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The Energy Efficiency of the Last Mile in the E-Commerce Distribution in the Context the COVID-19 Pandemic

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Abstract: The e-commerce industry has been developing extremely dynamically for many years. This development was intensified during the COVID-19 pandemic. According to the research conducted by the authors of this paper, in Poland, during the pandemic, the number of delivered parcels increased 20–100%, depending on the courier company. The research of the authors of this article focused on the energy efficiency of the last mile, which is very important for the efficiency of the entire delivery process to customers. As the authors calculated, the last mile can consume over 70% of energy of the whole distribution channel. The article presents the results of research concerning the energy efficiency of deliveries performed by couriers and express companies in Poland. Two models of distribution used Poland have been compared—direct deliveries to final customers, and deliveries to parcel lockers. The research methods are interviews with the managers and couriers, analysis of the literature, and the simulation method. According to the results of the simulations performed by the authors, distribution with the use of parcels lockers can help reduce the consumption of fuel even by 74–87% per parcel or 36% per m^3. Apart from this, the authors calculated the impact of scale of operations on the energy efficiency of the transport processes on the last mile, which is an indirect effect of the growth of the e-commerce market, caused by the pandemic. Based on the results of the original research of the authors, it can be assessed that the growth of the number of the delivered parcels during the pandemic resulted in the consumption of fuel per one parcel being reduced in some cases by over 36%. The novelty of the authors' research is that the conducted simulations regarded not only the efficiency of the processes, but also the energy consumption in delivering parcels at the last mile and during the pandemic.

Keywords: e-commerce; last mile; parcel lockers; efficiency of logistics processes; energy efficiency; economies of scale; simulation of logistics processes; COVID-19

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1. Introduction

E-commerce has been developing for many years. This development has been accelerated by the pandemic. In the EU-27, whereas total retail sales diminished by 17.9%, e-commerce sales in April 2020 increased by 30%, compared with April 2019 [1]. This increase is related to the growth of the courier and express services market.

In Poland, the market of courier and express services grew from PLN 4.5 billion in 2015 (EUR 1.08 billion) to 7.9 in 2019 (EUR 1.89 billion) [2] (increase by 39%). The growth was caused by the growing volume of parcels in the e-commerce market. In 2020, online sales in Poland increased by almost 26% and already accounted for 14% of the retail market in Poland [3]. Thus, the effects of the pandemic for this sector of the economy turned out to be positive. Not only did the turnover in this market increase, but the pandemic has also expanded the scope of the e-commerce market (new firms, consumer segments, e.g., elderly) and products (shift from luxury goods and services to everyday necessities, e.g., groceries) [4].

The growth of the e-commerce market causes an increase in transportation. The problem is particularly important in the so-called "last mile", where deliveries are made to various customers, sometimes with a low payload and less efficient vehicles (e.g., vans and trucks) with a lower load capacity than in deliveries to large stores, e.g., discount stores [5,6]. Other factors specific to the e-commerce industry also affect the efficiency of transportation processes. A question arises here: what may be the consequences of the increase in transport to internet customers for energy consumption and in consequence to quality of life and social costs?

However, it can be assumed that the market growth will allow for the achievement of economies of the scale in transport (better use of capacity and shorter routes per 1 vehicle). In addition, the e-commerce industry uses innovative solutions aimed at increasing delivery efficiency, such as parcel lockers or alternative fuels.

The e-commerce market influences energy consumption in various ways. The more efficient the operations, the bigger the efficiency of the consumption of energy and the lower the negative impact on the environment. The type of energy used at each stage of the parcel delivery processes is also important. This is a significant problem as operators are starting to use alternative energy sources (e.g., electric vehicles). The transition from traditional technologies to, for example, the use of biofuels also requires a change in the supply chains of these fuels, which also consume energy [7]. Thus, the impact of the e-commerce industry on energy consumption and the natural environment is of a diverse, direct, and indirect nature.

The problem of the impact of the supply chain strategies of production companies and their suppliers on the economic efficiency of logistics and production processes on the one hand, and on energy consumption on the other hand, has been the subject of studies presented in the literature. For example, Vandana et al. [8] developed a model that allows to calculate the level of production at which energy consumption is optimal. The energy consumption can be controlled by the production rate. It complements traditional cost accounting with environmental and emission issues.

The environmental impact of supply chain models has also been studied by other authors. The issues that were the subject of these studies, and which were included in the models developed by individual authors, are: the positive impact of increasing the flexibility of supplies on the possibility of reducing waste [9], and a strategy to repair defective products to reduce waste [10]. This issue in relation to various decision problems was also the subject of other studies [11–13].

The simulations carried out by the authors of this article concern the problem of energy consumption, not in entire supply chains and not in production companies, but in the distribution services sector—in the e-commerce industry and in the last mile. The results of the performed calculations fill the gap in the literature, the more so because they were carried out in the context of a pandemic.

The issue of the development of the e-commerce industry and the effects of this development is very wide. However, the intention of the authors of the article was to focus on the problem of the impact of this development on energy consumption, assuming that traditional fuels are used to power delivery vehicles. Studies concerning the process performance on the last mile of e-commerce were conducted, but were carried out before the pandemic. The research conducted by the authors thus fills the knowledge gap regarding the effectiveness of these processes and the impact on energy consumption in the new reality created by the pandemic.

The aim of this article is to present the impact of the models of e-commerce deliveries and the increase in the scale of operations on the energy efficiency of the deliveries on the last mile, on the basis of the authors' own research.

The essence of the problem addressed by the authors is contained in the following questions:

- To what extent can the use of parcel lockers help to improve the delivery process in the e-commerce industry and, consequently, to reduce energy (fuel) consumption?

- Does the impact of the development of the e-commerce market result in the economies of scale and thanks to that in the decrease in the energy consumption in the transport processes?

Authors tried to find answers to the above questions.

2. The Literature Review

The pandemic had a significant impact on the e-commerce market and, consequently, on the courier and express services market. Turnover in the e-commerce industry has increased significantly; however, the increases vary on individual markets, in individual companies, including companies dealing with the deliveries of goods to final recipients. Higher turnover results in greater transports, which raises concerns about the impact of this market on the quality of life of residents. However, for example, a study in Madrid showed that the number of parcels delivered to customers in the central district doubled, but an increase in pollution was lesser than the growth of e-commerce [14]. The question arises therefore whether this is due to economies of scale? Are the delivery processes more efficient (better use of capacity, time) when more parcels are delivered?

However, the problem is very complex. In recent years, there has been an increase in the number of low-tonnage vehicles (light goods vehicles up to and including 3.5 tones gross weight), which are in many cases poorly utilized. However, it should be borne in mind that while goods are delivered to warehouses or distribution centers of retailers with high-tonnage (i.e., more efficient) vehicles, the final distribution to stores is carried out by medium-tonnage vehicles. Thus, the economic and environmental benefits of traditional distribution channels do not have to be greater than in e-commerce. In addition, customers of retail shops often use ineffective individual motorization. This problem, in relation to external costs transport, has already been the subject of the authors of this article [15].

Factors which influence the efficiency of deliveries in e-commerce are: seasonal peaks in demand, reduced lead times, meeting delivery time windows, first-time delivery failure rates, high levels of product returns [16,17], fragmentation of freight shipments [18–20], increase in customer demands for service quality [21], and different sizes of shipments and their packaging.

A high level of returns is an important problem. Returns for the fashion segment in 2013 accounted for more than 18% of all parcels [22]. From logistics point of view interesting is of course how this problem generates additional trips. Additional trips can be also caused by customers themselves. A considerable share of customers (even 50%) first visit a shop before ordering goods via Internet [23].

The situation is also not improved by the fact that the infrastructure is often not adapted to this type of distribution of goods in cities [24].

The most frequent problem which customers in the Visegrad Four countries (Poland, Slovakia, Czechia, Hungary) face when online shopping was that the delivery time of goods was longer than it was stated by the seller on the store's website. The highest incidence of problems with online shopping was reported in 2015 in Hungary (40%), in 2017 in Poland (18%), and in 2019 in the Czech Republic (28%) [25].

If the e-commerce market is small, the problem may be the lack of critical mass in a given region, especially on the "last mile", which in that case can be very long [26].

The last mile is regarded as the most expensive section of distribution of goods [27,28]: its cost can amount up to half of total logistic costs [29] and contributes to an increase in social costs [30].

Rural deliveries can be three times more expensive than urban ones [31,32]). However, in urban areas external costs are higher [33].

New effective solutions are needed, which are effective both from the point of view of operators, users, and society, and, therefore, solutions that will meet the requirements of sustainable development [34–36]. Organizational, technology-enabled, and data technique-enabled innovations [37] can help improve efficiency of the last mile deliveries [38,39]. They include: urban consolidation centers [40–42], crowdsourcing [43–46], pickup points, parcel

lockers [47], automated technologies, robots [48–50] "mobile warehouse" [51], reception boxes [52], drones [53], autonomous vehicle deliveries [54], such as autonomous cars [55], and bike deliveries [56]. Technologies aimed at increasing the efficiency of deliveries and reducing the negative impact on the environment are implemented and tested [57–59], such as alternative fuels (e.g., biodiesel), and the use of electric vehicles (EVs) for home deliveries [60,61]. For example, the analysis conducted in Milan proved that the use of electric vehicles (EVs) leads to a decrease in greenhouse gas (GHG) emissions to 54% [62].

Research is underway to solve the problem of congestion in cities caused by the increase in transport carried out by courier companies. One such interesting concept is the use of underground railways to distribute parcels [63]. Another solution, which can improve the efficiency of the last mile deliveries in e-commerce, can be smart parcel stations (SPS), which have been widely deployed in several countries [64]. The innovations have the potential to reduce externalities generated by the last-mile delivery activities [65,66]. Research conducted in Poland shows that parcel lockers can help reducing negative environmentally impact by reducing the number of deliveries in the city area, in some cases even tenfold [67]. However, under conditions that the parcel lockers found in the vicinity of homes, on the way from work and in places where it is possible to park a car [68]. Another interesting information is that in traditional delivery system, a courier is able to deliver 60 parcels in a distance of 150 km, whereas in the system with parcel lockers—600 parcels in just one day, with a travel distance of about 70 km. Similar results were achieved in other analyses [69].

However, the specificity of a given market is important. For example, research conducted in Brazil showed that 70% customers are willing to walk up to 1000 m to a parcel collection point (drugstores, gas stations, post offices, supermarkets, and malls) [70], whereas 95% of pedestrians and 48% of car drivers would agree to collect their goods within 2000 m (30 min or less). Finally, 52% of car drivers are willing to travel up to 5000 m to retrieve purchased goods in CDPs. However, as authors stated, these limits are more representative of the Brazilian reality and differ from those stated in the literature.

Although there are opinions that e-commerce has a negative impact on external costs, the results of the studies indicate the opposite. For example, research in Italy showed that e-commerce can have 10–30% lower energy consumption and CO_2 emissions compared with traditional retail [71,72].

Research conducted in Japan in the book market showed that in e-commerce, considerably more energy per book is used than conventional retail in dense urban areas, because of additional packaging in courier services. On the other hand, more energy can be consumed in suburban and rural areas due to the inefficiency of personal automobile transport [73]. Overall consumption at the national level is nearly the same: 5.6 megajoules (MJ) per book for e-commerce and 5.2 MJ per book for traditional retail [74].

The research conducted in the USA showed that, when customers order films online, less energy is consumed (33%) and less CO_2 (40%) is emitted than in traditional retailing [75,76].

The problem of the impact of the development of the e-commerce industry on individual motorization (and, consequently, on social costs) in cities was also the subject of research of M. Stinson et al. [77]. According to the results of the study, although e-commerce has generated an increase in parcel truck delivery trips, the net effect of e-commerce is a reduction in fuel consumption due major via shopping trip reductions.

3. Materials and Methods

The considerations presented by the authors are based on the results of the original research supported by the analysis of the literature.

The authors conducted telephone interviews with courier companies in Poland and with couriers themselves. The interviews were conducted in July and August 2021.

Interviews were conducted with representatives of two courier companies UPS (deliveries to customers' homes) and INPOST (deliveries to parcel lockers) and five couriers

who work for these companies and for GSL company (deliveries to customers' homes). This made it possible to compare alternative parcel distribution systems. People taking part in the study were informed about the purpose of the study and gave their consent to the interview and publication of the study results. During the interview, these people were asked 7 open-ended questions (free-form interview). The replies were very extensive; one interview lasted about 1 h. Couriers had at least several years of experience, usually with more than one courier company. Two couriers interviewed also worked in the UK (2020 year) and Germany (2021). Couriers also compared the situation on the e-commerce market before the pandemic and currently during the pandemic. All couriers delivered parcels in urbanized areas.

The main purpose of the interview was to obtain data to simulate energy consumption for two typical models of last mile deliveries in Poland.

To justify the importance of the issues undertaken by the authors, the calculations of the consumption of energy on the last mile have been conducted. Results are presented below. The authors elaborated following formula of the consumption of fuel on a given section of the whole route of a parcel:

$$Cpp = (Cpv*D)/(C*U) \quad (1)$$

where:

Cpp—Unit consumption of fuel [l/km/parcel]
Cpv—Consumption of fuel by a given vehicle [l/km/vehicle]
D—Distance [km])
C—Capacity [parcels]
U—Utilization of the Capacity

The above formula has been used also in the calculations, results of which are presented in the Section 4 of this article.

The assumptions for calculations are in Table 1 and results of the calculations are presented in Table 2.

Table 1. Assumptions for calculations.

Capacity of a Vehicle	Consumption of Fuel
[parcels/vehicle]	[l/km]
100	0.15

Source: Own calculation based on the data from transportation market.

Table 2. Simulations of consumption of petrol in an e-commerce supply chain.

Supply Chain Stage	Capacity	Distance	Consumption of Petrol [L/km]		Share
	[Parcels]	[km]	per Vehicle	per Parcel	
From a supplier to a DC	1125	400	0.38	0.14	21.7%
"Last mile" (From DC to receivers)	100	325	0.15	0.49	78.3%

Source: Own calculation based on the data from transportation market.

Under assumed conditions the consumption of fuel on the last-mile section stands for the biggest part of the consumption of fuel per parcel on the whole route (78.3%). The basic reason is that final deliveries from a Distribution Centre to recipients are performed with the usage of smaller transport means, whereas to the Centre in the more economical full truck load mode (e.g., 24 tons of a load). Therefore, the efficiency of the processes on the last mile is important, and this the reason authors deal with this problem.

4. Results of the Research

4.1. Stages of the Conducted Research

On the basis of interviews, two basic models of the deliveries on the last mile in Poland have been identified: direct deliveries to homes of customers and deliveries to parcel lockers. These models are described in Section 4.2.

Next, the authors described for comparison how delivery parcels are performed in Germany and the UK (Section 4.3).

In the next stage, the authors have conducted a calculation of the energy efficiency of the deliveries on the last mile for two previously described models (Section 4.4). The intentions of the authors were to investigate which of these models are more energy efficient and to what extent. For calculations, the authors used data obtained during their own research and data from the literature. These are, for example: the number of parcels delivered by a courier during one delivery and number of addresses, consumption of fuel, a length of a route, and capacity of vehicles.

Then, the authors compared energy efficiency for two levels of demand for courier services—before and during the pandemic (Section 4.5).

Finally, conclusions were drawn (Section 5).

4.2. Models of Deliveries on the Last Mile to E-Commerce Customers in Poland

In Poland, there are two basic models of the last mile delivery to internet customers.

- Direct deliveries to homes of customers;
- Deliveries to parcel lockers.

Most courier companies in Poland use the first model—direct deliveries to homes of customers. An example of a company using this model in Poland is UPS Polska. Based on the interview, it can be concluded that in UPS number of delivered parcels indeed increased during the pandemic by 20–30%, but the capacity of the vehicles has not changed. The distances travelled by the transport means decreased, because more customers are served and one vehicle can serve smaller area. This evidently confirms of the occurrence of the phenomenon of the economies of scale, also in this industry. Furthermore, despite the increase in the number of parcels, the quality of service did not worsen.

In Poland, a big problem in deliveries to homes is the absence of the customers. Couriers do not leave parcels at the doors, and neighbors usually are not willing to receive parcels. For this reason, in many cases a courier has to deliver them on the next day.

The second model, used in Poland only by one company—INPOST, is based on the deliveries not to customers' homes, but to parcel lockers. Customers collect parcels on their own from parcel lockers. This form of distribution develops in Poland dynamically. During the pandemic, the increase in deliveries of parcels to parcel lockers was 100%. Before the pandemic, the number of parcel lockers was 7000, and nowadays it is 13,000. Presently, in cities in Poland, parcel lockers are located on average 450 m from each other. A courier visits per day only 4 parcel lockers, delivering on average 250 parcels to each parcel locker (1000 parcels delivered per day). However, if this number of parcels does not fit in one van, a courier has to perform 2–4 trips a day to a Distribution Centre.

According to information obtained from INPOST, the parcel lockers are more efficient—one parcel-locker replace 13 vans with a driver, who delivers 70–75 parcels per day, visiting 90–100 locations (the problem of the absence of inhabitants at homes). However, according to the couriers interviewed by the authors, these figures are currently slightly different, which are presented in Section 4.3.

Additionally, in this company, the capacity of vehicles is the same, such as it was before the pandemic, and is fully utilized. More and more often, electric vehicles are utilized. As for the distances, they did not change, which can be explained by the specificity of this business model. Despite the increase in the number of parcels during the pandemic, the quality of service in this company also did not worsen.

Of course, customers have to travel to parcel lockers to pick up parcels, which can contribute to the external effects of last-mile delivery. However, parcel lockers in cities are presently very densely located, which makes it possible to reach them even on foot. Above all, however, they are located near frequently visited places such as shopping centers, thus customers can pick up (and send) parcels while doing other things (e.g., shopping).

4.3. Comparison of the Models of Distribution of Parcels in Different Countries

Interesting information have been obtained by the authors during interviews with couriers in Poland, who deliver goods to customers or to the parcel lockers. Some of the responded couriers had experiences in work also in other countries—in Germany and UK. The results of these interviews indicate that logistics operations on the last mile in Poland are relatively less efficient than in Germany and the UK. In Germany and the UK, the problem of non-delivered parcels (and additional trips) is less severe than in Poland. In Germany, when a customer is not at home, the parcels are usually left with neighbors. They can also be left in a parcel collection point. In the UK, parcels are left at the door of a customer, thus the problem of the absence of a customer does not exist.

In study cases, a courier in Germany delivers about 100 parcels daily. In the UK, a courier delivers about 80—even 150—parcels daily. The pandemic also had impact on the e-commerce market in Germany—before the outbreak of the pandemic, a courier delivered 50% fewer parcels.

4.4. Comparison of the Energy Efficiency of Deliveries to Homes and to Parcels-Lockers

The authors performed calculations of the energy efficiency of deliveries to customers and parcel lockers based on the data:

(a) Presented in the literature;
(b) Obtained during their own research (interviews).

These data differ from each other, e.g., the distances covered during a day in case of different couriers, which results, e.g., from different distances to a Distribution Centre or different areas to which parcels are distributed. In the author's opinion, the reason is also that data in the literature are from the period 2011–2013, and the research conducted by the authors concerning the period in the time of the pandemic.

For the calculations based on their own research, the authors used the data most often repeated in the answers. For example, the indicated quantities were from 70 to 120 parcels, but authors used the number of 100 parcels. The number of parcels per vehicle delivered to customers' homes depends first of all on a season. Most of the parcels are delivered in December.

The authors adopted the following assumptions for the calculation:

(a) Calculations based on the data obtained from the literature ([63–65]):
    - During one day a courier has to deliver 60 parcels to customers or 600 to parcels lockers;
    - The distance to customers is 150 km/day, and in case of deliveries to parcel lockers 70 km/day.
(b) Calculations based on the data obtained by the authors during their own research:
    - During one day, a courier has to deliver 100 parcels to customers or 1000 parcels to parcel lockers;
    - In case of deliveries to homes of customers, the distances from the distribution center to the first customer's home and from the last customer's home to the distribution center is 25 km each, and the distance between customers to whom the courier delivers parcels per day is 30 km (80 km in total);
    - The distance from a Distribution Centre to a parcel locker and returning to the DC is 25 km (in total 50 km), and the distance between two parcel lockers—0.5 km;
    - Number of parcel lockers to which the courier delivers parcels per day—4;

- The number of loading operations in the distribution center per one day for a courier delivering parcels to the customer's homes—1;
- Number of loading operations in the distribution center per one day for a courier delivering parcels to parcel lockers—2 or 4 (it depends on the sizes of parcels because usually it is not possible to load 1000 parcels into a one van). Therefore, in the case of deliveries to parcel lockers, calculations have been performed for two variants in distribution:
  - Two runs—101 km/per day;
  - Four runs—202 km/per day.

This is based on the results of the research calculations which have been performed, the results of which are presented in Table 3 and compared with the results of the research from the literature.

Table 3. Comparison of efficiency of consumption of fuel of two distribution channels in e-commerce.

Source: Literature ([63–65])		**Source: [Own Research]**		
Deliveries to Homes	**Parcel Lockers**	**Deliveries to Homes**	**Parcel Lockers (V1)**	**Parcel Lockers (V2)**
Distances [km/day]				
150.0	70	80.0	102.0	202.0
Number of packages per day [pcs.]				
60.0	600	100.0	1000.0	1000.0
Consumption of petrol [L/parcel]				
0.38	0.02	0.12	0.02	0.03
Savings per parcel	−95.33%		−87.25%	−74.75%
Consumption of petrol [L/m^3]				
2.88	1.35	1.54	0.98	0.97
Savings per m^3	−53.33%		−36.25%	−36.88%

Source: Own calculation based on the data from transportation market.

Results of the calculations of the authors on the base of the data from the literature are in the first and second columns of Table 3 ([63–65]). Thanks to the use of the parcel lockers, the consumption of energy per parcel can be reduced by 95.33%.

Other results were obtained by the authors with the use of data obtained during interviews. In the first variant, savings amount to 87.25%, and in the second to 74.75%, thus they are lower than obtained with data from the literature, but still considerable. That confirms a high energy efficiency of the system with parcel lockers.

This is mainly because, thanks to the usage of parcel lockers, a courier can deliver about 10 times more parcels during a day than in the case of deliveries to homes. Additionally, the distances traveled by a courier delivering parcels to parcel lockers are usually shorter than for home deliveries. However, it depends on how many times a day a courier has to visit a distribution center due to the inability to load 1000 parcels into one van (in the studied cases, 2 and 4 times).

The authors calculated the energy savings of deliveries to parcel lockers not only per parcel, but also per m^3, in order to ensure comparability of both models. The parcels delivered to a parcel locker are usually smaller than those delivered to customers' home. The savings per m^3 are smaller but still significant—53.33% when we use data from the literature, and 36.25% for the first variant (V1) and 36.88% for the second (V2), when we use data obtained by the authors.

4.5. Economies of Scale on the Last Mile

Based on the data obtained from interviews, simulations have been conducted concerning the impact of the scale of operations on the efficiency of deliveries of parcels directly to homes.

Table 4 presents the results of these simulations.

Table 4. Impact of scale of operations on the last mile in e-commerce.

Lower Demand (before Pandemic)	Higher Demand (during Pandemic)
Distances [km/day]	
100.0	80.0
Number of packages per day [pcs.]	
80.0	100.0
Consumption of petrol [L/parcel]	
18.8	12.0
Savings	−36%

Source: Own calculation based on the data from transportation market.

Calculations have been made for two variants:

1. "Lower demand (before pandemic)";
2. "Higher demand (during pandemic)".

If demand increases, economies of scale are visible. The distances to customers are shortened from 100 km to 80 km. Apart from this, the capacity of vehicles is better utilized—there are more parcels to be delivered during the trip, at 100 in comparison with 80 before the pandemic. In effect, the consumption of fuel is lower by 36% per parcel.

5. Conclusions and Discussion

The growth of the e-commerce market results in an increase in the transport of goods, which raises concerns about an increase in social costs due to higher consumption energy. In Poland, during the pandemic the number of delivered parcels increased 20–100%, depending on the company. An especially high increase (100%) was experienced by the company INPOST, which delivers parcels to parcel lockers. Additionally, the number of parcel lockers increased by almost 100%.

According to the calculations made by the authors, delivery processes on the last mile are particularly important—the last mile can consume even over 70% of energy per parcel in the whole distribution channel. However, the impact of the deliveries on the last mile on the consumption of fuel can be minimized.

The simulations conducted by the authors of this article were based on the results of different studies, but first of all on the information and data from the transportation market.

According to the research conducted by the authors of the article, there are opportunities to increase the energy efficiency of the deliveries of parcels. The authors calculated that the biggest savings can be obtained by the use of the parcel lockers instead of deliveries to homes. In Poland, deliveries to parcel lockers are performed only by one company—INPOST. Thanks to the utilization of parcel lockers, the savings of energy consumption can reach 74–87% per parcel or 36% per m^3. Such good results are possible because a courier delivers parcels per day only to four parcel lockers, leaving in them about 10 times more parcels than a courier delivering parcels to homes. However, the energy efficiency of deliveries with the use of parcel lockers depends on the number of trips performed by a courier during one day to and from a Distribution Centre. A courier delivering parcels to parcel lockers replaces 10–13 couriers delivering to homes, depending on the distances between customers and sizes of parcels.

Another factor which has an impact on the energy efficiency of transport processes in INPOST is the introduction of electric vehicles.

Additionally, in this market, the economies of scale are visible—when the e-commerce market grows, such as recently during pandemic, the efficiency of deliveries also increases (about 36%). The routes are shorter, the vehicles are better utilized, which also decreases the negative impact on social costs and consumption of energy.

In Poland, the problem of non-delivered parcels is more severe than in Germany and the UK, which may impact the efficiency of transport (necessity of additional trips). Some of the couriers indicate the problem of overloaded vehicles.

The research also show potential for improvement, especially when different models and different markets (e.g., in different countries) are compared. This problem requires further and in-depth research.

Apart from this, in concrete situations the energy efficiency depends on many factors. Different transportation means are used in different conditions—urban spaces, crowded streets, problems with parking. The authors also did not refer to the other solutions only mentioned in the paper—models of distribution (crowdsourcing), and new technologies (e.g., automated, electric vehicles), which could further increase energy efficiency in the e-commerce on the last mile.

Taking into account all of the above-mentioned problems, further research is needed.

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