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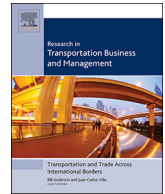
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Last-mile logistics fulfilment: A framework for energy efficiency

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ABSTRACT

Purpose: Last-mile fulfilment is among the most energy consuming logistics operations in the supply chain because of the vast amount of stops and low fill rates. The study's purpose is to explore last-mile fulfilment options in regard to their energy efficiency and to develop guiding propositions for energy efficient last-mile fulfilment options.

Design/methodology/approach: Interviews with Swedish retailers and their logistics service providers (LSPs) were conducted to compare different last-mile fulfilment options for consumer goods. Data of these options in respect to energy efficiency was analysed in regard to a framework with the components of distribution structure, transportation execution, and household logistics capability.

Findings: This study analysed the energy efficiency of six distinct options in the last-mile fulfilment. Since transportation in the last mile is highly energy consuming, energy could be saved in last-mile fulfilment when goods are carried as far as possible collectively down in the supply chain to collection points close to the point of consumption (POC) in commercial vehicles with high fill rates. The end consumer should be responsible for only the last part of the last mile. Proximity between private households and collection points increases the possibility that the consumer will walk or use public transportation.

Practical implications: This study provides insights to managers of logistics companies and retailers regarding how to save energy in last-mile logistics fulfilment.

Originality/value: Viewing consumers as co-producers of logistics solutions and aligning the distribution structure, transportation execution, and household logistics capability suggest propositions for the improved energy efficiency of last-mile fulfilment options in the supply chain.

1. Introduction

To reduce greenhouse gas (GHG) emissions from transport of good is a huge challenge in connection to reducing climate impact. Road freight transportation is mainly powered by fossil fuels, which generate GHG emissions, particularly CO₂ emissions, responsible for climate change. To be in line with the goals set by the EU on GHG emission reduction of 80%–95% by 2050 (European Commission, 2011b, 2011c), this requires a reduction of at least 60% of GHG emissions in the transport sector, a sector which is emitting a still growing amount of GHG emissions (European Commission, 2011c). The International Energy Agency expects the transported volume to nearly double by 2050 compared to 2006 (OECD/IEA, 2009). However, the high and growing demand of transported products in the forward flow of the logistics system is an increasing challenge. Particularly, transportation during the last mile, that includes the transport of goods from retailers' last contact point to the good, e.g. store, terminal or another place of hand-over, to households at the point of consumption (Hübner, Kuhn, &

Wollenburg, 2016; Hübner, Wollenburg, & Holzapfel, 2016) is of high interest when studying how energy use can be decreased, under consideration of the growing demand for this kind of transport.

Transportation in the last mile takes place at the customer-end of the supply chain, is concentrated in urban areas and is responsible for around 25% of GHG emissions from all transportation (European Commission, 2011c). Digitalization is transforming current distribution structures and a range of new fulfilment modes are emerging (Hagberg, Sundstrom, & Egels-Zandén, 2016; Hübner, Kuhn, & Wollenburg, 2016). The high energy consumption of road freight transport, particularly downstream in the supply chain (Browne, Allen, & Rizet, 2006) increases the demand for development of sustainable logistics solutions. Much attention has been devoted to clean-vehicle technology, biofuel (Svanberg & Halldórsson, 2013) and transportation modes, such as bikes and electric vehicles in the last mile (Bubner, Bodenbenner, & Noronha, 2016) to mitigate the adverse impact of logistics systems on environmental sustainability. To achieve this goal, resource utilisation, such as load factor, plays a major role (McKinnon, 2010; Rizet, Cruz, &

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Mbacke, 2012) as well as capacity utilisation (Wehner, 2018).

Fulfilment of last-mile logistics concerns logistics activities in the last leg of the supply chain, where goods are transferred from the retailer at the point of sales to the end consumer at the point of consumption (POC). This transport can be provided by logistics service providers (LSPs) with commercial vehicles (such as heavy or light trucks), or carried out by the consumers themselves with private vehicles, by foot, bike or similar. As Carbone, Rouquet, and Roussat (2018) point out, the household is often involved in the fulfilment of this last leg. Because of demographics, most people live in urban areas and road freight transport is the dominating mode in this area. Energy efficiency of urban road freight transport is impacted through the settlement size, provision of local facilities, accessibility to local transport infrastructure and networks, availability of parking facilities and road network type (Allen, Browne, & Cherrett, 2012).

Transportation during the last mile is among the most energy consuming operations in the supply chain due to the high number of single-packed parcels carried in commercial vehicles or passenger cars to the POC (at the private households). The use of passenger cars for consumer transport even worsens this problem (Browne et al., 2006). Browne et al. (2006) state that energy consumption in the last mile can correspond to the total freight transport energy consumption employed in the supply chain from the place of origin to retail outlet. Therefore, the last-mile transportation leg offers great potential to increase energy efficiency. Goods which are transported in the upstream part of the supply chain are transported in large quantities and, therefore, the total energy consumption per transported unit is relatively low. However, products in the downstream part of the supply chain are often responsible for higher energy consumption per transported unit because of low fill rates in delivery vehicles and poor utilisation of private cars.

Against this backdrop, this study's purpose is to explore last-mile fulfilment options in regard to their energy efficiency and to develop guiding propositions for energy efficient last-mile fulfilment options. To achieve this, the energy efficiency characteristics of last-mile logistics fulfilment options will be analysed with respect to a framework with the following three components: (A) *distribution structure*; (B) *transportation execution*; and (C) *household logistics capability*.

The first two components, distribution structure and transportation execution, are adapted from Colicchia, Marchet, Melacini, and Perotti (2013), who present energy related initiatives of LSPs. The third, household logistics capability, is not addressed in the current literature, but many fulfilment options place greater and varied emphasis on the consumer's role in the operation of logistics solutions. Extending the system boundaries to include not only GHG emissions from company-owned operations and purchased electricity sources, but also indirect emissions from outsourced activities means that companies also bear responsibilities for the emissions produced by subcontractors (Tacken, Sanchez Rodrigues, & Mason, 2014). This responsibility can be extended to the transportation of goods during the last mile, recognizing the importance of including the last-mile fulfilment in the company's logistics planning. In connection, different supply chain strategies that are based upon a contingency approach, such as postponement and speculation strategies (Pagh & Cooper, 1998), are used to conceptualise the options that are investigated in regard to energy efficiency.

The present study investigates energy efficiency in the last mile and examines different fulfilment options, ranging from consumer pickup to home delivery by a logistics service provider. To accomplish this, the energy efficiency of last-mile fulfilment options will be assessed in qualitative terms in regard to energy efficiency indicators; distances driven by commercial and private vehicles, fill rates of commercial vehicles and the time to drop off parcels.

The paper is structured as follows: Section 2 starts out with the presentation of a framework that explains characteristics of energy efficiency in last-mile fulfilment and six different last-mile fulfilment options. In Section 3, the method is outlined. In Section 4, the characteristics of last-mile fulfilment options and their implication on

energy efficiency are analysed. Propositions for energy efficiency in last-mile logistics fulfilment are drawn. Section 5 discusses some of the implications of the research undertaken. and finally, Section 6 concludes the research.

2. Conceptual framework

Following the research process suggested by Edwards, O'Mahoney, and Vincent (2014), based on abductive reasoning a conceptual framework was developed at an early stage to guide data collection and analysis. This conceptual development builds on MacInnis (2011) with the goal to integrate and synthesize the three components in last-mile fulfilment into a conceptual framework. Energy efficiency is seen as the result of the interaction among entities in a supply chain (logistics service providers and end consumers) as well as the structures in which these entities operate.

This approach to this study is threefold. First, supply chains are described as inter-organizational entities that can be designed and managed (Halldórsson, Kotzab, Mikkola, & Skjøtt-Larsen, 2007). Second, the study is embedded in the literature ranging from transportation (Brown & Guiffrida, 2014; Liimatainen, Hovi, Arvidsson, & Nykanen, 2015) to logistics (Brown & Guiffrida, 2014) and supply chain management (Halldórsson & Kovács, 2010). Third, distribution structure, transport execution, and household logistics capability relate to each other, and the importance of these three components alone and in combination with each other are analysed.

2.1. A contingency approach and systems approach to logistics fulfilment options

To tackle the overall problem of high energy consumption and GHG emissions of last-mile fulfilment, improving energy efficiency is seen as a solution. Building upon a systems perspective, the study subscribes to the notion that 'all phenomena can be regarded as a web of relationships among its components' (Arbner & Bjerke, 2009, p.103), energy efficiency as a result of the system it is in. This study seeks to understand 'common patterns, behaviour, and properties' (Arbner & Bjerke, 2009, p.103) in the last mile of the supply chain, which contribute to energy efficiency. By applying a 'soft' systems approach, the importance of human activities is also incorporated into the approach (Lindskog, 2012) and is reflected in the conceptual framework through the household logistics capability. Energy resources are used to execute supply-chain solutions, such as transportation and warehousing operations.

Building upon a contingency approach of organization for logistics (Pfohl & Zöllner, 1997), a supply chain is here viewed as a structure characterized by specific properties, such as the potential to influence energy efficiency, which cannot be solely understood by focusing on individual components of a logistics solution. The analysis must focus on the system as a whole. Therefore, energy efficiency can be understood in relation to (A) the *distribution structure*, which determines the involvement of the actors; (B) the *transportation execution*; and (C) the *household logistics capability*. This paper offers a structural rather than processual perspective (Arbner & Bjerke, 2009, p.120) on environmentally sustainable development of logistics. In other words, the characteristics of components and relationships define different types of logistics solutions. A processual perspective would show the flow of these components and relationships over time by explaining how the different structures emerge.

To illustrate the situational nature of achieving last-mile fulfilment with respect to energy efficiency, the study makes use of speculation and postponement (Bucklin, 1965) which have been applied to determine an appropriate supply-chain strategy by Pagh and Cooper (1998). Ultimately, logistics performance objectives such as costs of inventory, warehouses, and transportation and lead times (Abrahamsson, 1993; Bowersox & Daugherty, 1995) set conditions for

usage of energy resources to power activities such as logistics (e.g. Halldórsson, Gremyr, Winter, & Taghavi, 2018; Wehner, 2018). Departing from a demand-pull, the postponement strategy describes a centralised logistics system in which inventory is kept centrally at terminals until customer order is initiated (Pagh & Cooper, 1998). Postponement encourages just-in-time delivery of small quantities of goods. From a buyer's perspective costs decrease and delivery times shorten as postponement increases (Bucklin, 1965). In contrast, the push-driven speculation strategy, on the other hand, describes a logistics system in which larger quantities of goods are moved close to the customer in anticipation of demand (Pagh & Cooper, 1998). According to Bucklin (1965), speculations allow for ordering large quantities of goods and focus on high fill rates, hence favouring more energy efficient transport options compared to postponement.

2.2. Components of a conceptual framework

Energy efficiency of freight transportation has high priority in achieving environmentally sustainable development in logistics operations (Browne et al., 2006; Golobic, Boerstler, & Ellram, 2010; McKinnon, 2016; Taptich, Horvath, & Chester, 2016). Energy efficiency in logistics helps decrease the total energy consumption and can contribute to the EU target set for 2050 (European Commission, 2011a, 2011c). Energy efficiency is defined in the Directive 2012/27/EU. as “the ratio of output of performance, service, goods or energy, to input of energy,” and energy efficiency improvement is defined as “an increase in energy efficiency as a result of technological, behavioural and/or economic changes.” The International Energy Agency applies the term energy efficiency when something “delivers more services for the same energy input, or the same services for less energy input” (OECD/IEA, 2014). Whereas most logistics operations take place in a business-to-business (B2B) context, last-mile fulfilment focuses on business-to-consumer (B2C) deliveries (Bask, Lipponen, & Tinnilä, 2012). E-commerce is fast-growing within the B2C segment, characterized by “small order size, increased daily order volumes, small parcel shipments, and same-day shipments” (Joong-Kun Cho, Ozment, & Sink, 2008, p.337). High frequency and low volume require a different logistics approach than that for B2B deliveries. Joong-Kun Cho et al. (2008) conclude that internally strong logistics capabilities are needed to perform well in the e-commerce context. Although the current literature primarily focuses on commercial operations (such as the distribution structure and transportation execution) when investigating energy efficiency, this paper includes private households in the analysis and assigns them a distinct role. Households do not necessarily just receive goods for consumption but can also be regarded as relevant actors in the logistics fulfilment, especially concerning the energy efficiency of last-mile fulfilment.

This paper adopts an interactive approach to energy efficiency in logistics (Wehner, 2018). Rather than approaching energy efficiency in quantitative terms, energy efficiency is explored in qualitative terms (Halldórsson, Sundgren, & Wehner, 2019). Energy efficiency is understood as a performance objective, similar to cost efficiency or lead times that have been studied in qualitative terms as performance objectives in supply chains in the past (Bowersox & Daugherty, 1995; Chopra & Sodhi, 2014). Energy efficiency of the last mile of the supply chain is understood in regard to three interacting components in the logistics system: (A) distribution structure; (B) transportation execution; and (C) household logistics capability. The explanatory idea of this framework lies in the notion that the conditions for energy efficiency in logistics are shaped by different parts of the logistics system. Fig. 1 summarizes this logic, and the three components are considered with respect to their implications for energy efficiency of last-mile fulfilment options.

2.2.1. Distribution structure (A)

Goods can be moved to the POC through an array of distribution structures. These structures differ by the origin of the shipment (such as

distribution centres, terminals, and stores), intermediate stations, destination of the shipment (such as stores, other collection points, and private households), and attributes of delivery processes (such as speed and flexibility) (Fernie & Sparks, 2009; Hübner, Holzapfel, & Kuhn, 2016; Hübner, Kuhn, & Wollenburg, 2016). Structure is a crucial factor when choosing the distribution strategy (Bowersox & Daugherty, 1995; Colicchia et al., 2013) and determines the energy consumption in the last-mile fulfilment. Further distinction can be made with regard to actors' involvement in last-mile fulfilment; LSPs, shippers, and end consumers have a distinct role in the distribution structure. The distribution structure is regarded as one determining characteristic for the energy consumption in the last mile since the chosen structure also influences the transport execution and household logistics capability.

2.2.2. Transportation execution (B)

Transportation was included in the proposed framework since it represents one of the most energy consuming activities in the supply chain, and it is a key focus for companies that want to reduce GHG emission from their logistics activities (Tacken et al., 2014). Transportation is executed by moving goods with various types of vehicles. During the last-mile, transportation can be executed by commercial or private vehicles. In *commercial transportation*, energy consumption and efficiency are influenced by vehicle size and utilisation, such as the vehicle fill rate (McKinnon & Ge, 2004). *Private transportation* is performed by end consumers, mainly with their own vehicles (passenger cars), but they may also opt to public transportation or walking. Current research suggests that the downstream part of the supply chain, from retail to consumption, consumes a great deal of energy compared to all other transportation legs of the supply chain due to heavy reliance on private transportation (Brown & Guiffrida, 2014; Edwards, McKinnon, & Cullinane, 2009). Browne et al. (2006) conclude that the energy consumption by consumers to transport goods to their homes by car can be as high as the total energy consumption for all upstream freight transport activities combined. To counteract this, companies that offer home deliveries seek to improve route planning, aim for more efficient deliveries, and establish a more fuel-efficient transportation fleet. For example, Edwards, McKinnon, and Cullinane (2010) compared CO2 emissions resulting from home delivery from online shopping to customer pickup in the non-food retail sector. They concluded that a conventional shopping trip is only efficient in regard to CO2 output when more than 24 items are purchased. Otherwise, a home delivery is likely to be more energy efficient. Vanelslander, Deketele, and Van Hove (2013) stated that the distribution cost for the last mile can be as high as half of the total supply-chain costs. Edwards et al. (2010) also emphasized the importance of investigating the last mile and identified consumer transportation as an area of great improvement due to its low utilisation rate. They concluded that a well-planned delivery route is more efficient than an end consumer driving the last mile. In economic terms, the last mile also offers improvement potential.

In summary, transportation in the last mile is one of the most energy consuming activities in the supply chain. Examining various fulfilment options in terms of commercial in comparison to private transport allows for improved understanding of energy efficiency of last-mile fulfilment options.

2.2.3. Household logistics capability (C)

End consumers can be engaged in last-mile fulfilment by either *collecting* the goods at a pickup point or store (active role), or *receiving* them through a home delivery (passive role). The ability to collect and receive goods has implications for the overall energy efficiency. In theory, in logistics and supply-chain management, the household is often viewed as a passive recipient of goods and services when ordering online. By extending the system boundaries, households are assigned more active roles in the execution of logistics in certain fulfilment options. Such involvement is in line with the recent literature on retailing

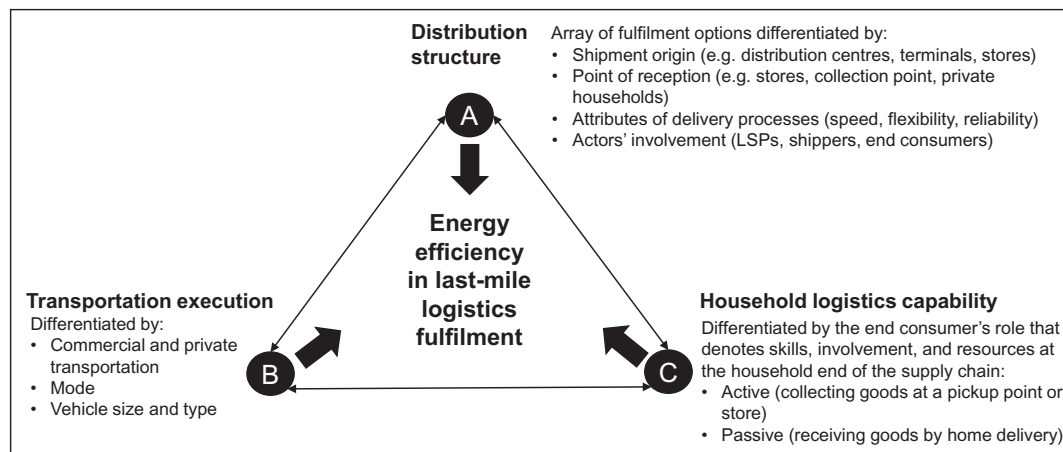


Fig. 1. The three components that shape energy efficiency in last-mile fulfilment.

(Hagberg et al., 2016) and service management (Bask, Tinnilä, & Rajahonka, 2010), which assigns the end consumer the role of ‘co-producer’ for a final service (Grönroos, 2011; Vargo & Lusch, 2004). In this paper, the term *household logistics capability* denotes skills, involvement, and resources at the household end of the supply chain to perform logistics activities regarding collecting or receiving goods. Household logistics capability is not solely denoted by an active or passive role, but also by the degree of involvement, such as meeting the LSP halfway in the last mile.

Goods delivered to the end consumer's residence can be divided into attended or unattended deliveries (Edwards et al., 2010). *Attended home deliveries* require the consumer to be available to accept the delivery. This is especially common for grocery deliveries in Europe (Hübner, Kuhn, & Wollenburg, 2016). Attended deliveries set constraints for all involved actors, which have implications for energy efficiency. The recipient must wait at home, and the LSP must adjust to a certain time slot, making the routing more complex and sensitive to changes in delivery times. In the case of *unattended home deliveries*, the product can be left in a mailbox or, in some cases, at the door. Unattended home deliveries are normally successful because the presence of the consumer at the POC is not required, but an alternative provision for receiving the delivery needs to be in place.

In comparison, attended home deliveries have higher failure rates because the deliverer and consumer must meet at the POC (Hübner, Kuhn, & Wollenburg, 2016). The literature reports various failure rates for home deliveries. Edwards et al. (2009) consider an average till good failure rate of 12.5% and a first-time failure rate of 25% for deliveries in which carriers require a recipient signature.

2.3. Last-mile logistics fulfilment options

The characteristics of the three components of the logistics system described in the previous section vary, and their particular combination has consequences for the energy efficiency of the fulfilment option. Derived from current literature (Browne et al., 2006; Hübner, Kuhn, & Wollenburg, 2016; Vanelander et al., 2013) and the three components presented above, a set of six last-mile fulfilment options are explored with regard to their energy efficiency. This is not an exhaustive list of all possible last-mile fulfilment options, but rather examples of well-established as well as emerging fulfilment solutions. Fig. 2 illustrated the chosen six last-mile fulfilment options.

The terminal is the shipment origin for the depicted options and all goods pass through it. However, it is only part of the last mile in Option 5 and 6, in cases when no retail store or other station is used. Depending on when the customer order is received, shipments might be repacked to customised orders at the terminal. In Option 1 and 2, this might

happen only at the retail store. The household symbolises the end consumer at the point of consumption (POC).

The option can be described as follows:

1. During a *conventional shopping* trip, the end consumer buys goods at the retail store and is responsible for the last leg of transportation. This trip is executed by the end consumer by driving a private car, using public transportation, bicycling, or walking to collect the goods. In regard to energy efficiency, the trip by car is most crucial.

The following five options are all associated with e-commerce:

2. For ‘*click and collect*’, end consumers order goods online, collect them in the retail store, and then bring them home. This option is often applied to groceries or other consumer goods and they are collected at the respective store. The distance for the private transportation is the same as for a conventional shopping trip, but shopping is less time-consuming since the order is placed online. The ordered goods are either already available at the store or picked and sent from the terminal to the store. If the goods are sent from the terminal, they can either be sent with a regular replenishment or as a separate shipment.
3. Using *pickup points*, the consumer orders the goods online and collects them at a pickup point, which is an issuing office from a postal provider. These are often located in the entrance of supermarkets, which have sometimes extended opening hours compared to other retail stores. This means, that consumer goods, such as clothes, books or electronics, can be picked up at the nearest pickup point; but POC and good are not further connected. Pickup points are spread throughout the country, normally located close to the end consumer's home and often within walking distance in urban areas. Since this option is relatively widespread, and the order is placed online, it can be less time-consuming for the end consumer than a conventional shopping trip.
4. *Locker stations* work similarly to pickup points. A key advantage is that the pickup time does not depend on store opening hours. The lockers often belong to LSPs, but some are operated by online retailers. The infrastructure belongs to local parcel deliveries, often located close to central hubs, such as railway stations.
5. *Home deliveries* entail end consumers ordering goods online, which are then home delivered. In this fulfilment option, no private transport is required. In case of attended home delivery, the delivery time must be aligned between the logistics service provider and the end consumer. An emerging variety of home delivers, that has gained popularity, is delivery of food by bike and scooters. However, this study focussed on delivery by LSPs which use large

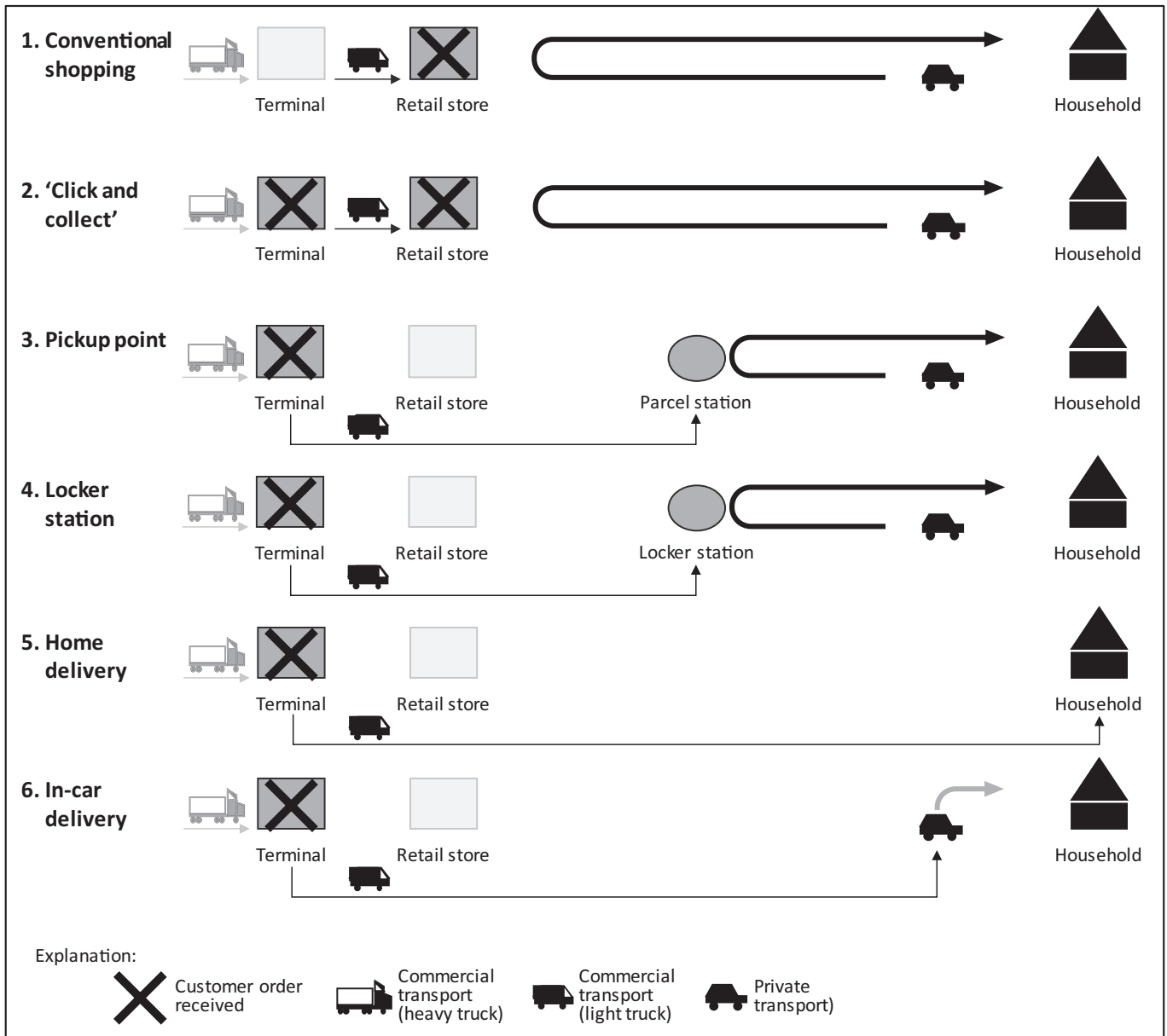


Fig. 2. Overview of last-mile fulfilment options.

commercial vehicles to move goods during the last mile. Factors influencing the energy consumption in home deliveries are the drop densities, the distance and nature of the delivery round, the type of vehicle used, and the treatment of failed deliveries and returns (Edwards et al., 2010).

- In-car delivery* is an emerging fulfilment option in which the end consumer orders goods online, which the LSP then delivers to the consumer's car which needs to be parked in a certain urban area during a particular time slot. Mobile phone applications provide temporary access to the trunk of the car. So far, this option is only offered to consumers in large cities. The consumer carries out the last transportation leg, but the energy consumption of this trip cannot be allocated to the goods in the trunk.

Each of the six options represents a particular configuration of the three components presented in Fig. 1 – distribution structure, transportation execution, and household logistics capability – which shape the energy efficiency of the particular fulfilment option.

3. Method

The study's purpose, to explore last-mile fulfilment options in regard to their energy efficiency, and the interactive nature of the conceptual framework guided the research design and led to the decision of conducting an explorative interview study.

3.1. Data sampling and collection

Empirical evidence was collected through semi-structured interviews with logistics managers in organizations in Sweden on both sides of the logistics service, buying and providing logistics services, to gain insights from both sides operating. Choosing different supply chain actors and following a multi-actor approach helped validate the fulfilment options, exploring the options' energy efficiency characteristics, as well as common patterns and behaviour. The sample is based on convenient sampling, which is motivated by the explorative nature of the study, resulting in 12 interviews with logistics managers from six companies (see Table 1). Three cases included on-site observations at

Table 1
Sample.

Organization	Industry	Size ^a	Number of interviews
Retailer with e-commerce channel	Apparel	medium	3 (+ on-site observation)
E-retailer in Sweden	Grocery	small	1 (+ on-site observation)
Logistics service provider	Logistics	large	4
Logistics service provider	Logistics	large	1 (+ on-site observation)
Nordic logistics service provider	Logistics	large	2
Nordic logistics service provider	Logistics	medium	1

^a Small: < 1000 employees, medium: 1000–9999 employees, large: > 10,000 employees.

the terminals. Three companies were interviewed more than once. The interviews lasted between 60 and 120 min.

To cover the journey of goods and parcels during the last mile (from terminals to private households), retailers and LSPs were included in the analysis (see Fig. 3). Because these companies work professionally with traditional retailing and e-commerce, they could provide in-depth views on different last-mile fulfilment options. Furthermore, several LSPs that work for the same retailer were included, so the last-mile fulfilment of a certain product range could be viewed from different perspectives.

Although this study focuses on last-mile fulfilment, interviewees were also asked about the second-to-last leg: the transport leg from a terminal to a retail store. This information was collected to investigate the impact on energy efficiency due to changes upstream in the supply chain. In other words, depending on the last-mile fulfilment option, goods need to be repacked, reloaded, and handled, and these changes impact the overall energy efficiency of that fulfilment option. Indicators of energy efficiency in the last mile were collected through the following logistics performance objectives:

- average distance a commercial vehicle must drive to drop off a parcel,
- average fill rate of the commercial vehicle,
- average time needed to drop off a parcel,
- average distance driven by a private vehicle to pick up the parcel.

3.2. Data analysis and research quality

The interview guide was semi-structured and based on a literature

review on e-commerce, possible last-mile fulfilment options and their energy consumption, involvement of the end consumer in last-mile distribution, and relative challenges. During the interviews extensive notes were taken. The content of the interviews and the field notes taken during the on-site visits were analysed with the qualitative data analysis software NVivo for the key terms *e-commerce*, *consumer*, *speed*, *energy consumption*, *energy efficiency*, *collaboration*, *capacity*, *home delivery*, and *pick-up*. Implications for energy efficiency for an array of last-mile fulfilment options were derived, and the interviewees helped map the energy consumption of these fulfilment options and to rank them in relative terms to each other.

To enhance research quality, the criterion of trustworthiness suggested by Halldórsson and Aastrup (2003) to judge qualitative logistics research was applied. The authors propose to assess trustworthiness with the dimensions of credibility, transferability, dependability, and confirmability. Credibility means to accept that there is no single objective reality, but rather that reality is a construct of individuals (Erlandson, Harris, Skipper, & Allen, 1993). Therefore, the research findings are validated with the studies' participants by discussing the findings to ensure the correctness of the understood world. The second dimension is transferability, which describes the general application of the findings (Halldórsson & Aastrup, 2003). To ensure transferability, data richness is required. In several rounds, the framework and overview of the fulfilment options, together with the relative energy efficiency indicators, were presented to and discussed with the interviewees, which helped validate the results and helped to produce a detailed description. The third dimension is dependability, and it is ensured by keeping records of all phases of the research process and documentation of all methodological decisions (Halldórsson & Aastrup, 2003). Furthermore, peers viewed and discussed this material with the authors at a conference. Finally, confirmability is reached by ensuring that the findings represent the results and are free of bias on the researchers' side (Halldórsson & Aastrup, 2003). This was ensured by comparing across the range of the data and with the literature.

4. Findings

Six last-mile fulfilment options were analysed in regard to the framework of distribution structure, transportation execution, and household logistics capability. Fig. 4 provides a summary of the six last-mile fulfilment options and outlines the logistics performance objectives that serve as indicators for evaluation of energy efficiency; the average distance a commercial vehicle must drive to drop off a parcel, the average fill rate of the commercial vehicle, the average time needed

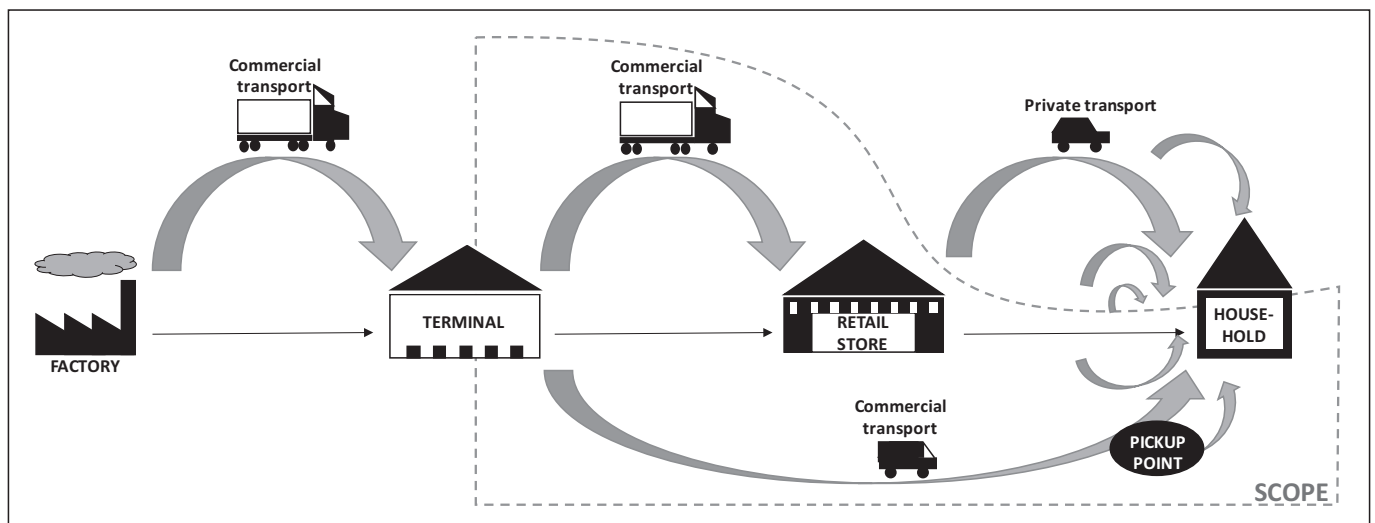


Fig. 3. Scope.

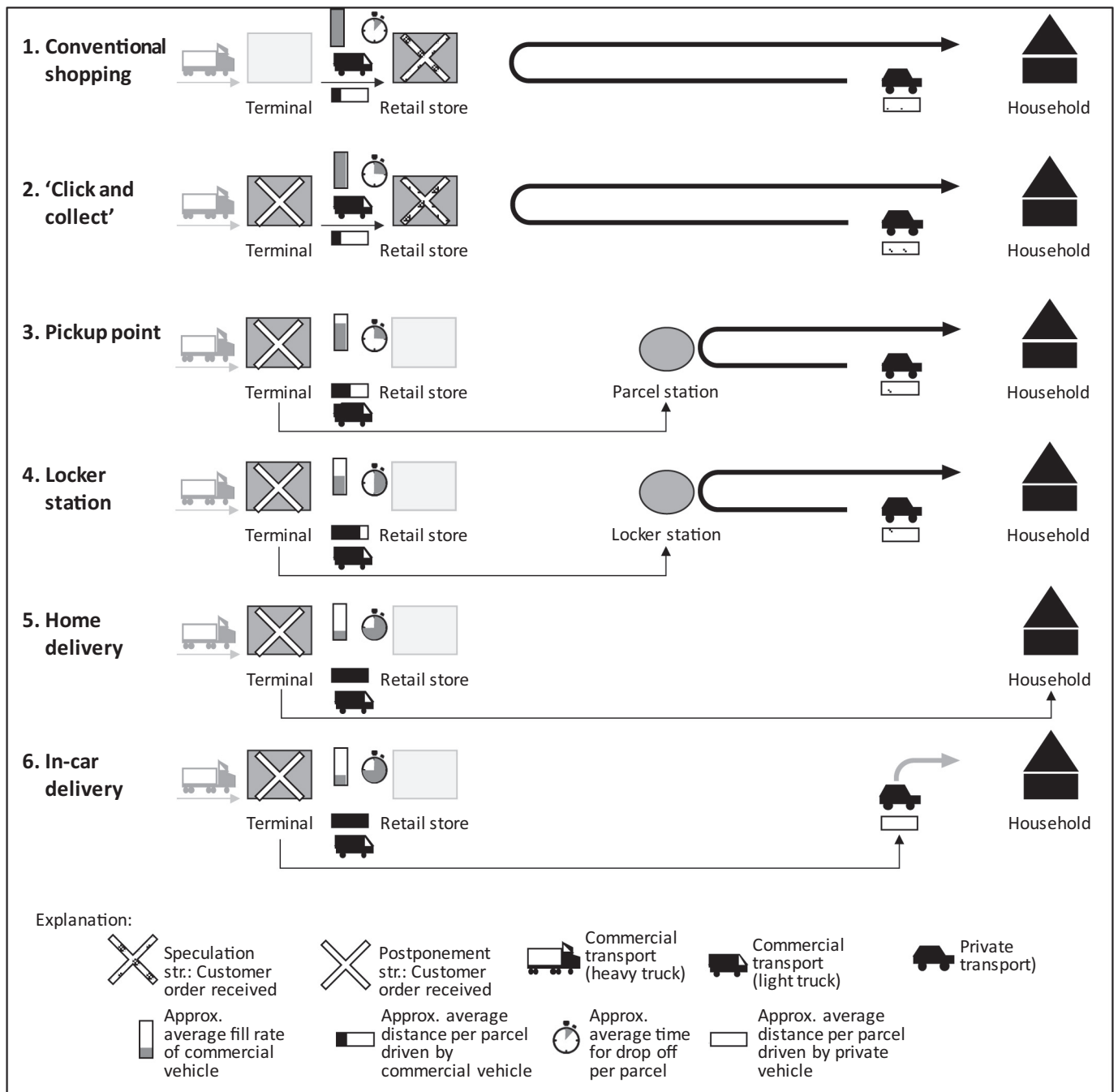


Fig. 4. Overview of last-mile fulfilment options with energy efficiency indicators.

to drop off a parcel, and the average distance driven by a private vehicle to pick up the parcel are particularly important energy efficiency indicators. In what follows, the options are visualised and explained.

4.1. Option 1 – Conventional shopping

Conventional shopping resonates with the push-driven speculation fulfilment options were analysed in regard to the framework pt in stock at retail stores until purchase and collection by the consumers. The distribution structure allows for deliveries of large quantities at once to the retail stores which is characterized through high fill rates for commercial vehicles, short drop-off times per parcel, because goods are delivered on pallets or roll containers in large quantities. The stores need to provide large spaces, which needs energy in respect to lighting

and cooling. The households need to be active in this fulfilment by transporting the goods the final leg, either with their private vehicle or through another mode. The fill rate in the private vehicle depends on the quantity of purchased goods. The consumer has the possibility to merge the shopping trip with other trips or errands. The distance to large supermarkets outside the city, the ones that encourage using the car, is relatively long.

4.2. Option 2 – 'Click and collect'

In 'click and collect', goods are only picked after the customer order is initiated. It can be differentiated between a) goods are picked in retail store and then collected by the consumer or b) goods are picked in a terminal or 'dark room' and are delivered with the replenishment or a

separate shipment to the store to be collected by the consumer. While the picking in the store follows a push (or speculation) strategy, the picking at a distribution center or 'dark room' and the initiation of a separate shipment to the store, can be understood as a logistics postponement strategy in which just-in-time delivery of small quantities of goods is pursued. Retailers use this option to draw customers into their shops with the hope that additional goods are bought. In the speculation strategy, when goods are picked in the retail store, the distribution structure allows for deliveries of large quantities at once to the retail stores. This delivery is characterized through high fill rates for commercial vehicles, short drop-off times per parcel, because goods are delivered on pallets or roll containers in large quantities to the stores. However, the collection of personalized orders is time-consuming. The stores need to provide large spaces, which also impacts energy consumption for lightning and cooling. The households need to be active in this fulfilment by collecting the order and transporting the goods the final leg, either with their private vehicle or through another mode. The fill rate in private vehicles is expected to be rather low. The consumer has the possibility to merge the shopping trip with other trips or errands. The distance to the store is assumed to be as long as in Option 1.

4.3. Option 3 – Pickup point

The transport of the goods to the pickup point is provided by the LSPs after the consumer's order is received; hence following a postponement-informed strategy. The LSPs can have a relatively large fill rate, dropping of many parcels at the same time at the pickup point, however not in the same large quantities as when delivered to a retail shop. Parcels are wrapped separately and stored individually, thus the fill rate of the commercial vehicles is lower, i.e. the vehicle contains a smaller quantity of goods but more packaging material. The goods are picked up by the consumer either by using a private vehicle or another mode, executing an active role in the last-mile fulfilment. The fill rate of the private vehicle is expected to be lower than in Options 1 and 2, because less goods in average are purchased this way than purchased during a conventional shopping trip. If a dense net of pickup points is available and the distance from home to POC is short, the use of private vehicles can be reduced.

4.4. Option 4 – Locker station

Option 4 can also be illustrated by a demand-pull, or a postponement strategy. The transport of the goods to the locker station is conducted by the LSPs after the consumer orders the good. Locker stations are limited in their holding capacity, therefore, LSPs would need to stop at several stations in order to drop off a high amount of parcels. Furthermore, it is very time-consuming to place one parcel at a time in a locker. Therefore, the average distance per parcel for the commercial vehicle and the time per parcel for drop-off are relatively high. The fill rate of a commercial vehicle is relatively low, more often influenced by time constraints than the weight or place constraints in the vehicle. The distance for a private car is rated the same as in Option 3. However, locker stations might have a higher availability and are located at central hubs, so customers can pick up their parcel on the way to work or on other trips and avoid using their cars.

4.5. Option 5 – Home delivery

In a home delivery, initiated through the consumer's order, goods are dropped off at the POC by the LSPs, hence illustrated by a demand-pull strategy. The average distance driven by a commercial vehicle and the time to drop off a parcel are very high. The average fill-rate of the truck is considered to be low because shipments are individually wrapped and much air is transported, especially when compared to well stacked pallets that are transported in Option 1. Furthermore, as mentioned by interviewees, the fill rate of the truck is most often

determined by the number of parcels the driver will manage to drop off during the shift, rather than through the physical loading ability of the truck. A further issue arises because the most popular delivery slot is the afternoon, and that interferes with peak hours which leads to delays because of congestions. In this option, the consumer can pick between a passive role, when they do not need to be available to receive the good (unattended home delivery) or a low involvement, when their presence is a must in order to confirm the reception of the good (attended home delivery). In many cases, the consumer does not need to pay the extra transportation leg, which can encourage over-use.

4.6. Option 6 – In-car delivery

The fulfilment option of in-car delivery resonates with a logistics postponement strategy. After the consumer initiated the order, the LSP delivers the goods to the trunk of the private vehicle. The average distance driven by a commercial vehicle and the time to drop off a parcel are very high, since every order has to be handled individually. The average fill-rate of the truck is considered low. The location of private car becomes the POC and most often is limited to certain regions or certain urban areas. The car is bound to a certain pre-defined area during the delivery time. But since the location of the car is not 100% exact, difficulty with routing can arise. Although the consumer will move the car and transport the good to get home, the distance is not allocated to the good.

5. Discussion

5.1. Energy efficiency indicators in last-mile fulfilment

Transportation execution represents the immediate energy consuming activity within the fulfilment options, and can be evaluated through energy efficiency indicators, such as the average distance a commercial vehicle must drive to drop off a parcel, the average fill rate of the commercial vehicle, the average time needed to drop off a parcel, and the average distance driven by a private vehicle to pick up the parcel. The other two components, distribution structure and the household logistics capability, can be regarded as underlying mechanisms for energy efficiency.

First, for transportation execution, previous research suggests that private vehicles can be less energy efficient than commercial vehicles, when distances to a local store are short (Browne et al., 2006). For the first two fulfilment options, the use of private vehicle for last-mile transportation execution does not differentiate in principle, if in Option 2 goods are picked at the store and a push-oriented, speculation strategy applies. If goods are sent from a terminal or "dark room", Option 2 resembles with the demand-pull orientation of Option 3. However, more dispersed location of collection points will inevitably result in consumers driving longer distances by car. Furthermore, it is less likely that consumers will use public transportation, bicycles, or simply walk if distances are long or purchased quantities high. When the physical retail store is substituted by a close pickup point, locker station, in-car delivery, or even home delivery, dependency on a private vehicle can be reduced. Although, the supply-push of the speculation strategy promotes high fill rates and an energy efficiency transport, a postponement-oriented strategy should be followed in favour of reducing use of a private vehicle. Pickup points, in-car deliveries, and locker stations or similar local collection points allow for synergy effects in terms of better use of existing capacity, or even conversion to public transportation or non-vehicular modes of transportation.

Second, the distribution structure sets the conditions for energy efficiency in different ways and determines if a supply-push of speculation or demand-pull of postponement strategy is followed. Depending on the focal point of goods collection, the use of a private vehicle can be promoted, as this is the case for the first two options (i.e. retail store) and partly Option 3, the pickup station. The structure using

locker station should promote use of public transport or walking, according to the interviewees. In the options of home delivery and in-car delivery, LSPs cover the last mile until the POC by using commercial vehicles. Furthermore, the distribution structure also has influence on where a service location is placed and how dense a net of retail stores, pickup points and locker stations is available to consumers. Currently, large supermarkets and grocery chains offer ‘click-and-collect’ and pickup-point services. Local lockers substitute physical stores and allow LSPs to deliver closer to the POC. By decoupling options from certain time slots and opening hours, further release can be given to the structure. A large time window allows consumers to combine collecting goods with other trips, avoid peak traffic hours, and even use non-vehicle options (such as a bicycle or walking), which influences the overall energy efficiency. The use of local locker stations can release time constraints, as both providers and consumers can deliver and collect at times that are independent of each other. Lockers offer a time-independent decoupling point but setting the parcels into each locker box is very time-consuming for the LSPs. Furthermore, this option allows for advanced planning since its location is fixed. In comparison, in-car delivery requires more flexibility by the LSP as they need to track the car first and adapt their routing.

Third, Browne et al. (2006) state, applicable for all six fulfilment options, household logistics capability plays a key role in the energy efficiency of last-mile solutions. By viewing household logistics capability as part of the effort towards energy efficiency and the consumer as co-producer of logistics solutions (Halldórsson, Altuntas Vural, & Wehner, 2019), at least two attributes are identified. First, the use of passenger cars to collect goods is apparent in all options, except home deliveries. At first glance, the growth in e-commerce is not viable from the perspective of energy efficiency, since it increases, rather than reduces, the use of energy. Second, the ability to receive home deliveries is important to reduce the number of delivery failures, for which LSPs must show up several times or drop the shipment off at a central collection point.

Fig. 5 maps all six last-mile fulfilment option on the four energy efficiency indicators and shows which of the options release the highest energy efficiency potential. While Options 1 and 2 are very good in respect to the energy efficiency indicators of commercial transport, they offer the lowest potential in respect to distance driven by a private vehicle. Options 3 and 4 received a medial evaluation throughout all indicators. Options 5 and 6 release the lowest potential throughout the first three indicators but have no implication on private transport.

5.2. Propositions for energy efficiency in last-mile fulfilment

Based on the findings of this study, propositions for energy efficiency in last-mile fulfilment were derived. The highest potential of

energy efficiency in last-mile fulfilment is created when goods are carried collectively as far downstream in the supply chain in commercial vehicles with high fill rates to collection points as possible, such as pickup points or locker stations which are located close to the POC. Only the last part of the last mile should be executed by the end consumer. Proximity to these collection points increases the chances that the consumer will walk or use public transportation. It is important that a dense net of collection points is available, and that the consumer can select to which collection point the product should be delivered when ordering it. This improves the chances that the consumer will not use their car to collect the goods.

Home deliveries offer unique and customised fulfilment solutions. However, a heavy commercial truck that approaches every individual household with relative long distances in between does not enable energy efficiency. The three emerging options – pickup points, locker stations, and in-car deliveries – tap into existing resources and flows, in different ways. By assigning the end consumer an active role, energy efficiency can be improved, as long as a private vehicle dedicated to the transportation is not used in the last mile. In the case of locker stations, the end consumer is involved in picking up the shipment without using a car. Furthermore, this option also has the advantage of offering a high flexibility regarding pickup times. Integrating commercial and private transportation in the last mile by transporting goods with commercial vehicles in large quantities to a collection point and finalizing the last mile by private transport without a car is the most energy efficient fulfilment option. Sweden is on the path to strengthening that option with a well-developed net of collection points and end consumers who prefer pickup over home delivery (Okholm et al., 2013). Also, other options in the consumer-to-consumer segment emerge, where transport capacity in the last mile is shared among end consumers.

While the speculation strategy follows a push-approach, it is accompanied by high fill rates, however, in the case when high fill rates are only reached because of products that are unnecessarily sent though the logistics system, a high energy efficiency cannot be reached. Hence, it is advisable to consider following a pull approach, such as the postponement strategy suggest.

Derived from the findings and analysis, the following proposition for energy efficiency in last-mile logistics fulfilment are proposed:

1. High fill rates in vehicles are essential to release a great potential for energy efficiency.
2. Avoidance or minimisation of private transport is essential.
3. A pull approach in last-mile fulfilment should be favoured to avoid unnecessary transport.
4. Commercial trucks need to deliver goods collectively to pick-up points close to the household or locker stations at central hubs that are passed by the end consumers on a regular schedule.

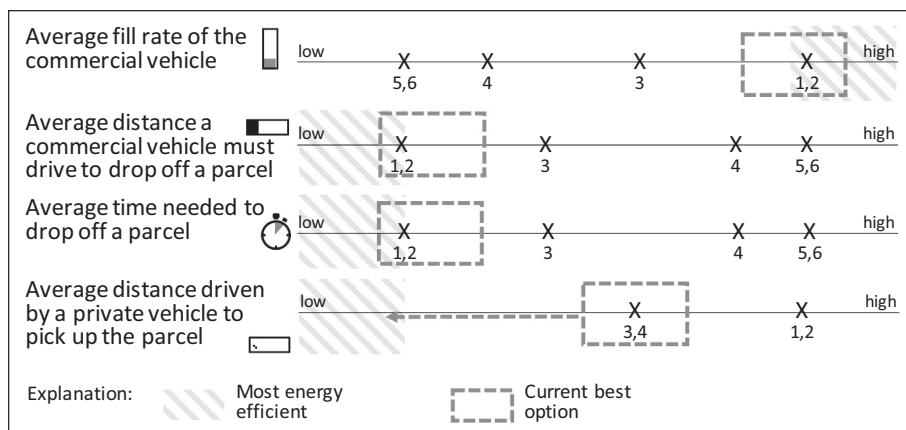


Fig. 5. Indicators of energy efficiency in last-mile logistics fulfilment.

5. A dense net of pick-up points, which are independent from providers, is favourable.
6. If home deliveries are a preferred solution, not recommended in terms of energy efficiency, high fail rates should be avoided though either unattended deliveries or information sharing.

6. Conclusion

This study suggested a framework with last-mile fulfilment characteristics, outlined last-mile fulfilment options, assessed their energy consumption, and illustrated propositions for energy efficient last-mile logistics fulfilment. Due to the increasing demand for transportation, developing an environmentally sustainable approach in which energy consumption can be reduced in the last and highly energy consuming leg of the supply chain is essential. The contributions of the study are fourfold.

First, the paper complements the current body of knowledge on new and emerging *last-mile fulfilment solutions*, with a focus on energy. Hagberg et al. (2016) discuss the importance of the retailer-consumer interface and the continuously developing fulfilment options driven by digitalization, but do not relate their research to the environmental or energy components. The digitalization of retailing should be used to strengthen the environmental sustainability of contemporary supply chains. Similarly, Hübner, Kuhn, and Wollenburg (2016) investigate different fulfilment options and develop a framework with characteristics and design parameters for all options, but do not relate them to sustainable development or energy efficiency.

Second, the logic from Pagh and Cooper (1998) on postponement (demand-pull) and speculations (supply-push) strategies is extended to last-mile fulfilment. This provides a new understanding to this leg of the supply chain and extends the body of knowledge of how those strategies can be applied. It challenges the current understanding that the speculation strategy, that favours transport of large quantities of goods and high fill rates, is the most energy efficient strategy because if unnecessary transport. The postponement strategy, in which goods are stored centrally and only forwarded when customer order is received, holds the notion of a pull-approach. Even though the transportation in itself is not the most energy efficient one, because of low fill rates, with the system perspective, this strategy holds valuable implications.

Third, the proposed framework extends the system boundaries of energy efficiency from transportation execution (Browne et al., 2006) and distribution structure to also include the attributes of household logistics capability. Improving energy efficiency requires understanding its dynamics and the possibility to influence individual elements as well as the systemic effect. This paper assigned the end consumer a passive or active role in last-mile fulfilment.

Fourth, by displaying differences of last-mile fulfilment options, this study provides an understanding of consequences of the distribution structure. Edwards et al. (2010) compare both home delivery and conventional shopping with respect to carbon intensity but do not consider further options. This paper considers an array of last-mile fulfilment options and suggests that energy efficiency must focus on the interplay between the distribution structure, transportation execution, and household logistics capability. The potential for improving energy efficiency lies not only in the choice of the transportation mode, but also in the configuration of the fulfilment option.

Regarding practical implications, this study provides a new perspective for logistics managers at LSPs but also at retailers on how energy can be saved. A comparison of several last-mile fulfilment options in respect to their energy efficiency is provided. This study also provides a hands-on approach to energy efficiency by suggesting several energy efficiency indicators which can be followed up by practitioners.

This research is a first attempt to highlight the importance of energy efficiency in last-mile logistics fulfilment. The data was collected in Sweden, Europe's fifth largest country by area but with only 10 million

people a very disperse country (Statistics Sweden, 2019). Yet, data was collected in southern Sweden where the population density is comparable to other European countries. Nonetheless, a particularity of Sweden is that the world largest technology company focussing on e-commerce, i.e. Amazon, is not yet established in the same scale on the Swedish market as it is in many countries. Therefore, this option has not played a role in the data collection process. But for many other countries this could be an option worth to investigate. The authors expect its market share also to increase in Sweden in the future. Thus, the research does not provide an exhaustive list of possible fulfilment options. Another avenue of future research could be to examine combinations of different channels, such as multi- and omni channel logistics (Bubner et al., 2016; Hübner, Wollenburg, & Holzapfel, 2016). These solutions are largely driven by the combination of increased e-commerce, digitalization, new business models, and changing consumer behaviour, which constitute an increasing challenge in regard to designing energy efficient last-mile fulfilment solution.

Author statement

Both authors contributed equally to the conduct of the research and writing of the paper. Authors are listed in alphabetical order by last name.

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