The net environmental impact of online shopping, beyond the substitution bias

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Abstract

Internet, digitalisation and access to technology have transformed contemporary consumption patterns and habits. Whether or not these changes hold beneficial or detrimental implications for society is subject to ongoing debate. Specifically concerning the environmental impacts of online and omnichannel retail, claims have been made on both sides: crediting the efficiency of home deliveries versus individual shopping trips on the one hand and pointing out complex consumer behaviour on the other hand. Despite intensive research efforts, a solid consensus lacks. The disperse and contradicting scientific knowledge base that is currently available prevents policymakers and practitioners from implementing sustainability improving measures and from steering consumers towards sustainable practices. Supported by a systematic review of the literature, this article presents a framework for understanding the net environmental sustainability of shopping. The debate is broken down in three impact categories that need to be considered simultaneously: individual purchases, consumer behaviour and consumption geography. The majority of research articles focus on the environmental impact of purchasing a single item or a basket of items, in which in-store purchases are substituted by purchases online. Such studies conclude in favour of e-commerce. The balance shifts when taking changes in behaviour and geography into consideration. While behavioural reflections are on the rise, hardly any empirical work takes the spatial (re)organisation of businesses and consumers into account. The article surpasses the case-study approach and in doing so comprises the body of literature in a solid framework that is able to guide future discussions and research in more sustainable directions.

Keywords

E-commerce; online shopping; omnichannel retail; transport; mobility; environmental sustainability; conceptual framework

Introduction

Consumption patterns and habits have changed tremendously over the last decades, driven in particular by the development of the worldwide web, the digitalisation of processes throughout all aspects of society and the incremental improvements in access to technology. As with many societal developments, the consequences of transformed consumer behaviour are discussed and studied at large. Notable subjects of debate have been the impact of online shopping on local and independent retail, the implications of the on-demand economy on the organisation of work and the transformation of restaurants and supermarkets due to meal kit and prepared meal delivery services. Subject of ongoing debate as well is the impact of online and omnichannel retail on the environment, i.e. on climate change, air pollution, congestion and noise emissions.

As a sector, retail is one of the most visible economic activities. Retailing accounts for 3.6 million businesses in Europe and, together with wholesaling, represents over 23% of all enterprises (European Commission, 2018). To organise their activities, retailers depend heavily on transport, a leading contributor to greenhouse gas and air polluting emissions (WHO, 2011). Transport operations of retailers involve different forms of transport; different sizes of containers and vehicles; and the scheduling and availability of drivers and vehicles (Fernie and Sparks, 2009). Among consumers, travel for shopping represents approximately

20% of trips (Guy, 2009; Jiao et al., 2011). Transport for retail is an important aspect of mobility (Hagberg and Holmberg, 2017) and thus vital to include in our global and local environmental sustainability goals.

The advent of the online retail channel, said to replace many individual store visits by one efficient home delivery round, inevitably spurred questions about its capacity to lower the retail sector's environmental footprint (Cairns, 2005; Cullinane, 2009). E-commerce is defined as the sale or purchase of goods or services, conducted over computer networks by methods specifically designed for the purpose of receiving or placing of orders, whereas payment and delivery of the goods or services do not have to be conducted online (OECD, 2011). In essence, the environmental sustainability question of shopping online or in-store is a matter of transport operations and conditions, albeit one that concerns retailers, logistics service providers as well as consumers.

While e-commerce comprises pure players with an online-only approach, it also advanced omnichannel retail. This retail model comprehends the gradual change of pure players to a combined and integrated bricks-and-clicks approach (Lazaris and Vrechopoulos, 2013; Piotrowicz and Cuthbertson, 2019; Verhoef et al., 2015). Traditional store-based retailers in particular transformed towards an omnichannel retail approach first (e.g. many high-street clothing chain brands). Later on, also established pure online players created a physical presence (e.g. Amazon with the acquisition of Whole Foods). As such, the retail sector developed into a realm in which online and offline channels blurred and converged into one another. Conventional in-store shopping has online extensions through mobile web-shops, kiosks and screens, among others. Contrary, through services such as click-and-collect (or buy-online-pick-up-in-store), ship-from-store and in-store return of online purchases, online shopping has a physical extension in-store.

Along with these advancements, it has become increasingly difficult to understand the environmental implications of shopping in one retail channel over another. Accordingly, research initiatives aimed to provide an answer to this question are bound by parameters, assumptions and specific context conditions. Although based on solid scientific knowledge (e.g. consumers' average travel distances for shopping), these parameters, assumptions and conditions are often set quite strictly (e.g. specific product type), leading to contradicting research results. Setting system boundaries is necessary and not problematic in itself. In providing answers and guidelines on which way of shopping impacts the environment less, the narrow purchase-focused approach that is used, is.

By comparing for example the vehicle-kilometres and vehicle emission factors associated with an in-store purchase and a purchase executed online, very detailed and context-specific research results are obtained that are hardly generalisable into actionable guidelines. More importantly, this approach disregards the broader behavioural and geographical developments that are pushed by e-commerce. On the behavioural side, Rosqvist and Hiselius (2016) for example discuss "car-dependent lifestyles" facilitated by online shopping while Buldeo Rai et al. (2019) investigate the carbon footprint of pre and post-purchase travel behaviour. On the geographical side, Wygonik and Goodchild (2016) demonstrate the importance of land use conditions such as consumer density and warehouse location while Gee et al. (2019) consider supply chain differences in production and storage location for online and offline shopping scenarios. Possibly, such changes in consumer behaviour or consumption geography could impact the environmental footprint of online shopping to a more important extent.

The objective of this article is to comprehensively approach the environmental sustainability question of shopping online and offer a comprehensive view that explicitly includes behavioural and geographical considerations. By conducting a systematic review of the scientific literature, all relevant parameters are organised in a summary framework. The article contributes by providing a straightforward basis for discussion as well as communicable and actionable guidelines for every stakeholder involved in the retail realm, including consumers. The methodological approach applied in this article is presented in section two and its findings are discussed in section three. The fourth section ends with concluding remarks.

Methodology

Systematic literature review

The systematic literature review is a method of locating, appraising and synthesising evidence and an efficient technique for hypothesis testing, summarising the results of existing studies and assessing consistency among previous studies (Petticrew, 2001). Petticrew and Roberts (2005) specifically point out their relevance to support policy and practice: by creating a valuable backdrop of evidence on which decisions about policies can draw and by providing a key source of evidence-based information to support and develop practice (Petticrew and Roberts, 2005). In this way, the methodology fits the objective of this study seamlessly.

Systematic literature reviews differ from traditional, narrative reviews in that they strive to locate all relevant studies and provide an explicit description of what types of studies are to be included (Petticrew, 2001). In doing so, the method limits the impact of publication and selection bias on behalf of the reviewer. Systematic literature reviews usually start off with a clear question to be answered or hypothesis to be tested (Petticrew, 2001). In this research, the methodology serves to firstly, verify and validate the understanding of the net environmental impact of online shopping that includes behavioural and geographical developments pushed by e-commerce and secondly, identify relevant parameters that need to be taken into consideration.

Systematic literature reviews have been applied in research fields related to the subject of this study. For example, Seuring et al. (2012) address their significance in supply chain management. The authors encourage researchers to “deliberately head for transparency and rigour in their review endeavours”. Lagorio et al. (2016) consolidate the scientific knowledge on urban logistics published between 2000 and 2015. In doing so, the authors identify e-commerce as a recently emerged topic and call for “further methodological investigation”. On the topic of e-commerce in particular, Mangiaracina et al. (2015) systematically review the environmental implications from a logistics perspective. The authors identify transport planning and management, (2) warehousing, (3) packaging and (4) distribution network design as key issues.

Using three scientific databases (Science direct, Scopus and Google scholar) and 18 combinations of 23 keywords, a total of 43 articles was compiled on February 9th, 2021. The keywords were selected to locate articles that empirically or theoretically compare (keyword “comparative”) the environmental impact (keywords “environmental impact”, “environmental sustainability”, “carbon”, “greenhouse gas”, “CO_2”, “emissions”) of shopping physical products online (keywords “e-commerce”, “electronic commerce”, “online retail”, “online retailing”, “electronic retail”, “online shopping”, “e-shopping”, “home delivery”, “omnichannel”, “omni-channel”) versus in-store (keywords “conventional”, “traditional”,

"offline", "brick-and-mortar", "pickup", "pick-up"), to meet the article requirements. See annex 1 for a detailed overview. In addition, only peer-reviewed journal articles published after 2005 were included to guarantee quality and relevance, see annex 2 for a complete list. Only the 150 first results of Google scholar searches were taken into consideration. Despite an extensive list of references found in response to the keywords, only a comparatively limited number of articles actually compare online and offline shopping based on environmental variables such as carbon footprint, energy consumption or transport-kilometres. Moreover, many of the same articles appeared in multiple searches.
All articles were read, reviewed and analysed in a spreadsheet file. Two types of information were collected, first on the article details and content and second on the parameters applied in the articles. Specifically, information on the article title, year of publication and journal of publication was stored, as well as information on the geographical context to which the research applies, the product type investigated, whether the last mile or the broader supply chain was assessed and which impacts were investigated in the article. The latter categorisation addresses whether the research in the article focuses solely on the environmental impact associated with a purchase online or in-store, or if it also addresses behavioural and geographical changes by consumers, retailers or logistics service providers as a consequence of e-commerce.

Review corpus

The environmental impact of online shopping compared to shopping in-store is a relatively new research topic that emerged in the last twenty years, but gained particular momentum in the last decade. Less than half of the articles considered in this research were published between 2005 and 2015, more than half were published in the five years after. One fourth of articles (11) are set in the United States, one third (16) are focused on a European country and three articles investigate the Chinese case. This roughly reflects the places around the world were e-commerce developments are most mature, although countries such as Japan are missing and countries such as China are considerably underrepresented. In the aftermath of the COVID-19 pandemic, research on this topic is expected to continue to grow and its research contexts to diversify.
Three types of journals were found to publish the articles considered in this research: (1) environmental journals such as *Environmental Science & Technology*, *Journal of Cleaner Production* and *Resources, Conservation & Recycling*, (2) transport journals such as *Research in Transportation Economics*, *Transport Reviews* and *Transportation Research* and (3) logistics journals such as *International Journal of Logistics Systems and Management*, *International Journal of Physical Distribution & Logistics Management* and *Supply Chain Forum: An International Journal*. Evident explanations are (1) the focus on environmental issues, (2) transport activities being key in assessing the environmental impact of e-commerce and (3) e-commerce being a rapidly growing supply chain type that disrupts logistics processes. Yet the absence of retailing journals is striking. Moreover, with end-consumers at the outset of supply chain demand (as buyers), as well as at the end (as receivers), also the lack of marketing and psychology journals stands out. It highlights the research needs associated with consumer behaviour. Geography journals are missing as well, hampering our understanding of how e-commerce shifts the spatial organisation of businesses (e.g. retailers and logistics service providers) and consumers and how that impacts on the environment. As such, this gap emphasizes the research needs associated with consumption geography.

Figure 1 illustrates the journals that contribute more than one article to the review corpus, the publication year of the articles and the investigated countries.

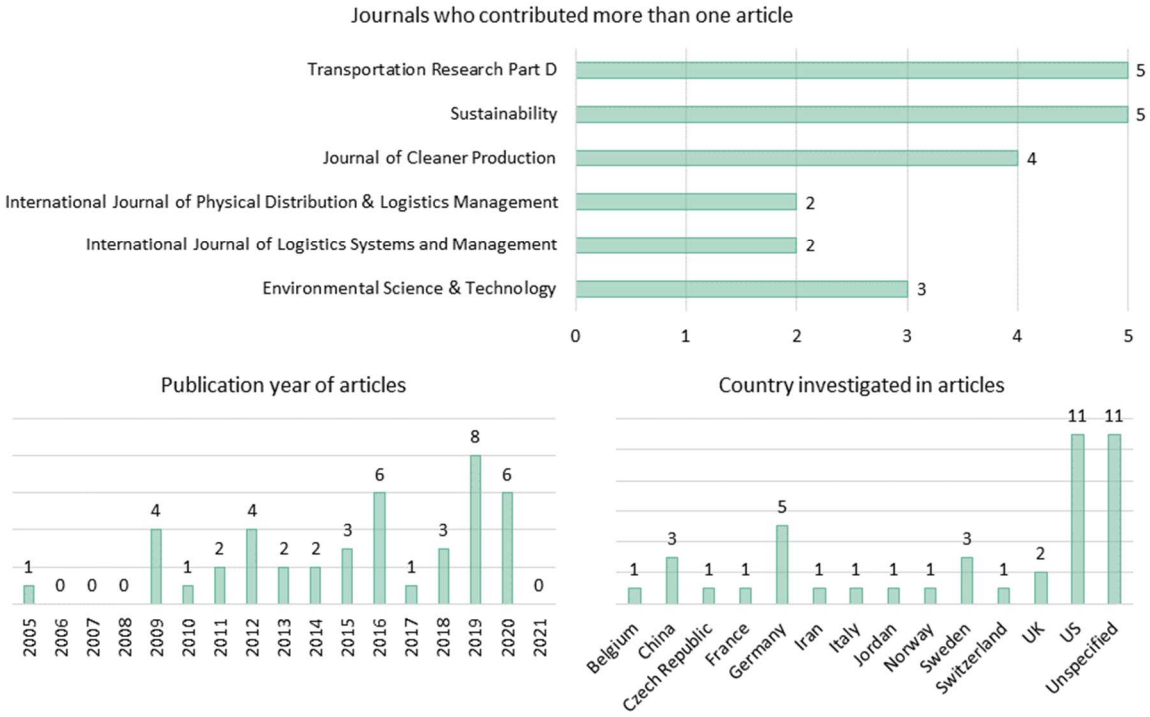

Figure 1. Review corpus journals, publication year and country investigated.

This research focusses on shopping physical products, allowing to compare their environmental implications throughout conventional retail on the one hand and online retail on the other hand. Nevertheless, e-commerce has greatly facilitated the digitalised consumption of products that were once solely available in material form (e.g. entertainment such as music, books, films). Where these products required transport before, they do not anymore. An evolution that can be considered positive from the perspective of this research, although its behavioural consequences are even less investigated or understood. In our review corpus, most articles (24 articles) investigate non-food products, mainly apparel, books, electronics and fast-moving consumer goods. Food products are studied as well (10 articles), mainly groceries but also meal kits. Meal kits have emerged as a research topic in the last years, comprising boxes of pre-portioned ingredients and corresponding recipes that are delivered directly to consumers as a way of replacing regular groceries (Gee et al., 2019).

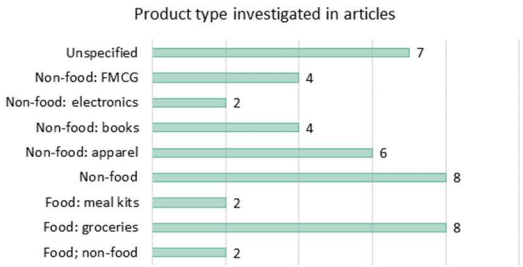

Figure 2. Product types in review corpus.

Six articles (or 14%) of the review corpus are literature reviews. Seven articles (or 16%) present questionnaire analyses and the majority (thirty articles or 70%) provide case-study calculations of environmental impacts. This article reorganises previously proposed concepts and considerations, extends them into a framework and proposes a straightforward basis to discuss and enhance the environmental sustainability of online shopping.

Findings

The findings of the systematic literature review can be fitted into the framework that has been proposed earlier. Thus, to understand the net environmental impact of online shopping, consideration needs to be taken of key parameters associated with (1) individual purchases in which deliveries are considered substitutes for store travel, (2) consumer behaviour transformed by e-commerce and (3) implications to consumption geography that transform the act of purchasing in a broader sense. All relevant parameters are presented in Figure 3 and Table 1, as well as discussed more profoundly in the following sections, focussing specifically on how they contribute to contradictions in research.

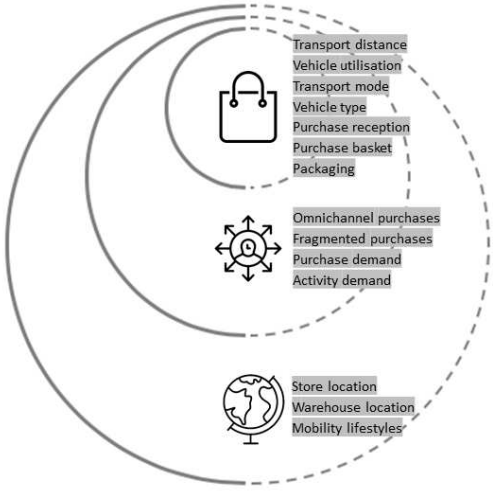

Figure 3. Three categories to assess the net environmental impact of online shopping.

Individual purchases		**Consumer behaviour**		**Consumption geography**	
Transport distance	Long -	Omnichannel purchases	More trips per purchase -	Store location	Remote -
	Short +		Less trips per purchase +		Close +
Vehicle utilisation	Low activity density -	Fragmented purchases	More trips for purchases -	Warehouse location	Remote -
	High activity density +		Less trips for purchases +		Close +
Transport mode	Motorised -	Purchase demand	Increased demand -	Mobility lifestyles	Car-dependence -
	Non-motorised +		Maintained demand +		Car-independence +
	Private -		Decreased demand +		Unsustainable -
	Shared +	Activity demand	Motorised -		Sustainable +
Vehicle type	High emission factor -		Non-motorised +		
	Low emission factor +		Non-transport +		
Purchase reception	Delivery failure -				
	Delivery success +				
	Return -				
	No return +				
Purchase basket	Less items -				
	More items +				
Packaging	Excessive packaging -				
	Optimal packaging +				

Table 1. Three categories and their parameters to assess the net environmental impact of online shopping.

First level: individual purchases

Literature focuses primarily on what has been addressed in this article as “individual purchases”, meaning that the calculated environmental impact of an in-store purchase is

compared with the environmental impact of purchasing the same item online. To identify which way of shopping can be considered more environmentally sustainable, half (51% or 22 articles) of the reviewed articles employ this approach. Such research follows the so-called "substitution hypothesis", i.e. the assumption that online retail channels replace physical retail channels without any effects on individual or household travel patterns (Rotem-Mindali and Weltevreden, 2013). In doing so, Karbassi and Tehrani (2005) find 81.5% savings in fuel consumption by changing the shopping system from traditional shopping to e-shopping.

This assumption might hold for stand-alone purchases such as books, as suggested by Borggren et al. (2011). They conclude: "buying the book via an internet bookshop and getting it delivered resulted in the lowest potential global warming impact". This bias is also applied to research on groceries (Figliozzi, 2020), fast-moving consumer goods (Shahmohammadi et al., 2020) and meal kits, where it is more disputable. Heard et al. (2019) state for example that meal kits "displace the typical grocery shopping experience for U.S. consumers, creating a systemic change", despite the fact that meal kits only supply dinner and still require to shop food and non-food items for other meals and activities. Building on substitution facilitates a more straightforward research design and allows to disregard more elusive, fickle and changeable behavioural parameters associated to shopping. As such, only included are so-called "first-order effects on travel patterns" or "direct transport impacts" (Cullinane, 2009), on which detailed and accurate information is more likely to be available (e.g. from travel surveys, company data). Yet as research on this topic grows, behavioural impacts are increasingly taken into consideration.

The widely accepted premise of e-commerce being more environmentally sustainable than visiting stores, builds on the number of vehicle-kilometres per purchase. **Transport distances** are naturally lower in home delivery rounds as compared to individual store visits. Wygonik and Goodchild (2012) provide an illustration to this end, in which they describe home deliveries as "shared-use vehicle travel" (Figure 4). Because of the individual nature of their shopping trips, consumers are disadvantaged in terms of distance travelled for a single purchase (Brown and Guiffrida, 2014). Yet the distance covered for delivery is influenced by so-called "stem distances": the travel required before the delivery round takes place, which largely depends on the shipping location (e.g. warehouse, store). Although not always taken into consideration, stores are replenished from warehouses too. Because of the international coverage of online retailing, as compared to the national or even regional presence of offline retailing based on stores, e-commerce warehouses are potentially located further. Partly because of these stem distances, Shahmohammadi et al. (2020) conclude that the environmental footprint of brick-and-mortar shopping in the United Kingdom is actually lower than shopping at a pure online retailer.

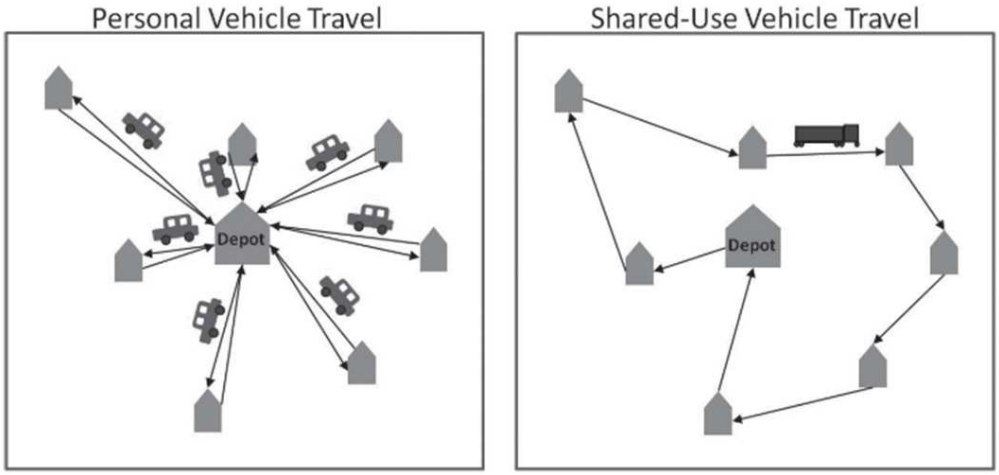

Figure 4. Illustration of personal vehicle travel compared to shared-use vehicle travel by Wygonik and Goodchild (2012).

"Energy use for transportation is thus not driven solely by kilometres travelled, but also by weight transported and transportation type", conclude Gee et al. (2019). Instead of focussing on vehicle load factors with respect to weight, Edwards et al. (2010) find that the number of drops per round is more representative of **vehicle utilisation** in the home delivery sector. The drop density rate is "a key productivity measure", more so than parameters of vehicle fill and empty running (Edwards et al., 2010). To Goodchild et al. (2018), whether a delivery service or personal travel provides a lower CO_2 solution mainly depends on customer density. As such, retailers and logistics service providers can reduce the environmental impact of deliveries by increasing the number of purchases to be delivered in a certain area. According to US-based research, e-commerce performs poorly compared to in-store shopping when fewer than four deliveries are consolidated in a delivery round, while e-commerce performs better in every aspect if more than 92 deliveries are consolidated (Jaller and Pahwa, 2020). Consumers can limit the environmental impact of their shopping trips as well by chaining several activities to a purchase (i.e. "trip chaining"), thereby avoiding dedicated shopping trips and optimising vehicle usage (Brown and Guiffrida, 2014). Yet Durand and Gonzalez-Féliu (2012) find that because consumers individually optimise their shopping trips, "by making work-shopping-household trips", the travelled distances of home delivery are larger. For both personal and professional vehicle use, high activity densities are preferred over low.

In terms of environmental impact, the importance of parameters related to transport distance increases or decreases depending on **transport modes** and vehicle types used. Generally, non-motorised and shared transport modes are more beneficial, while motorised and private transport modes are less favourable. Despite the surge in bikes for e-commerce deliveries, vans and trucks are still commonplace in practice and thus in research. Zhang and Zhang (2013) summarise the environmental impact as follows: "trucks > vans > electric bicycles". In accordance, Shahmohammadi et al. (2020) calculate that substituting delivery vans with cargo bikes for last mile delivery activities leads to a 42% reduction of greenhouse gas emissions. Consumer travel is generally assumed to be car-based as well, which is more difficult to support. To relax this assumption, Shahmohammadi et al. (2020) apply different input variables for consumers' mode of travel based on sources from the United States, the United Kingdom, the Netherlands and China. Hardi and Wagner (2019) consider a different modal split for shopping trips in Germany depending on community size, showing that motorised private transport use decreases as the number of inhabitants in a community

increases. Studies often conclude their research findings with transport mode recommendations, but how much does travel by foot, by bike or by public transport weigh in? In their UK-based research, Edwards et al. (2010) calculate that a personal shopping trip by car emits twenty-four times more CO_2 than a single drop within a home delivery round, while taking the bus lowers the difference to seven times the amount of CO_2 emitted. Nonetheless, Hardi and Wagner (2019) conclude that "even if a huge share of customers shifts to environmentally friendly modes for the shopping of groceries, a delivery would still offer opportunities to save energy and CO_2".

Ultimately, motorised road transport remains the main mode for personal and professional transport. Accordingly, **vehicle types** with a lower emission factor are preferred (Hardi and Wagner, 2019). Zhang and Zhang (2013) argue that the environmental impacts of trucks in the United States are much greater than those of vans in China. Vans are more common as well in a European context. Therefore, while Wygonik and Goodchild (2016) conclude that delivery services in a county in Washington, United States result in lower CO_2 emissions but higher emission of air pollutants (i.e. NO_x and PM_{10}), this might not be the case when vans carry out deliveries. Most studies however focus on climate change implications, thereby omitting local impacts such as air pollution. Given the significant influence of vehicle type on environmental assessments, electrification is considered in several recent studies. Hardi and Wagner (2019) find that using regular vans for grocery delivery leads to 73.3% in CO_2 savings and 85.8% in savings when the vans are electric. Figliozzi (2020) incorporates the growth of electric vehicles for personal transport and new autonomous vehicle types for goods transport: drones, sidewalk robots and road robots. He concludes that autonomous vehicles have a vast potential to reduce CO_2 emissions when replacing regular vans and are even more efficient than electric vans.

Even when substitution of individual purchases is assumed, several parameters in the framework are behavioural in nature. Connected to a particular purchase instead of purchase behaviour overall, they are discussed in this section. These parameters include **purchase reception**, i.e. whether a delivery at home was successful or failed and whether a purchase was retained or returned and purchase basket, i.e. whether a purchase contained one or multiple items. Typically, returns are higher when using online channels (Wiese et al., 2012) and consumers are found to "over-order" knowing that they will send some of it back (e.g. clothing in several sizes and colours) (Cullinane, 2009). How delivery failures and purchase returns are treated by retailers and logistics service providers determines the degree of negativity it induces on the environment, but it also depends on consumers' travel behaviour (Van Loon et al., 2015).

On the logistics' side, delivery failures can be met with (multiple) redelivery attempts or the use of alternative delivery locations such as collection points and lockers. Some logistics service providers achieve very high first-time delivery rates as they leave deliveries with neighbours or in the garden (Edwards et al., 2010). Purchase returns can be consolidated into existing delivery rounds or collected on dedicated rounds. While the first is likely to generate very little additional distance, the second generates a lot more. Wiese et al. (2012) calculate that nearby brick-and-mortar retail is the more sustainable option when 10% of items is returned. The same is true for retailers at nineteen kilometers from consumers in case of 35% returns and at twenty-five kilometers when 100% of items are returned. Contrary, Schmitz (2020) finds that the return rate, even though it is three times higher for online shopping, does not significantly influence the end result in favour of online shopping. On the consumers' side, redelivery can be requested and their collection and return trips to

stores, collection points or neighbours can be carried out more sustainably or less. This is important to consider in discussing the environmental advantage of home delivery alternatives. Although they avoid delivery failure (Pålsson et al., 2017), they require consumers to carry out trips that can have a more negative environmental impact compared to home delivering a purchase twice. Despite its decisive impact, consumers' collection and return trips are often excluded in research (Buldeo Rai et al., 2019).

In terms of **purchase basket**, larger baskets are considered more efficient and thus sustainable as they are packaged and delivered together in one trip, as opposed to packing and delivering the very same number of items in separate trips (Belavina et al., 2016). Because they consider "the link between the retail channels and the basket size", Shahmohammadi et al. (2020) conclude that brick-and-mortar retail has a lower footprint than pure online retail but higher than brick-and-clicks, which carries out deliveries from stores. Yet in the study, the baskets considered for pure online retail (1, 2, 5) are much lower (5, 45, 100 for bricks-and-clicks and 1,30,70 for car-based brick-and-mortar). The size of a purchase basket also relates to the frequency of shopping and associated collection and delivery trips. For clothing, Hischier (2018) for example compares consumer profiles that go shopping very frequently and consumer profiles that only shop a few times a year. Thus, assuming that consumers need a certain number of items, the transport sustainability point of view prefers them to be bought in less shopping sessions rather than more. Van Loon et al. (2015) summarise that "regardless of the fulfilment method, emissions per item increase inversely with basket size".

Particularly in e-commerce discussions, **packaging** is an important parameter to consider as it protects purchases during transport (i.e. thereby limiting damages, returns and redeliveries). Consumers use shopping bags for in-store shopping as well (although increasingly replaced by reusable bags) but comparatively more packaging is needed when purchases are not self-delivered by consumers to the home (Mangiaracina et al., 2015). Pålsson et al. (2017) find that packaging consumes on average five times more energy per book in home delivery systems than in store supply chains. Beyond its protective purpose, packaging used for online purchases is often considered excessive and wasteful of material such as plastic, cardboard and paper. As such, Hischier (2018) summarises the key question in assessing the environmental sustainability of shopping as follows: "car versus packaging". Consumers' car travel argues in favour of online shopping, while e-commerce packaging pleads in favour of shopping in-store. This trade-off is especially pressing for meal kits, in which each ingredient is wrapped separately in single-use packaging (Gee et al., 2019). In response to developments in reusable packaging, Matuštík and Kočí (2020) consider reusable plastic crates instead of cardboard boxes, demonstrating a great potential.

Second level: consumer behaviour

Eleven articles within the review corpus or 26% explicitly consider consumer behaviour and the ways in which it transformed due to e-commerce in their environmental comparisons of shopping. Echoing Matuštík and Kočí (2020), neither online shopping nor conventional retail significantly outcompete the other, it depends on consumer behaviour. Generally, research initiatives that address the "behavioural level" surpass the substitution bias and acknowledge the very different experiences that online shopping and in-store shopping offer. As such, they are not direct substitutes. This is important, as also Jaller and Pahwa (2020) note, as the assumption of full substitution exaggerates the potential of e-commerce to cut congestion and emissions, among others. Behavioural effects probably play out

differently as well from one person, purchase and situation to the other (Ren and Kwan, 2009). Based on a survey in Germany, Frick and Matthies (2020) demonstrate substitution effects for clothing but a direct consumption-increasing effects for digital devices. Although more detailed and generalisable data are difficult to get by (Edwards et al., 2010), three hypotheses are proposed. Cullinane (2009) describes modification, generation and addition effects that can occur when new technology interacts with old. In light of the e-commerce discussion, these terms entail the following:

- Modification occurs when online retail channels are used to conduct or change planned shopping activities, which is likely to reduce travel.
- Generation occurs when online retail channels give new information, new acquaintances and new possibilities which induce more travel.
- Addition occurs when online retail channels come in addition to physical retail channels and there is no specific relationship between them.

As such, not only direct transport effects are found important but also "indirect transport impacts", which includes changes in household and weekend travel, while "indirect non-transport impacts" result from changes in energy consumption elsewhere (Cullinane, 2009). Four parameters on consumer behaviour are proposed to evaluate the environmental impact of shopping.

Online and omnichannel retail facilitates consumers to use and combine several retail channels for a single purchase (Melacini and Tappia, 2018). Different types of **omnichannel purchase** behaviour exist, with very different environmental effects (Buldeo Rai et al., 2019). Shopping behaviour in which online browsing is combined with travel for purchasing (i.e. "webrooming"), collection (i.e. "click-and-collect") or delivery is not considered problematic as it does not result in additional transport. Possibly, it optimises shopping and its associated travel (Wiese et al., 2012). Promising from an efficiency point of view as well are "virtual stores", in which images of store shelves are attached in public spaces such as transport terminals that allow to scan items, create a virtual shopping cart and get the items home delivered (Buldeo Rai et al., 2019). In these cases, modification effects seem likely.

Other behaviours lead to more detrimental environmental effects as they induce several trips for a single purchase. Common examples include online purchases following an in-store visit (e.g. "showrooming" or ordering in-store selected items lower-priced online on a competitor web-shop) or home delivery of in-store purchases (i.e. "ship-from-store"). Edwards et al. (2010) assume that one in ten shopping trips results in no immediate purchase. A survey among shoppers highlighted by Cullinane (2009) found that the third most purchased product type is "nothing" (16% of cases). Not only in-store browsing activities are considered, also shopping trips for social, recreational or hedonistic purposes are important to take into account (Edwards et al., 2010). Accordingly, a hypothetical shopping trip's negative environmental effects increase by a factor 1,1. On an individual level however, the environmental impact doubles with a second trip to the stores (Edwards et al., 2010). Yet as the use of technology among consumers and retailers has surged immensely, the share of shopping trips that are complemented by another trip is very likely to be higher. Although omnichannel retailers encourage the simultaneous and combined use of their channels to increase consumer convenience, loyalty and ultimately spending, a growing share of consumers behave omnichannel regardless. Ultimately, the omnichannel retail environment provides new information and possibilities to execute various purchase activities. As such, it is very likely to generate additional travel and negative environmental implications that are associated with travel.

When it comes to consumers' purchases overall, online and physical retail channels are not only used complementary to support one specific purchase, they also exist separately from each other. As flagged by Van Loon et al. (2015), it is likely that shopping trips are still executed despite ordering certain products online. Consumers who frequently shop online are found to make the same number of trips to stores, as those who do not (Shahmohammadi et al., 2020). What's more, online grocery shoppers visit the supermarket even more frequent than traditional shoppers (Van Loon et al., 2015). In this sense, e-commerce and the endless assortment it offers has become a preferred channel for specific and specialised purchases. Amplifying that trend is the surge of specialty web-shops for practically all types of products (Kim et al., 2009), as well as new services such as meal kit and prepared meal delivery (Gee et al., 2019). Edwards et al. (2010) find consumers making more frequent purchases of less items, often from several different companies and Bjørgen et al. (2019) establish that consumers who order online groceries still visit physical stores to supplement online purchases. Compared to a pre e-commerce baseline situation, it seems only natural that a process of increasing fragmentation takes place. In essence, while any consolidation of shopping activities reduces their environmental impact, **fragmented purchases** create the opposite.

Yet e-commerce does not only facilitate specific purchases from all over the globe, it also influences overall **purchase demand**. By creating new needs of products that were not available, known or even existent before or by offering products at lower prices, the worldwide web increases transport demand. Based on an activity diary dataset from Columbus metropolitan area in the United States, Ren and Kwan (2009) conclude that "people who engage in more shopping activities in the physical world, are more likely to become e-shoppers". More recent studies, although based on surveys, follow this finding. "People who purchase online more frequently seem to have a higher shopping demand", say Shi et al. (2019) based on a survey in Chengdu, China. Similarly, a study in Germany points out that the time spent online is a considerable predictor for consumption overall (Frick and Matthies, 2020). The likelihood that active online shoppers reduce their shopping trips is thus potentially limited.

Ultimately, even if online channels provide consumers with a more efficient and less time-consuming alternative and full substitution takes place, the key question remains which activities fill up the saved time (Laghaei et al., 2015). Addressing the question of overall **activity demand**, Rosqvist and Hiselius (2016) highlight a rebound effect in trips for other purposes. When it comes to environmental sustainability, of interest is specifically which role transport plays therein: i.e. more unsustainable travel, more sustainable travel or no travel at all. For instance, the elimination of shopping trips can lead to other "maintenance trips" for eating meals, medical care, taking care of the household or personal obligations (Cullinane, 2009). Or think about going to the cinema or visiting a friend instead of performing a shopping trip, while food is delivered at home. True reductions in transport and negative environmental effects associated with it only occur if consumers stay at home or perform trips using other modes than private motorised ones. A reduction in consumer travel by car is essential if the environmental benefits of e-commerce are to be realised (Van Loon et al., 2015). In that respect, Norwegian research by Bjørgen et al. (2019) suggests that the use of home delivery services for food and groceries is associated with more environmentally friendly travel modes.

Some consumers may use the internet to inform their conventional shopping decisions and rationalise their shopping-related travel, while others may continue to shop as much by

conventional means as before. As such, while increasing the proportion of online shopping can improve drop densities and vehicle loading percentages, it still adds to traffic rather than replaces. Above all, what this shows is the need to take consumer behaviour into account from a comprehensive point of view: in its variation of activities taking place in various times and various places.

Third level: consumption geography

Ultimately, the context in which any type of transport occurs determines its environmental impact. Beyond cultural preferences for certain transport modes or certain types of retail location, research refers to the importance of area density or whether consumers live in urban, sub-urban or rural settings. It reflects on transport distance, vehicle utilisation and transport mode parameters. "About half the variation in CO_2 emissions can be explained by service area" conclude for example Wygonik and Goodchild (2012). Ten articles or 23% of the review corpus consider wider geographical implications of e-commerce on environmental sustainability: seven articles (16%) do so next to assessing individual purchases, three articles (7%) while also taking consumer behaviour into account. They touch upon the spatial location and relocation of stores, warehouses and consumers, as well as the transport consequences that it entails.

With consumers resorting more and more online for their purchases, a decline in the local store network is unavoidable and already set in motion in many cities, in particular the small to mid-sized ones (Shi et al., 2019). As store accessibility decreases, e-commerce is more likely to be adopted (Ren and Kwan, 2009). Of course, a future without stores is unlikely given the many reasons consumers still prefer the physical shopping experience, including the experience of "non-digital product attributes" (e.g. the feel of a shirt, the look of a pair of glasses), "instant gratification", advice and service from staff as well as social, recreational and hedonistic purposes. Also retailers' shift towards an omnichannel model, integrating online and physical channels, demonstrates the significance and importance of stores in consumers' contemporary shopping journeys.

Yet, while urban inhabitants might remain well-serviced and able to reach their shops by foot, by bike or by public transport, the opposite might prove to be true for consumers living in suburban and rural areas. In accordance, Durand and Gonzalez-Féliu (2012) find that click-and-collect locations near the heart of residential neighbourhoods leads changes in user behaviour, including the use of their car. Changes in **store location** as they are anticipated now, are likely to have an impact on all other parameters considered in this research and thus on the environment. Rosqvist and Hiselius (2016) support this statement: "the location of retailers can reduce CO_2 emissions from customer travel by 22% while the location of shopping centres can lead to a reduction of 8-9%". The authors add that similar reductions of CO_2 emissions are achieved by supporting neighbourhood stores and online shopping at the expense of shopping further away. A closely located store network is thus important for reducing the environmental impact in both online and physical shopping scenarios.

Warehouse location (or distribution centre or logistics hub) equally matters (Goodchild et al., 2018; Wygonik and Goodchild, 2016). Two opposing trends are detected here, including the creation of centralised "XXL" warehouses ever further in the urban periphery and the reintroduction of smaller ("S" or "XS") warehouses on the edge of and in the middle of urban centres. Shahmohammadi et al. (2020) suggest retailers to locate warehouses closer to consumers in order to decrease stem distances and reduce their environmental footprints, Gee et al. (2019) raise a similar point for meal kit delivery. Kellner and Igl (2012) find that a

higher number of hubs and an improved concentration of retailers result in better greenhouse gas performance of the distribution system. Yet the closeness or remoteness of warehouses is evidently determined as well by consumers' choice of retailers. E-commerce facilitates consumers to shop at web-shops all over the world. For example, European consumers are particularly attracted by retailers from China and the United States, resulting in individually packaged products that are not rarely shipped by airfreight (Cullinane, 2009). In cases where air freight is used over traditional road transport, the impact of goods transport on the total energy consumption of e-commerce skyrockets, show Pålsson et al. (2017). Evidently, shopping online at local or remote retailers makes the world of a difference in terms of sustainability, although the difference between the two is rarely raised (Mangiaracina et al., 2016). Schmitz (2020) urges for future research to shift its focus from the last mile to further up the transportation flow. What's more, e-commerce shipping charges never truly reflect the distance a purchase needs to cover, if a delivery price is charged at all.

Ultimately, it is highly likely that e-commerce induced changes in behaviour impact consumers' **mobility lifestyles** in the long run. There are different scenarios possible, some with positive environmental effects and others that are more detrimental. A shift towards proximity shopping by foot or by bike in combination with online orders of items that cannot be found locally has the potential to render car-ownership obsolete. In this respect, Rosqvist and Hiselius (2016) propose to use online shopping as a facilitator for implementing other policies promoting a less car-dependent planning regime. There are contrary views as well, in which e-commerce growth causes store closures in remote areas and as such forces consumers to rely on their cars even more (Cullinane, 2009).

Conclusions

In the aftermath of the COVID-19 pandemic, pushing an "e-commerce crash course" around the world, this research responds to an ever so relevant question: "what is the net environmental impact of online shopping?" With the emergence and continuous adoption of new retail models (e.g. omnichannel retail with click-and-collect and ship-from-store), new delivery services (e.g. meal kits and subscriptions) and digitalised consumption replacing physical products (e.g. music, books, films), it is increasingly difficult to understand the environmental implications of shopping in one retail channel over another. Universal models to outline how "the virtual" impacts "the physical" do not exist, instead this article proposes a framework of three impact categories that discusses (1) individual purchases, (2) consumer behaviour and (3) consumption geography. Evidently, there is no particular type of shopping that has an absolute environmental advantage and it is in no way possible to shop ourselves out of the environmental crisis. Yet it is clear that some developments and behaviours are more favourable than others. The framework lists fourteen parameters and the ways in which they positively or negatively affect the environment, as a way to guide necessary case-study assessments in the future and support comprehensive understanding of the trade-offs that potentially take place.

In the shopping sustainability question, many topics remain unexplored and provide ample avenues for future research. The most pressing gaps stretch further than the intensively researched last mile and instead concern behavioural consequences (including fragmented purchases and overall purchase demand) and spatial organisations of retail supply chains in their entirety (including store and warehouse locations), both transformed by and transforming online retail. The first need is to better comprehend consumer behaviour

beyond generalising statistics of online shopping frequency, volume and spending. A clear view on the (different types of) e-consumer in relation to its general consumption patterns, travel habits and domestic circumstances is missing, which is ideally accumulated through standardised mapping of actual behaviour than highly specific questionnaires that limit comparability. The second need is to enhance our view on the supply chain operations of international online retailers, by mapping their retail and logistics footprint and the transport operations that are put in place. Focussing our research efforts on consumers with the heaviest purchase demand and similarly on retailers who contribute the most in supply, is perhaps the most promising way forward to accelerate environmental savings.

Although consumer behaviour is scrutinised in particular, by detailing different ways in which e-commerce drives consumption and transport, it is vital to stress the shared responsibility of all stakeholders involved. When organised locally, efficiently and consciously, e-commerce has the potential to be a sustainable alternative to in-store shopping. Yet with increasingly convenient service conditions for delivery (e.g. instant) and return (e.g. collection at home), it is not set up to be. Consumer behaviour adapts accordingly while environmentally-conscious consumers are left with limited clarity and possibility to reduce their impact. In addressing the environmental implications that are directly associated with consumers' purchases, retailers and logistics service providers have important tools in hand to make significant positive contributions, such as greening their delivery fleet, reducing delivery failure, encouraging sustainable collection trips and transforming their packaging (in line with the individual purchase parameters). Together with policy-makers, they can create and raise awareness on a more conscious consumerism: which actions to take and decisions to avoid (in line with the consumer behaviour parameters) as well as plan for and implement optimal supply chains (in line with the consumption geography parameters).

It is clear that e-commerce is here to stay regardless of environmental consequences. Although the margins of this systematic literature review are defined in the methodology, it is important to consider its limitations including biases based on publication, language and geography. Still, the framework attempts to encourage actions, behaviours and decisions that enhance the environmental footprint of online shopping processes and to guide a more comprehensive approach towards environmental e-commerce assessments in the future.

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Annex 1: Keywords search strings

Search strings applied in scientific databases	Number of results found (and retained)		
	Science direct	Scopus	Google scholar
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("e-commerce" OR "online retail") AND ("conventional" OR "traditional" OR "offline")	444 (6)	7 (5)	11,710 (21)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("online shopping" OR "online retailing") AND ("conventional" OR "traditional" OR "offline")	157 (4)	9 (3)	3,296 (20)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("home delivery" OR "electronic retail") AND ("conventional" OR "traditional" OR "offline")	99 (4)	2 (1)	1,599 (18)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("e-shopping" OR "electronic commerce") AND ("conventional" OR "traditional" OR "offline")	103 (2)	7 (4)	4,400 (18)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("e-commerce" OR "online retail") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	122 (5)	0 (0)	2,374 (27)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("online shopping" OR "online retailing") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	54 (4)	1 (1)	1,007 (28)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("home delivery" OR "electronic retail") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	50 (4)	1 (0)	725 (26)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("e-shopping" OR "electronic commerce") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	27 (2)	0 (0)	823 (22)
Year: 2005-2021; ("environmental impact" OR "carbon" OR "emissions") AND "comparative" AND ("omnichannel" OR "omni-channel")	19 (2)	2 (1)	565 (5)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("e-commerce" OR "online retail") AND ("conventional" OR "traditional" OR "offline")	209 (4)	5 (4)	6,450 (22)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("online shopping" OR "online retailing") AND ("conventional" OR "traditional" OR "offline")	88 (3)	3 (2)	2,006 (23)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("home delivery" OR "electronic retail") AND ("conventional" OR "traditional" OR "offline")	60 (3)	2 (1)	1,013 (22)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("e-shopping" OR "electronic commerce") AND ("conventional" OR "traditional" OR "offline")	62 (1)	6 (4)	2,358 (16)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("e-commerce" OR "online retail") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	60 (5)	0 (0)	1,351 (2)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("online shopping" OR "online retailing") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	51 (4)	1 (1)	603 (26)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("home delivery" OR "electronic retail") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	29 (4)	0 (0)	484 (24)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("e-shopping" OR "electronic commerce") AND ("brick-and-mortar" OR "pickup" OR "pick-up")	21 (2)	0 (0)	455 (20)
Year: 2005-2021; ("environmental sustainability" OR "greenhouse gas" OR "CO2") AND "comparative" AND ("omnichannel" OR "omni-channel")	12 (2)	1 (1)	384 (5)

Annex 2: Review corpus

Author(s)	Article title	Year	Journal
Karbassi, SM Tehrani, AR	Application of E-commerce in local home shopping and its consequences on energy consumption and air pollution reduction	2005	Journal of Environmental Health Science & Engineering
Cullinane, Sharon	From Bricks to Clicks: The Impact of Online Retailing on Transport and the Environment	2009	Transport Reviews

Kim, Junbeum Xu, Ming Kahhat, Ramzy Allenby, Braden Williams, Eric	Designing and assessing a sustainable networked delivery (SND) system: Hybrid business-to-consumer book delivery case study	2009	Environmental Science & Technology
Ren, Fang Kwan, Mei Po	The impact of geographic context on e-shopping behavior	2009	Environment and Planning B: Planning and Design
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