von and Haller, S. (2019) 'Konzeptionierung von Use Cases für die urbane Logistik in einer Schweizer Smart City mittels Design Thinking', in Tokarski, K.O. et al. (Eds): *Nachhaltige Unternehmensführung*, Springer Fachmedien Wiesbaden, Wiesbaden, pp.391–420.

Kämäräinen, V., Saranen, J. and Holmström, J. (2001) 'The reception box impact on home delivery efficiency in the e-grocery business', *International Journal of Physical Distribution and Logistics Management*, Vol. 31, No. 6, pp.414–426.

Koupon Media (2018) *2018 State of the Industry: Mobile Offers in Convenience Stores*. Available online at: https://go.kouponmedia.com/2018-state-of-the-industry-mobile-offers-in-convenience-stores

Lademann, R.P. (2007) 'Zum Einfluss von Verkaufsfläche und Standort auf die Einkaufswahrscheinlichkeit', in Schuckel, M. and Toporowski, W. (Eds): *Theoretische Fundierung und praktische Relevanz der Handelsforschung*, DUV, Wiesbaden, pp.143–162. https://doi.org/10.1007/978-3-8350-9535-9_8

Landeshauptstadt Hannover (2017) *Strukturdaten der Stadtteile und Stadtbezirke 2017* (STATISTISCHE BERICHTE der Landeshauptstadt Hannover), Hannover. Available online at: https://www.hannover.de/content/download/668750/16039812/file/Strukturdaten+2017.pdf

Landeshauptstadt Hannover (2018a) *Urbane Logistik Hannover: Innovation*. Available online at: https://www.hannover.de/Urbane-Logistik-Hannover/Innovation

Landeshauptstadt Hannover (2018b) *Untersuchungsräume für das Projekt "USEfUL": Untersuchungs-, Simulations- und Evaluations-Tool für Urbane Logistik*. Available online at: https://e-government.hannover-stadt.de/lhhSIMwebdd.nsf/60FEA46F6A149348C125823600 2325C7/$FILE/Druckversion.pdf

Leyerer, M., Sonneberg, M-O. and Breitner, M. H. (2018) 'Decision support for urban e-grocery operations', *Proceedings of the 24th Amercias Conference on Information System* (AMCIS) 2018, New Orleans.

Nielsen (2011) *Shopping and Saving Strategies Around the World: A Nielsen Report*. Available online at: https://www.nielsen.com/content/dam/corporate/us/en/reports-downloads/2011-Reports/Nielsen-Global-Shopping-Saving-Report-October-2011.pdf

Nobis, C. and Kuhnimhof, T. (2017) 'Mobilität in Deutschland – MID Ergebnisbericht: Eine Studie von infas, DLR, IVT und infas 360 im Auftrag des BMVI', (FE-NR.70.904/15) Bonn. Available online at: http://www.mobilitaet-in-deutschland.de.

Otten, M.B.J., Hoen, M.J.J., Boer, L.C., CE, Oplossingen voor milieu, economie en technologie, Connekt and Topsector Logistiek (2016) *STREAM Freight Transport 2016: Emissions of Freight Transport Modes*, CE Delft. Available online at: https://books.google.de/books?id=O7upnQAACAAJ.

Papastefanou, G. and Zajchowski, D. (2016) *Zeit fürs Einkaufen: Sozialer Wandel der Zeitverwendung für Einkaufsaktivitäten 1990-2012*. Available online at: https://www.gesis.org/fileadmin/upload/forschung/publikationen/gesis_reihen/gesis_papers/2016/GESIS-Papers_2016-14.pdf

Patterson, J. (2018) 'Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies', *LowCVP*, 1 August, pp.1–54.

Plachetta, S. and Röttig, B. (2012) 'Ein Geschäft auf allen Kanälen', *Lebensmittel Praxis 2012*, No. 8, p.32.

Recker, W.W. and Kostyniuk, L.P. (1978) 'Factors influencing destination choice for the urban grocery shopping trip', *Transportation*, Vol. 7, No. 1, pp.19–33. https://doi.org/10.1007/BF00148369

Reutterer, T. and Teller, C. (2009) 'Store format choice and shopping trip types', *International Journal of Retail and Distribution Management*, Vol. 37, No. 8, pp.695–710. https://doi.org/10.1108/09590550910966196

Saskia, S., Mareï, N. and Blanquart, C. (2016) 'Innovations in e-grocery and logistics solutions for cities', *Transportation Research Procedia*, Vol. 12, pp.825–835.

Schulz, M. (2012) 'Zusammenfassung', in Kemper, F.-J., Kulke, E. and Schulz, M. (Eds): *Die Stadt der kurzen Wege*, VS Verlag für Sozialwissenschaften, Wiesbaden, pp.163–171. https://doi.org/10.1007/978-3-531-19383-0_8

Seebauer, S., Kulmer, V., Bruckner, M. and Winkler, E. (2016) 'Carbon emissions of retail channels: the limits of available policy instruments to achieve absolute reductions', *Journal of Cleaner Production*, Vol. 132, pp.192–203.

Seitz, C., Pokrivčák, J., Tóth, M. and Plevný, M. (2017) 'Online grocery retailing in Germany: an explorative analysis', *Journal of Business Economics and Management*, Vol. 18, No. 6, pp.1243–1263.

Stüber, E., Hudetz, K. and Becker, G. (2017) 'Veränderung der Geschäftsmodelle im Handel durch die Digitalisierung', in Gläß, R. and Leukert, B. (Eds): *Handel 4.0*, Springer, Berlin Heidelberg, pp.213–233. https://doi.org/10.1007/978-3-662-53332-1_11

van der Laan, J. (2017) 'Nine battles of online grocery', *Retail Economics*. Available online at: https://retaileconomics.com/wp-content/uploads/2017/05/Ebook-Online-Food-Retail-PART-1.pdf

Vom Brocke, J., Simons, A., Niehaves, B.B., Riemer, K., Plattfaut, R. and Cleven, A. (2009) 'Reconstructing the giant: on the importance of rigour in documenting the literature search process', in Newell, S., Whitley, E.A., Pouloudi, N., Wareham, J. and Mathiassen, L. (Eds): *17th European Conference on Information Systems*, Hampton Press, Verona, Italy, pp.1–13. http://aisel.aisnet.org/ecis2009/161

Walter Fries (2017) *Brachenanalyse E-Commerce: Markt and Deals*. Available online at: https://www.walterfries.de/wp-content/uploads/2016/07/Branchenanalyse-E-Commerce-02_2017.pdf

Weiss, M., Bonnel, P., Hummel, R., Manfredi, U., Colombo, R., Lanappe, G. et al. (2011) *Analyzing on-road emissions of light-duty vehicles with Portable Emission Measurement Systems (PEMS)*, JRC Scientific and Technical Reports, EUR, 24697.

Williams, E. and Tagami, T. (2002) 'Energy use in sales and distribution via e-commerce and conventional retail: a case study of the Japanese book sector', *Journal of Industrial Ecology*, Vol. 6, No. 2, pp.99–114.