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Unloading Bays as Charging Stations for EFV-Based Urban Freight Delivery System—Example of Szczecin

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Abstract: The problem of urban logistics operations in the context of their impact on the environment has become the key challenge. Due to that, there has been a growing interest in increasing the use of alternative fuels, including electro-mobility. However, an important barrier to the utilisation of electric freight vehicles (EFVs) is their travel range and battery capacity. The paper is focused on the idea of EFV utilisation improvement by implementation of charging stations in unloading bays. First, the Authors analysed the efficiency of chosen vehicles during daily work. Next, the potential improvement of their travel range was analysed, considering the short-time charging processes carried out during delivery operations, using the charging systems provided in unloading bays. Moreover, the concept of wireless chargers utilisation was proposed as a challenge for future work. According to the analysis, utilisation of unloading bays equipped with short-time battery chargers could improve significantly the travel range of EFVs. As a result, it could improve the efficiency of electric vehicles in last mile deliveries in city areas.

Keywords: urban freight transport (UFT); unloading bays; electro-mobility; electric vehicle (EV); electric freight vehicle (EFV); charging stations; charging infrastructure

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Citation: Iwan, S.; Nürnberg, M.; Bejger, A.; Kijewska, K.; Małecki, K. Unloading Bays as Charging Stations for EFV-Based Urban Freight Delivery System—Example of Szczecin. *Energies* **2021**, *14*, 5677. https://doi.org/10.3390/en14185677

Academic Editors: Pedro Roncero-Sanchez and Woojin Choi

Received: 6 July 2021
Accepted: 6 September 2021
Published: 9 September 2021

1. Introduction

One of the main sources of pollutant emissions in cities is urban transport [1,2], including urban freight transport which makes a particularly important ecological footprint [3,4]. Analyses of solutions supporting urban logistics in the context of its impact on the environment are carried out, especially since the interests of various stakeholder groups are often contradictory [5,6]. Hence, in recent years, there has been a growing interest in increasing the efficiency of transport telematics systems [7], and the use of alternative fuel vehicles in freight transport in urban areas, e.g., those equipped with electric drives [8–10].

Progress of electromobility is a fact. Many research teams and groups have been working on this subject, analysing the carbon footprint, i.e., impact on the environment, and economic aspects connected with electromobility implementation. According to Quak et al. [11], the cost of charging batteries in electric vehicles (EVs) is ca. 6 times lower than the cost of fuel combusted by motor vehicles, assuming more or less the same distance covered by both kinds of vehicles. In addition to that, EVs feature lower insurance costs, a simpler motor structure (which means lower maintenance costs), provide the possibility of moving around and parking in city centres without additional fees, and produce lower levels of noise and pollution, which makes it more reasonable (in economic and environmental terms) to keep large EV fleets rather than ICEV (internal combustion engine vehicle) fleets [12,13], despite the higher initial cost of investment, i.e., the higher cost of purchase of electric vehicles [14,15]. Sierpiński in [16], analysing the potential of electromobility in passenger and freight transport, showed that in view of the distances covered by commercial EVs and the applied journey schedules, electric vehicles are predestined to be used in urban logistics, also for the purposes of 'last mile' deliveries. Despite all those advantages, the share of EVs in commercial fleets is very small [17], while the initiatives aimed at increasing the utilisation of EVs in freight transport have not delivered the expected results [18,19].

The question is: why is it so? Despite the decades of electric engine development [20], the basic problem is storage of electric power in the vehicles and the process maintenance. Engineers have been working to develop batteries that are relatively light-weight and that can be quickly recharged [21]. At the same time, EV charging infrastructures are being developed [15], so as to enable application of this type of vehicles on longer distances, without the need to stop the vehicle for hours during the day, thus putting it out of service. Even though authors of various research studies describe EVs as a good alternative for local freight transport [22,23], the authors of this paper focus on more effective utilisation of EVs in 'last mile' delivery of goods.

The idea introduced in this paper is focused on the integration of both solutions—electro-mobility and unloading bays. The major assumption for the study was to demonstrate the feasibility of using micro-charging stations in unloading bay areas that will extend the range of the electric freight vehicles (EFVs) by a few kilometres. The Authors introduced the general concept of the system, the technical expectations and the first part of the analysis. It is the result of the first stage of the works carried out under the international project called EUFAL (Electric Urban Freight And Logistics) which is co-funded by the ERA-NET Cofund Electric Mobility Europe. The paper is structured as follows: Section 2 is focused on literature investigation of the chosen city logistics measures, unloading bays and the development of electric freight vehicles and a short overview of EV charging systems. Section 3 describes the general conceptual framework of the presented research. The next parts of the paper cover the results of the experiments featuring utilisation of chosen electric vehicles and simulation of the usability of short-time charging during the delivery processes, with a view to increasing the EFV range as well as the discussion related to the future works focusing on utilization of wireless charging systems in proposed concept. The paper ends with a summary including conclusions and the discussion of the achievements.

2. Analysed City Logistics Measures—Literature Review

2.1. Unloading Bays as an Efficient City Logistics Measure

Unloading bays are an example of an efficient, environmentally friendly and easy to implement measure that supports urban delivery systems [24]. Provision of unloading bays makes it possible to reduce congestion in city centres. Excess congestion is caused by freight vehicles parked directly on streets, while the unloading activity is performed. Unloading bays are designated to support the logistics of goods in cities so that unloading any goods in cities does not unnecessarily interfere with road traffic, and thus does not cause excessive pollution of the environment through additional fuel or power consumption in ICEVs and EVs, or additional costs and downtimes related to traffic jams. It should be underlined that this is a pull-type measure which is very simple to implement. It's mainly based on administrative activities and cooperation between stakeholders such as city authorities, freight shippers and carriers [25]. Due to the fact that the costs of setting up unloading bays are relatively low, it is a cost-effective measure for the local government. The authors of [26] analysed the effectiveness of using the unloading bays in urban goods deliveries in terms of their number and distribution [26]. A major disadvantage of this solution is the need to take up some parking spaces in order to separate the space for unloading the goods, which is one of the objections raised by residents [27,28]. However, it could be counterbalanced by the noticeable improvements in the form of reduced traffic congestion for both the traffic users and the residents [18].

The most important profit from utilisation of unloading bays for the city is its impact on reduction of traffic congestion, and therefore an observable reduction of pollutant emissions.

Research studies completed in Bordeaux (France) have shown that the implementation of unloading bays has decreased CO_2 emissions by almost 40 kg per day [29]. Furthermore, an analysis made in Szczecin (Poland) and Oslo (Norway) has exposed that delivery vehicle drivers have to drive 1.8–2.0 km (on average) more in order to find a parking space to unload their goods, or they stop directly in the traffic lane [30]. Designation of special spaces for delivery operations helps to reduce this effect [30,31].

The environmental efficiency of unloading bays has been analysed also in [31]. The basis of this analysis was the implementation of two unloading bays in the city centre of Szczecin (Poland) at the second biggest street in the analysed area in terms of the number of commercial entities (41 retail outlets, 37 service entities, 4 HoReCa (Hotels, Restaurants, Catering) entities and 3 small production plants). The total number of weekly deliveries equalled 518. To analyse the efficiency of the implemented unloading bays, traffic data were acquired by Sierzega SR4 mobile traffic detectors. The data included four vehicle categories and their speed. The process of data collection lasted over one week from Monday to Friday, between 6 a.m. and 6 p.m.

Additionally, using the cellular automata based computer simulation, the authors of [31] proved that implementation of unloading bays in the studied area of the centre of Szczecin (Poland) increased the traffic flow by 8% on average. Appropriate calculations showed reductions in pollutant emissions on average by [31]: 4% in the case of carbon monoxide (CO), 5% in the case of hydrocarbons (HC), and 4% in the case of nitrogen oxides (NOX). The evaluating problems and measures for a sustainable urban freight transport was presented in [32]. The authors of the study [33] focused on optimizing the unloading bay system in order to increase their efficiency and thus proved their hypothesis that having optimal bay locations and enforcing use are good practices leading to improved traffic flow and thus better mobility in the road network.

2.2. Development of Electric Vehicles in City Logistics

Nowadays, a number of city logistic activities and projects involve modifying freight vehicles, including EFVs [34,35]. Development of EFVs in city logistics is one of the most important options for implementation of sustainable goods deliveries, which significantly reduces the environmental impact of urban freight transport, especially local pollutant emissions, like CO, NOx, SOx, PM, etc. [30,31]. Moreover, thanks to the low level of noise, this measure could be connected with the other city logistics measures, like night deliveries [34]. These issues have been analysed from the beginning of the present century or even earlier. One of the first research projects regarding the utilisation of EVs in city logistics was ELCIDIS (Electric Vehicle City Distribution) [36]. In recent years, many renowned initiatives of this kind have been implemented, such as: EVD Post (Electric vehicles deliveries in postal services, 1998–2000), CIVITAS (Cleaner and better transport in cities, 2002–2016), CO_2NeuTrAlp (CO_2—Neutral Transport for the Alpine Space, 2009–2012), TURBLOG (Transferability of urban logistics concepts and practice from a worldwide perspective, 2010–2013), ENCLOSE (Energy efficiency in City Logistics Services for small and mid-sized European Historic Towns, 2012–2015), SMARTFUSION (Smart Urban Freight Solutions, 2012–2015), SELECT (Suitable electromobility for commercial transport, 2012–2015), Grid-Motion (2017–2018), and Sustainable Porto Santo (2018–2020). All these projects involved a large number of researchers from different countries and they were focused on such aspects as: applying EFVs in the postal services, general utilisation of EFVs, using the refrigerated units in the aspect of goods distribution, reducing CO_2 emissions, etc.

Thanks to the projects mentioned above as well as the other experimental works completed around the world, a lot of effective measures have started to be implemented in cities [31,34,36–38]. These activities helped to analyse the efficiency of the vehicles, availability of the proper conditions for their utilisation as well as the expectations regarding business models, legal regulations, technological issues, and needed local or regional regulations related to improvement of their utility. However, based on the results of above mentioned studies, the costs of purchasing EVs are still perceived to be a substantial barrier to their wide-spread use [39], taking into account operational parameters of EFVs and the needs of the logistic processes they should serve. Therefore, the key challenge is optimisation of the transport fleet while taking into account a multi-criteria evaluation of benefits [9,10]. The range of electric vehicles is still one of the current research topics, e.g., related to the problem of electric vehicle routing [40–42] and a new technology that allows the vehicle to be charged while it is in motion [43].

Although today's EFVs demonstrate better and better performance parameters (longer travel range, more capacious batteries and more carrying capacity), their actual usability in urban logistics still remains limited. Therefore, participants of the FREVUE project [44] specified a selected number of factors and challenges which influence successful implementation of EFVs in everyday logistic operations in cities [45]. They categorised them as: technical performance, operational performance, economics, environmental, social and attitudinal impact, local policy and governance structure [45]. Under the FREVUE project [44], some challenges and factors that influence successful implementation of EFVs in everyday logistic operations in a city have been specified [45]:

- technical performance—from focus on the range to the importance of aftersales,
- operational performance—fine-tuning urban logistics operations to EFVs,
- economics—searching for new forms of ownership and successful business models,
- environmental, social and attitudinal impact—confirmation of positive trends,
- local policy and governance structure—to a more integrated city management approach.

Efficient and successful development of electric vehicles depends on many different factors, but one seems to be the most important—appropriate charging system [46]. That means a network of charging stations, which is well-fitted and customised for users and local conditions. The charging process itself is not only about connecting the voltage to EV batteries. The process flow is much more complicated due to the necessity to determine charging parameters considering power network conditions, state of charge, technical limitations, and most of all, the user's safety. It needs bidirectional communication between the EV charging module and the charging station. To protect the battery cells from overheating and damage, the charging station supplies a constant current with a continuously increasing voltage, which fills up battery cells quickly only up to 80% of its capacity. Afterwards, the voltage becomes constant and the current is significantly decreased to prevent further battery temperature increase, but the charging time is noticeably extended. EV batteries may be charged with DC or AC in the following modes [46]:

- Mode 2—slow charging—charging with alternating current is easily available from the mains power supply with 230 V AC, supplying power up to 3.7 kW;
- Mode 3—accelerated charging—three-phase alternating current up to 22 kW. The limitation here is the vehicle charger, which is the 'bottleneck', and the parameters of the charging process depend on its parameters;
- Mode 4—rapid charging—in the case of DC charging, the vehicle battery is directly charged, without the use of a charger. The standard is 50 kW, but 150–350 kW chargers are already available, enabling ultra-rapid charging.

3. Research Contextual Framework

The analyses of the projects and activities mentioned in Section 2 inspired the Authors to connect utilisation of EFVs with utilization of unloading bays. Previous works were mostly focused on a direct analysis of EFVs efficiency and typical charging infrastructure development [47–49]. Due to that the Authors asked the major research question as follow: How can we improve the utilisation of EFVs by means of a short-time charging process carried out during the delivery service?

Analysing both city logistics measures—unloading bays and utilization of EFV, the hypothesis for the research work has been established, like below:

Utilization of unloading bays as a short-time charging stations will help to increase the range of EFV in appropriate way and will improve the delivery process giving higher number of parcels delivered.

The idea introduced in a paper is a new approach. It must be underlined that unloading bays were not yet usedas the charging stations and so far no research has been done in this context. Following that, this is the conceptual work based on the framework shown in Figure 1.

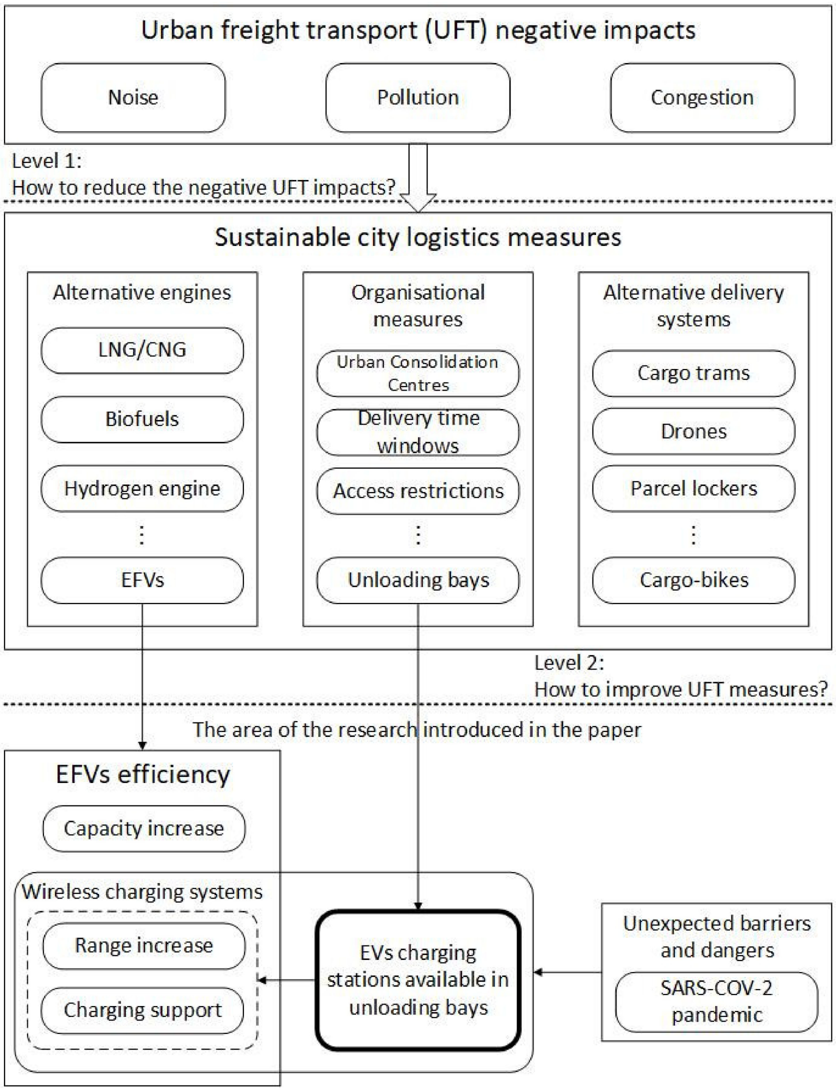


Figure 1. Research conceptual framework.

The starting point for this concept is the fact that urban transport systems generate a significant number of problems and impacts, like pollution, congestion, or noise. It results from the dynamic development of urban areas and the ever increasing number of city users. A significant part of these problems is generated by urban freight transport (UFT). This is due to both the need to deliver goods and supplies to business facilities (shops, hotels, restaurants, industrial plants, etc.), as well as to fulfil orders generated by individual recipients, in particular as part of electronic commerce. Accordingly, it is necessary to find the answer to the question: How to reduce the negative impacts of UFT? This is the first level of the decision making processes for all stakeholders engaged in urban delivery management.

For many years, different city logistics measures have been developed, considering three major types of actions: alternative engines, alternative organisation of deliveries, as well as alternative delivery systems. Recently, alternative engines seem to be one of the most interesting and promising solutions. Especially electromobility is becoming a very efficient and valuable measure. However, in the process of the measures development, the next strategically important question arises: How to improve the efficiency of those measures? How should we organise them to achieve the possibly highest level of their usability?

In the case of electric freight vehicles, the major conditions for their effective utilisation are: loading capacity, travel range (considering the battery capacity as well as the energy consumption) and support for charging processes. The research study presented in this paper is directly related to the latter two issues. The concept of utilisation of unloading bays as additional charging stations is based on the general assumption that the time of delivery could be used for the short-time charging process. As a result of that, the travel range of the EFVs can be improved. The ambition of the Authors was to assess how this concept can increase the range of the vehicles, considering the given number of stops during the delivery process carried out by a courier. For this purpose, a chosen type of vehicle (Nissan eNV200) was utilised for the experiments held in real conditions. Based on this, the potential range increase was assessed. Additionally, to minimise the driver's engagement in the battery charging process (to connect and disconnect the vehicle), the idea of wireless charging systems was emphasised in the next step. This issue appears more significant in the context of the pandemic crisis and the need to reduce direct contacts with different public devices.

It must be underlined that this paper is a conceptual one. The practical experiments with the wireless charging systems were impossible to be completed at the present stage. It results from the fact that nowadays the EFVs are not equipped with that kind of energy charging systems. Following that, the Authors introduced the general concept and the potential added value of utilising unloading bays as additional charging systems for EFVs. The Authors have made an effort to ensure that the results are close to the real ones, analysing the space of a given city in Poland, including the location of electric vehicle charging stations and the location of service and sales points. In addition, the time needed for vehicles to travel between specific points, along with the time needed for unloading and delivering goods, was tested experimentally for the area with designated unloading bays. A further computational simulation consisted in considering the possibility of installing wireless charging points in unloading bays that could provide additional energy for EFVs during their delivery service and without a need for special attention to be paid by EFVs drivers. The next part of the paper presents the subsequent steps of the research study and the results.

4. The Idea of Using Unloading Bays as Charging Stations

4.1. Methodological Assumptions

The major assumption of the idea introduced in this paper is to improve the efficiency of EFVs by using unloading bays equipped with charging stations. This solution will be suitable for different kinds of city deliveries, with the special focus on home and shop/HoReCa deliveries.

To assess the efficiency of using unloading bays to increase the range of EFVs by additional charging during delivery stops, an experiment in relevant (real-world) environment has been carried out. Two major research methods were used—field research and participatory observation, considering the technological limitations (especially in the context of vehicles availability) as well as the fact, that the work is the conceptual one. In the experiment made in Szczecin, Poland, three electric vehicles were used for the estimation of efficiency and range improvement—Nissan Leaf, Nissan New Leaf, and Nissan eNV200. According to producer declaration, chosen technical parameters of using vehicles are presented in Table 1.

Table 1. Technical parameters of vehicles used in experiment.

Parameter	Nissan Leaf	Nissan New Leaf	Nissan e-NV200
Battery capacity (kWh)	24	40	40
Range (WLTP mixed cycle) (km)	117	270	301
AC charging time (h)	6 h 40 min	7 h 30 min	7 h 30 min
Engine power (kW)	80	110	80
Curb weight (kg)	1493	1594	1515
Maximum payload (kg)	395	450	705
Maximum payload capacity (m^3)	0.37	0.40	4.2

The first two are mostly related to the passenger transport. However, it’s possible to adapt them for freight purposes. The second vehicle is a small van, which is suitable for the last mile delivery processes. This experiment was divided into two stages:

- the preliminary research, based on the use of the two types of vehicles (Nissan Leaf and Nissan New Leaf)—during this stage the driver planned the route according to the present availability of the charging station system;
- the delivery-focused research—during this stage the real delivery operations were carried out with the use of Nissan eNV200.

The participatory observation method was used for both stages. The data were collected by means of the questionnaires shown in Table 2. It was significantly important to use the electric vehicles in a way as comfortable as with a conventionally fuelled vehicle. It means that the drivers used all the needed equipment, like radio devices, air-conditioning, etc. The totality of the research was carried out in the course of daily operation cycles of the couriers. The compared data were obtained from various sources (in relation to the two different categories of vehicle drives), which was followed by exploratory research aimed at recognising the context of the daily functioning of the delivery areas and the number of courier vehicle stops in the process of serving the delivery addresses.

Table 2. The questionnaire used in the data collection process.

<table>
<tr><td colspan="2" rowspan="11">License Plate No.</td><td rowspan="2">Remarks</td><td>address</td></tr>
<tr><td>B2B/B2C</td></tr>
<tr><td>%</td><td>cargo space occupancy rate</td></tr>
<tr><td rowspan="3">Electric devices</td><td>other</td></tr>
<tr><td>wipes</td></tr>
<tr><td>heating/AC</td></tr>
<tr><td>Avarange consumption
WITHOUT RESET</td><td>(kWh/100 km)</td></tr>
<tr><td rowspan="3">Range (heating OFF)</td><td>heating</td></tr>
<tr><td>end</td></tr>
<tr><td>start</td></tr>
<tr><td>Bettery level [%]</td><td>end
start</td></tr>
<tr><td rowspan="9">Vehicle</td><td rowspan="9">Driver</td><td>Odometer [km]</td><td>end
start</td></tr>
<tr><td>Temperature</td><td>end
start</td></tr>
<tr><td>Time</td><td>end
start</td></tr>
<tr><td rowspan="4">“delivery addresses”</td><td>number of picked up boxes</td></tr>
<tr><td>number of delivered boxes</td></tr>
<tr><td>number of delivery addresses</td></tr>
<tr><td>stop point</td></tr>
<tr><td colspan="2">Date</td></tr>
</table>

4.2. Preliminary Research

To analyse the efficiency of the present charging system in Szczecin, the city centre area was included in the experiment (Figure 2). The map presented in Figure 2 shows the charging stations available during experiment period within the analysed area. The vehicles were used for three weeks. Three different available charging modes were included in the assessment.

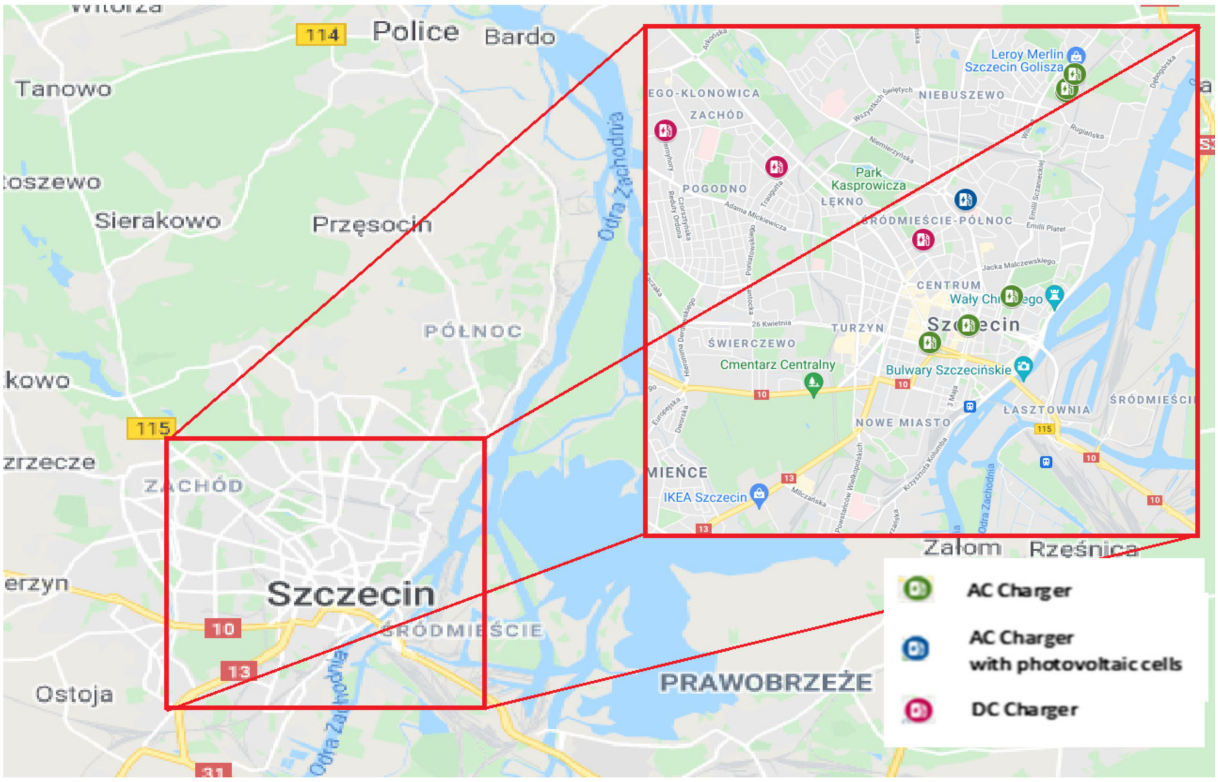


Figure 2. The area of the Szczecin experiment.

The main purpose of the preliminary research was to check whether the existing charging infrastructure allowed the EVs to be operated freely. In addition, we wanted to learn about the use of EV to determine indicators to quantify vehicle performance parameters, such as energy consumption, available range, and battery charge status. Input parameters in this stage were battery capacity and range at start of driving and output parameters were battery capacity and range at stop of driving and availability of public charging stations. The authors' assumption was to use the EVs (Nissan Leaf and Nissan New Leaf) in daily operation without charging during night stops. The tests were carried out on 19–24 February 2018 using Nissan Leaf and on 10–20 April 2018 using Nissan New Leaf. The results are presented in Table 3.

The driver had full freedom to use all energy-consuming devices, like heating and air-conditioning, and to choose the driving mode: eco, standard, or recuperation. This allowed checking whether the vehicle parameters (battery capacity and range of the vehicle) are sufficient so that the user does not have to use their own charger at the place of garage parking. The performed tests showed that the charging infrastructure existing in Szczecin allowed for free use of the EVs, it was never necessary to charge the vehicle from its own power source.

4.3. The Delivery-Focused Research

The second stage of the experiment was carried out in collaboration with DPD Polska, Szczecin branch, on 12 routes (Tables 4 and A1). It should be stated that EFVs are on the very first stage of development in Poland. Due to that, the companies have not had too many experiences related to that. At the moment of the authors work, DPD Polska didn't use electric vehicles in the Szczecin area. Therefore, the vehicles were delivered by supporting vehicles seller.

Table 3. The range increase for the analysed vehicles.

Date	Time		Odometer [km]		Battery Level (%)		Range [km] (Heating Off)		Range after Heating On [km]	Average Consumption [kWh/100 km]	Remarks
	Start	Stop	Start	Stop	Start	Stop	Start	Stop			
NISSAN LEAF											
19 February	15:30	18:47	6344	6393	74	20				22.6	temp. 2 °C
20 February	09:30	09:55	6393	6401	21	14	35	27	−7	20.4	temp. −1 °C
	10:10	10:45	Charging		14	27	27	53	–		CS Kaskada
	10:50	11:05	6401	6403	27	27	53	52	−7	19	temp. 0 °C
	11:50	12:35	6403	6428	27	3	52	**	**	19	temp. 2 °C
	12:35	13:14	Charging		3	84	**	167	**		CS Polmotor Chademo
	13:15	13:35	6428	6439	84	76	167	152	−14	16.7	ECO mode off
	14:55	15:10	6439	6448	76	71	152	133	−11	19.2	temp. 3 °C
	17:20	18:55	6448	6465	71	52	133	97	−10	23.8	temp. 1 °C
	20:30	20:46	6465	6473	52	45	96	84	−9	23.3	temp. −1 °C
	20:48	20:57	Charging		45	48	84	91	−10	**	CS Golisza-LiroyMerlin
	20:57	21:22	6473	6488	48	35	91	64	−6	21.6	temp. −2 °C
21 February	09:45	11:16	6488	6500	34	21	64	40	−6	19.5	temp. 0 °C
	11:20	12:45	Charging		21	62	40	117	−14	**	CS Golisza ZWiK
	12:45	14:16	6500	6545	62	27	117	48	−3	17.4	temp. 2 °C, ECO mode on, out of city center ride
	19:30	20:05	6545	6557	27	14	48	24	−3	21	temp. −1 °C, ECO
	20:05	21:05	Charging		14	36	24	69	−6	**	CS Kaskada
	21:05	21:20	6557	6565	36	28	69	53	−6	21.3	temp. −2 °C, ECO

Table 3. *Cont.*

Date	Time		Odometer [km]		Battery Level (%)		Range [km] (Heating Off)		Range after Heating On [km]	Average Consumption [kWh/100 km]	Remarks
	Start	Stop	Start	Stop	Start	Stop	Start	Stop			
22 February	09:30	10:10	6565	6577	29	15	53	30	−6	21.6	temp. −2 °C, ECO
	14:00	14:12	6577	6589	15	**	30	**	**	17	temp. 1 °C, ECO
	14:15	14:55	Charging		** (3)	87	**	166	−20		CS Polmotor Chademo
	14:55	15:20	6589	6605	87	76	166	152	−20	18.3	temp. 1 °C
	16:07	20:03	6605	6647	76	33	151	64	−18	24	temp. −3 °C
23 February	08:35	13:00	6647	6671	34	** (4)	64	**	−6	24.9	temp. −8 °C (8:30)
	13:05	13:52	Charging		** (4)	91	**	165	−22		temp. −1 °C (13:00). CS Polmotor Chademo
	13:55	17:03	6671	6699	91	67	155	112	−15	23.2	temp. −1 °C, ECO mode off
	18:30	23:10	6699	6741	67	24	112	39	−15	22.9	temp. −4 °C ECO mode off
24 February	10:40	11:25	6741	6752	24	10	40	20	−5	25.1	temp. −3 °C ECO mode off
	11:25	12:15	Charging		10	36	20	66	−10		temp. −2 °C. CS Kaskada
	12:15	13:25	6752	6785	36	6	66	** (19)	−1	20.7	temp. −1 °C
NISSAN NEW LEAF											
10 April	13:50	14:57	1698	1717	90	83	225	216	−5	14.8	temp. 24 °C
	19:00	22:05	1717	1742	83	70	216	186	−5	17.8	temp. 14 °C
11 April	07:35	12:40	1742	1754	71	62	185	161	−6	22.7	temp. 6 °C
	12:45	20:52	1754	1799	62	31	161	75	−6	20	temp. 13 °C, 20:25-temp. 11 °C
12 April	09:35	14:40	1799	1816	31	23	77	59	−2	15.7	temp. 11 °C, temp 22 °C
	14:40	16:04	Charging		23	47	59	118			CS Golisza ZWiK
	16:04	23:28	1816	1868	47	20	118	53	−4	16.3	temp. 22 °C, temp. 16 °C

Table 3. *Cont.*

Date	Time		Odometer [km]		Battery Level (%)		Range [km] (Heating Off)		Range after Heating On [km]	Average Consumption [kWh/100 km]	Remarks
	Start	Stop	Start	Stop	Start	Stop	Start	Stop			
13 April	11:00	11:20	1868	1876	20	18	53	50	−1	14.3	temp. 17 °C
	11:20	15:40	Charging		18	86	50	226			CS Park Hotel
	15:40	20:16	1876	1912	86	67	226	180	−4	18.5	temp. 28 °C, temp. 14 °C
14 April	10:16	10:31	1912	1918	67	65	179	169	−4	13.4	temp. 11 °C
	10:32	10:42	Charging		65	67	169	179			CS Manhattan
	10:45	21:27	1918	1955	67	44	179	116	−4	18.6	temp. 11 °C, temp. 9 °C
15 April	20:58	22:27	1955	2003	44	21	116	58	−2	15	temp. 14 °C, temp. 12 °C
16 April	10:40	13:46	2003	2029	21	9	58	24	−2	18.1	temp. 10 °C, ECO mode on
	13:48	14:23	Charging		9	58	23	175			temp. 10 °C, CS Polmotor Chademo
	15:20	00:23	2029	2047	62	51	175	138	−9	21.9	temp. 10 °C, ECO mode on
17 April	12:20	16:55	2047	2074	51	37	137	100	−7	15	temp. 13 °C, ECO mode on
	16:55	18:58	Charging		37	70	100	184	−9		temp. 18 °C, CS Park Hotel
	19:00	23:10	2074	2127	70	42	184	107	−9/−3	17.5	temp. 18 °C, temp. 8 °C
18 April	07:41	16:16	2127	2199	42	9	107	26	−3	15.2	temp. 8 °C, temp. 24 °C
	16:18	17:12	Charging		9	89	26	234	−6		temp. 24 °C, CS Polmotor Chademo
	17:12	20:47	2199	2218	89	80	234	210	−6	18.2	temp. 24 °C, temp. 17 °C
19 April	09:40	14:03	2218	2239	79	68	209	182	−5/−4	16	temp. 17 °C, temp. 22 °C
	14:05	14:45	Charging		68	79	182	209	−5		temp. 22 °C, CS Manhattan
	14:45	21:26	2239	2286	79	54	209	145	−5/−2	16.8	temp. 22 °C, temp. 14 °C
20 April	10:12	13:11	2286	2320	55	37	145	101	−2/−1	14.7	temp. 19 °C

** —no data: EVs on-board display shows "**" due to insufficient energy to calculate range.

Table 4. The routes included in the second stage of the experiment.

Indicator	Unit	Routes											
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
total distance	km	38.2	40.6	73.1	28.8	29	50.2	40.9	77.2	29.6	34.5	74	47.4
getting to the first delivery address	km	3.9	7.5	25.5	8.6	7.6	5.1	6.8	13.1	7.9	4	25.5	8.6
returning from the last delivery address	km	4.2	7.7	23.2	4.1	8.2	4.5	8.1	29.4	9.3	4.5	31.2	8.5
number of stops	pcs	51	73	51	38	32	48	69	51	33	53	38	39
number of delivery addresses	pcs	70	97	95	69	86	68	92	96	70	80	42	58
number of parcels	pcs	260	133	148	186	181	265	131	140	144	99	58	81
delivery addresses per stop		1.37	1.33	1.86	1.82	2.69	1.42	1.33	1.88	2.12	1.51	1.11	1.49
parcels per delivery address		3.71	1.37	1.56	2.70	2.10	3.90	1.42	1.46	2.06	1.24	1.38	1.40
parcels per stop		5.10	1.82	2.90	4.89	5.66	5.52	1.90	2.75	4.36	1.87	1.53	2.08
number of deliveries	pcs	72	117	125	69	112	67	103	125	72	80	53	66
number of pickups	pcs	188	16	23	109	69	198	28	15	72	19	5	15
average distances between stops	km	0.590	0.348	0.478	0.424	0.413	0.85	0.377	0.680	0.376	0.491	0.455	0.777

Each courier was assigned to a fixed, strictly defined area of the city. Designed conditions of second stage of experiment assumed carrying transport operations strictly according to DPD business process, depending on number of parcels ordered by the customers. The main assumption was that participant observation did not affect the courier's work. To ensure the widest possible diversity of research, researchers chose delivery areas located in the very centre of the city, outside the centre (residential areas), as well as suburban areas. Input parameters concerning EFV were battery capacity and range before start and concerning routes its length and number of parcels (delivery addresses). Output parameters were battery capacity and range after carrying out deliveries referring vehicles and number of delivered parcels (addresses), stops and duration of stops referring particular routes. Prior to the experiment, DPD couriers made deliveries only with combustion vehicles, which is why they were trained to operate the Nissan eNV200, moreover, to be absolutely sure that the quality of DPD services would not suffer, the study was divided into two periods. In the first delivery period, the courier carried out his work using a traditional vehicle, while the EV, driven by the researcher, followed him to record operational parameters and possibilities of EFV utilisation. The research was conducted from Monday to Friday on routes R1 to R5. In the second period, when DPD became convinced that EFV was a reliable means of transport, the same delivery areas were repeated on the same days of the week, routes R6 to R9, while in the third week deliveries were made in suburban areas, routes R10 to R12. Deliveries of parcels were carried out only using EFVs driven by a courier, while the researchers registered operational parameters.

Each route covered several stops related to the delivery processes. Employees who deliver to customers usually serve several nearby delivery addresses during one stop of the vehicle. This is due to their proximity, but also difficulties in finding a place to park the vehicle, especially in the city centre. Generally, the higher the urban density, the more delivery addresses are served at one stop (parking) of the vehicle. On the other hand, in suburban areas couriers enjoy greater freedom to park so they stop at almost every delivery address. It should be mentioned that in most cases the stop duration was short (5 min or less). However, with an increased number of delivery addresses served at one stop, the time of parking increases. In some cases it was possible to have one stop for more than one delivery, and then the stop duration was longer (15 min or more).

4.4. Improvement of EFVs Range on the Basis of Unloading Bays Charging System

Based on the research results mentioned above, the idea of utilisation of unloading bays as short-time charging stations was established. The specificity of the last mile delivery processes are short stops in a congested area. According to the data received from the couriers, the drivers need approximately 15 min to perform one delivery. Based on this assumption and the active work with the vehicles mentioned above, the range increase for a single charging station was calculated, see Table 5.

Table 5. The range increase for analysed vehicles.

Charging Mode	Charging Power	Charging Duration	Power Delivered	The Range Extension [1]	
				Nissan New Leaf	Nissan eNV200
Mode 2 AC 1 phase	3700 Wh	15 min.	925 Wh	5.44 km	3.57 km
Mode 3 AC 3 phase	6600 Wh	15 min.	1650 Wh	9.70 km	6.37 km
Mode 4 DC	50,000 Wh	15 min.	12,500 Wh	73.50 km	48.26 km

[1] Power reduced by on-board charger.

Based on the observations and data collected during the delivery-focused stage of the experiment, the potential range increase was calculated. Two different assumptions were considered:

- the possibility of additional charging the vehicle battery at a delivery stop lasting more than 5 but less than 15 min,

- the use of chargers only during the longer stops, exceeding 15 min.

The results of the analysis are shown in Table A1.

Stops lasting between 5 and 15 min occur several times during the working day and the sum of their durations is relatively long, often exceeding 2 h. As can be seen in Table 5, even during AC charging in mode 3, the amount of energy is considerable, reaching even half the battery capacity. However, the handling operations necessary to connect the vehicle to the charging station are a problem. Repeating them several times during a work day can be a significant disruption to the work continuity. However, stops lasting more than 15 min are a great opportunity to replenish energy. Of course, they occur less often, and the sum of their durations is shorter than the sum of stops taking from 5 to15 min, thus the amount of energy consumed by the vehicle is smaller. Nevertheless, the handling operations time is significantly reduced, so they don't disturb the courier's work. When charging with AC, the amount of energy consumed significantly extends the EV range, moreover, assuming DC charging, the amount of energy is often greater than the total battery capacity, so it's more than sufficient. It should be emphasised that it is about 2 or 3 stops at properly distributed public DC stations. Analysing the possible range improvements, the best option for short-time charging seems to be DC mode. However, considering high installation costs and the real needs of recharging during the typical delivery work, this option is financially unjustifiable. Consequently, the major concept of the proposed solution is to equip unloading bays with charging stations of Mode 3.

5. Discussion and Future Works

Charging by a plug-in connection is the most obvious method of charging the batteries, but not the only one applicable. Moreover, the necessity to perform the handling operations to connect and disconnect the vehicle to/from the charger consumes the time of delivery. Based on the Authors' experience, it takes 1–1.5 min per one operation. Taking into account the short time period of the last mile delivery stop (about 15 min), it could be much more efficient for the driver to reduce or completely remove this operation from the delivery action and save this time directly for the delivery process.

In the recent years, to make the power transfer more flexible, the trend was to eliminate cables as much as possible [50–54]. One of the options is the use of pantographs. It is reasonable when recharging a vehicle equipped with suitable connectors is repeated at the same stations. Considering that, it can be use in unloading bays. However, the disadvantage of this solution is a necessity to equip the vehicle with a pantograph, which makes sense only for larger vehicles, while the advantage is the speed of service and available charging with DC of up to 150 kW [55–59].

The alternative option for pantographs is utilisation of inductive charging systems. Inductive charging consists in cooperation of two coils, the first of them is located on-board the vehicle, the second one at the charging point. Both coils become magnetically coupled, establishing a transformer. The coil placed in the charging station provides a variable magnetic field, while the paired coil (on-board the EV) induces a current charging the vehicle batteries. It is a system that is still at the stage of continuous improvement. The big advantage of this system is the lack of any permanent connections between the vehicle and the charging station, but it requires a proper structure installed in the vehicle, as well as a special type of charging station.

There is only a resonant inductive coupling between the charging station wiring system and the vehicle (Figure 3). An induction coil powered from a high frequency (10–40 kHz) generator and a high power generator is mounted in the roadway, while the vehicle is fitted with an induction receiving system whose main elements are: a coil and a H/V AC converter.

Induction charging is very convenient and allows recharging the battery during a delivery process. Clearly, its greatest usefulness is seen in companies with a significant number of vehicles and spending many hours at stops. Hence, the target beneficiaries of this system seem to be couriers and mail deliverers.

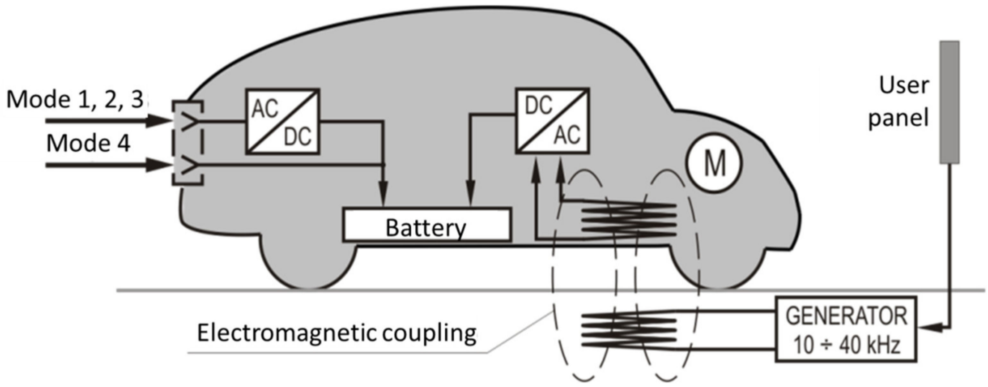
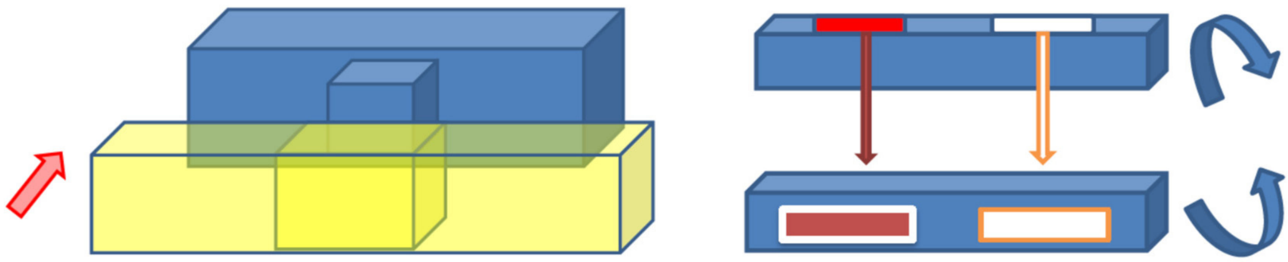


Figure 3. The general concept of utilising an unloading bay as a wireless charging station.

Considering the issues mentioned above, two options of wireless charging stations could be considered:

- inductive (Figure 4a),
- contact (Figure 4b).



(**a**) (**b**)

Figure 4. The general concept of wireless EV charging stations: (**a**) inductive, (**b**) contact.

In the inductive charging system (Figure 4a), the ramp supply system is connected (release of the charging element) to the socket in the vehicle. It is also proposed to consider another inductive charging option. Getting the vehicle to the unloading bay, after activating e.g., the purchased account, activates the induction loop charging the power system. Such a system can also be used in parking areas. Then the vehicle batteries are charged from the induction loop placed in the parking space the card that activates charging from the loop (in any parking spaces) after subscribing to the service.

The major problem with this option is that the charging process is not efficient enough. At the moment, the inductive charging devices need more time for the process. Therefore, the short time period charging, like in the case of last mile delivery process, needs significant improvements of the technical parameters of the chargers. Moreover, it must be underlined that, during the charging process, the receiving coil should be as close as possible to the coil of the transmitter. This distance should not be greater than 10–30 cm, this requires precise positioning of the car at the charging station. The variable magnetic flux generated by the transmitter coil, due to the magnetic coupling, causes a high frequency alternating current to be induced in the receiver coil. The task of the AC/DC converter is to rectify the current received from the receiver coil and determine the appropriate battery charging parameters. The efficiency of the discussed system is estimated to be higher than 75%, and the largest charging power is currently at approx. 3.3 kW.

To avoid the problems mentioned above, the contact system could be considered (Figure 4b). In the contact arrangement, the ramp would have a mounted (semi-rotary) system for 'contact' recharging of the batteries supplying the electric vehicle in the course of unloading. The element is normally closed while the vehicle is traveling. On the 'vehicle side', the driver switches the actuator actuating a similar system mounted in the bumper or a covered element at the front of the vehicle. Then the contact system of the quick-charge system connection 'opens'. On accessing the ramp, the system of rotary exposure of the contact charging system starts automatically (e.g., is activated by the vehicle weight).

6. Conclusions

The idea and the results introduced in this paper are part of the first stage of the international project called EUFAL (Electric urban freight and logistics). The project aims at providing a platform of exchange to be a decision support system for companies willing to integrate EVs in commercial vehicle fleets. Integrating project partners from Germany, Austria, Denmark, Poland and Turkey, the project will contribute to the transfer of knowledge on electric mobility between stakeholders and countries.

The ambition of the Authors was to analyse the real needs with regard to recharging the electric freight vehicles during the typical courier work. The results achieved during the first stage of the activities in Szczecin (especially the analysis of the vehicle types, their parameters and availability) helped to establish the assumptions for that step. Under them, the analyses of EFV efficiency in the real environment were carried out. In cooperation with a courier company, the tests on the operational level were completed. It helped to identify real needs related to the unloading bays utilisation as well as the real influence of potential charging during the delivery activities on the vehicle range.

During the tests, the distance covered by the EV performing real-life services did not exceed 80 km, moreover, the EV driving range did not exceed 50% of the battery capacity. Here it should be emphasised that heating, ventilation, and air conditioning devices could be freely used by the driver for their work comfort. This proves that already at the current stage of EV development they are able to successfully deliver the last kilometre in the fleets of companies in the courier and mail sector. Nevertheless, there is a huge space to increase utilisation of EVs via proper placement and management of the charging infrastructure.

Although the experiment was limited to the area of the Szczecin agglomeration, its results can be easily used in modelling the application of EFV in other areas. Firstly, all the results are based on indicators such as distance and number of deliveries for routes, and battery capacity and energy consumption for vehicles, which allows you to easily recalculate and estimate results in a different environment. Secondly, the assumptions of the second phase of the experiment, the strict adaptation conditions of EFV work to the conditions for the implementation of business processes according to DPD standards applied throughout the organization, guarantees the universality of its results.

Combining the concept of unloading bays with properly located charging stations with appropriately selected technical parameters on the one hand will significantly extend the use of EVs, even for entities performing transport operations within a larger territorial range; on the other hand, it will improve the flow of traffic in city centres. In addition, the use of unloading bays as charging stations can be an excellent promotion of individual electromobility by providing charging stations for individual users outside delivery times. What's more, it is easier to justify the use of parking spaces as unloading bays by offering residents public charging stations. The future works should be more focused on improvement of wireless charging system, including the one implemented in unloading bays. The significance of this approach is improved by the world crisis related to the coronavirus problem. The urban freight transport seemed one of the most important services. The number of goods deliveries increased due to the lack of other purchase possibilities. As a result of this, couriers have become one of the occupational groups that are the most exposed to coronavirus. Due to that, reduction of as many as possible opportunities for direct contact with any devices seems to be an important challenge for their work safety. The proposed solution, considering the wireless charging option, fulfil in some part the expectations related to these issues.

Author Contributions: Conceptualisation, S.I., M.N., A.B., K.K. and K.M.; methodology, S.I. and M.N.; validation, K.K. and S.I.; formal analysis, S.I.; investigation, S.I., M.N. and A.B.; resources, M.N., K.M. and K.K.; data curation, S.I., M.N. and K.K.; writing—original draft preparation, S.I., M.N. and A.B.; writing—review and editing, S.I. and K.K.; supervision, S.I. All authors have read and agreed to the published version of the manuscript.

Funding: The research introduced in this paper was completed under the EUFAL project (Electric urban freight and logistics) which was co-funded by the ERA-NET Cofund Electric Mobility Europe (EMEurope) and national funding organisations. EMEurope is co-funded by the European Commission within the research and innovation framework programme Horizon 2020 (Project No. 723977).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The results of the analysis.

Indicator	Unit	Route											
		R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**
Battery at start	%	76	100	100	76	98	100	100	100	69	100	96	100
Battery at stop	%	53	69	65	52	75	62	71	58	49	70	49	70
Energy consumption	kWh	9.2	12.4	14	9.6	9.2	15.2	11.6	16.8	8	12	18.8	12
Distance covered	km	38.2	40.6	73.1	28.8	29	50.2	40.9	77.2	29.6	34.5	74	47.4
Energy consumption per 100 km	kWh/100 km	24.08377	30.54187	19.15185	33.33333	31.72414	30.27888	28.36186	21.76166	27.02703	34.78261	25.40541	25.31646
Driving range left	km	128	148	168	123	176	139	157	145	110	154	115	172
Access to first delivery address	km	3.9	7.5	25.5	8.6	7.6	5.1	6.8	26.2	7.9	4	25.5	8.6
Return from last delivery address	km	4.2	7.7	23.2	4.1	8.2	4.5	8.1	29.4	9.3	4.5	31.2	8.5
Distance covered in delivery area	km	30.1	25.4	24.4	16.1	13.2	40.6	26	21.6	12.4	26	17.3	30.3
Number of stops	pcs.	51	73	51	38	32	48	69	51	33	53	38	39
Number of delivery addresses	pcs.	70	97	95	69	86	68	92	96	70	80	42	58
Energy consumption in delivery area (DA)	kWh	7.2	8.4	4.4	5.6	5.2	12.4	7.6	5.6	4.4	9.2	4	8
Energy consumption in DA per 100 km	kWh/100 km	23.92	33.07	18.03	34.78	39.39	30.54	29.23	25.93	35.48	35.38	23.12	26.40
Energy consumption in DA per stop	kWh/pcs.	0.14	0.12	0.09	0.15	0.16	0.26	0.11	0.11	0.13	0.17	0.11	0.21
Energy consumption in DA per delivery	kWh/100 km/pcs.	0.10	0.09	0.05	0.08	0.06	0.18	0.08	0.06	0.06	0.12	0.10	0.14
% of distance in delivery area	%	78.80%	62.56%	33.38%	55.90%	45.52%	80.88%	63.57%	27.98%	41.89%	75.36%	23.38%	63.92%

Table A1. *Cont.*

Indicator	Unit	Route											
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Average time of stop	min:sec	00:05:52	00:02:28	00:04:39	00:06:28	00:07:47	00:03:39	00:02:00	00:05:37	00:06:25	00:04:58	00:02:41	00:05:31
Number of stops 5 to 15 min	pcs.	19	3	17	17	16	10	3	18	13	19	2	15
Total time of stops 5 to 15 min	h:min	03:12:00	00:25:00	02:50:00	03:21:00	03:34:00	01:38:00	00:30:00	03:29:00	02:45:00	03:26:00	00:13:00	02:36:00
AC 22 kW(6.7) charged	kWh	21.44	2.79	18.98	22.45	23.90	10.94	3.35	23.34	18.43	23.00	1.45	17.42
DC 50 kW charged	kWh	160.00	20.83	141.67	167.50	178.33	81.67	25.00	174.17	137.50	171.67	10.83	130.00
Number of stops >= 15 min	pcs.	2	0	1	4	4	1	0	5	4	4	0	4
Total time of stops >= 15 min	h:min	01:07:00	00:00:00	00:19:00	01:31:00	01:38:00	00:22:00	00:00:00	01:33:00	01:25:00	01:10:00	00:00:00	01:05:00
AC 22 kW(6.7) charged	kWh	7.48	0.00	2.12	10.16	10.94	2.46	0.00	10.39	9.49	7.82	0.00	7.26
DC 50 kW charged	kWh	55.83	0.00	15.83	75.83	81.67	18.33	0.00	77.50	70.83	58.33	0.00	54.17
Charging balance; stops 5 to 15 min.	kWh	12.24	−9.61	4.98	12.85	14.70	−4.26	−8.25	6.54	10.43	11.00	−17.35	5.42
Charging balance; >=15 min	kWh	−1.72	−12.40	−11.88	0.56	1.74	−12.74	−11.60	−6.41	1.49	−4.18	−18.80	−4.74

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