Environmental and Climate Technologies
2024, vol. 28, no. 1, pp. 827–841
https://doi.org/10.2478/rtuect-2024-0063
https://content.sciendo.com

Sustainability of Shared e-Scooter Services in Riga

Aivars RUBENIS[1*], Armands CELMS[2], Leslie ADRIAN[3], Martins GARKEVICS[4]

[1,2]*Latvia University of Life Sciences and Technologies, Lielā str 2, Jelgava, LV-300, Latvia*
[3,4]*Lesla Latvia, Šmerļa 3, Riga, LV-1009, Latvia*
[4]*Sustainable Mobility Solutions, Pirts 9, Riga-LV-1003, Latvia*

Received 19.04.2024; accepted 15.09.2024

***Abstract* – This study examines the shared electric scooter usage patterns in Riga across 2021 and 2022 and assesses the potential for reducing greenhouse gas emissions in the city's urban transport system. Analysing 3.9 million scooter trips over the two-year period, the research highlights a tripling in the use of shared scooters and a shift towards shorter rides, resulting in an average use of only 7 km per day per scooter. This trend has resulted in CO_2 emissions to 54.16 g CO_2 per passenger kilometre, raising the total emissions from shared scooters in 2022 to 163.3 tonnes, and in fact increasing the net transportation CO_2 emissions in Riga by 49.2 tonnes, by largely replacing zero-emission modes of transport like walking. In response to these challenges, the research explores the implementation of photovoltaic (PV) energy-powered charging docks as a method to maintain scooter operations. While energy consumption is not the largest contributor to the scooters' CO_2 emissions, by also eliminating the need for scooter transportation for charging the adoption of on-site generated PV energy could yield a substantial CO_2 emission reduction of up to 34 %. This approach could hypothetically result in a 71-tonne reduction in CO_2 emissions from electric scooters, thus potentially establishing scooters as a net positive influence to Riga's transport emissions, producing a net 11 tonne CO_2 emisssion reduction.**

***Keywords* – E-scooter CO_2 emissions; micromobility; Photovoltaic (PV) charging; Renewable energy in transport; shared scooters.**

1. INTRODUCTION

The main aim of this article is to present the electric scooter travel data in Riga, and the CO_2 emission estimates, comparing the information with previous research, and to evaluate the effect that locally installed PV panels for scooter charging using solar energy would have on shared scooter CO_2 emissions in Latvia.

It has been few years already since electric scooter took the world by the storm. Started in 2017 in Santa Monica by scooter start-up Bird [1], shared scooters managed to reach 38.5 million rides already during their first year [2]. They have also become very popular in Latvia, reaching three quarters of a million trips in their first year in 2021 [3].

Since then, the initial passion has somewhat wilted: several cities like Paris, have forbidden their use altogether with many European countries imposing strict limitations [4]–[6]; which has assisted some of the first comers, like the dockless shared scooter system initiator Bird,

* Corresponding author.
E-mail address: aivars.rubenis@ivorygroup.eu

going into bankruptcy in 2023 [7]. The scooters, however, are here to stay, and being electric, they are often hailed as way to decrease CO_2 emissions from urban transportation.

Transportation is one of the main sources of CO_2 emissions in EU that still does not show signs of reduction despite all the activities aimed to support emissions-free vehicles. In 2023 the total air emissions for greenhouse gasses in transport and storage were 432.5 million tonnes CO_2 equivalent, which was 2.5 % more than a decade ago, and which accounted for 12.6 % of all CO_2 emissions in Europe [8]. According to national projections compiled by the European Environment Agency (EEA), even with the measures currently planned by Member States, domestic transport emissions are not expected to fall below 1990 levels until 2032 [19].

Most planned policies and measures in the transport sector focus on promoting low-carbon fuels or electric cars, as well as encouraging a modal shift to public transport.

Their operators have heavily preponed this – most of the companies working in this industry have sections dedicated to their sustainability: VOI claims that their scooter CO_2 emissions are as low as 18 g CO_2 per passenger kilometre (ppkm), which is reached by using swappable batteries, renewable energy in their warehouses and, which is most important, targeting their scooter lifespan to at least 20 000 km and more than 8 years based on their annual decommissioning and lost vehicles rate of 6.1 % [10]. Lime claims similar 19 g CO_2 ppkm for their Paris operations and 22.6 g CO_2 ppkm for Stockholm [11]. Others, like Tier informs to have reached 42.8 g CO_2 ppkm, Dott – 30 g CO_2 ppkm [12], which still are way above the independent research conducted earlier; in 2019 Hollingsworth *et al*. estimated the shared e-scooters used for two years have the average life cycle emissions to 141 gCO_2 per passenger-mile [13]. In 2020 detailed ITF analysis demonstrated, that new generation e-scooters can vary from 29 g CO_2 ppkm in the best case to 508 g CO_2 ppkm in the worst-case scenario in base case contribute 106 g CO_2 ppkm [14]. In Latvia, in 2021 Rubenis *et al*. calculated that the emissions from the scooters in Riga are 221 g CO_2 ppkm, however, as this was based only on one year of data, thus the lifetime of scooters could not be determined with sufficient certainty [15].

While scooter lifetime is the largest factor impacting the scooter emissions per passenger kilometre, the use of renewable energy is also very important. Today all scooter operators are noting that they are using renewable energy in their warehouses, where the charging happens.

It is challenging to validate independently the authenticity of some companies' eco-friendly energy claims. In certain instances, this could merely be a facade of environmental responsibility, known as "greenwashing" [16]. Often, it implies that these companies purchase energy from providers offering "green energy" tariffs, which does not guarantee that the energy is produced from renewable sources on-site.

The on-site generation of renewable electricity, such as using photovoltaic (PV) panels at scooter parking locations, would serve a dual purpose. It would not only ensure a sustainable power supply for the scooters but also substantiate the veracity of environmental sustainability claims.

Research on the direct use of solar energy to charge electric scooters is scant, despite the availability of docking stations designed for this purpose, offered by both start-ups [17] and established scooter operators. This article marks the beginning of our exploration into the feasibility of employing PV panels for charging scooters in Riga. We will scrutinize scooter usage patterns over the years and assess the potential impact that PV charging stations could have on reducing scooter emissions. In subsequent articles, we will investigate more detailed aspects of these chargers' practical usage, as well as the technical specifications required for their implementation.

2. Methods and Methodology

2.1. Scooter Data Acquisition

In this analysis we will analyse the scooter data from Riga city. Riga, the capital of Latvia, is located in Northern Europe with latitude: 56° 56' 45.60" N and longitude: 24° 06' 21.20" E. The scooter data has been obtained by logging data from main charger operator application programming interface (APIs) for two seasons in 2021 and 2022. The scooter trips were anonymised and not identifiable. For purposes of determination of scooter lifetime, a database of scooter IDs was maintained to mark the first and the last appearances of the scooter ID.

2.2. CO_2 Emission Calculation

In this research we have based our methodology for scooter emissions per passenger kilometre $CO_2e^{PPK}_{Scooter}$ estimation is based on International Transport Forum (ITF) methodology as a starting point and adapted it for the situation in Riga. For detailed methodology see Rubenis *et al* [15].

The total net scooter CO_2 emissions depends on which other transportation modes are replaced by scooters:

$$\sum CO_2e^{Net}_{Scooters} = \sum CO_2e^{Gross}_{Scooters} - \sum_i CO_2e^{Gross}_{ReplMix_i} \tag{1}$$

where

$CO_2e^{Net}_{Scooters}$ – net CO_2 equivalent produced as the result of introduction of Electric Scooters (tCO_2e);

$CO_2e^{Gross}_{Scooters}$ – gross actual CO_2 equivalent produced by the electric scooters (tCO_2e),

$CO_2e^{Gross}_{ReplMix_i}$ – gross CO_2 equivalent which would have been produced by the mix of transportation modes *i*, which has been replaced by electric scooter (tCO_2e).

The actual replacement transport mode mix depends on the trip distance, and it is specific for each city. User trips are grouped into bins using 500 m intervals, to match the replacement transportation mode mixes. The last group included all the trips which were longer than 3 km. The total distances within each group were calculated. For the replacement CO_2 emission calculations, we are using the replacement mix for Riga used by Rubenis *et al.* [15], presented in Table 1.

TABLE 1. SCOOTER TRIP REPLACEMENT CO_2 EMISSIONS BY THE DISTANCE OF THE TRIP

Trip distance, km	**0.5**	**1**	**1.5**	**2**	**2.5**	**3+**
Average CO_2 emissions (gCO_2e ppkm)	0	6	21	55	66	47

Thus, the emissions for each trip can be calculated:

$$CO_2e^{Net}_{Scooters} = \left(CO_2e^{PPK}_{Scooter} - CO_2e^{PPK}_{Mode\,x}\right) \cdot s_{Mode\,x}, \tag{2}$$

where: $CO_2e^{PPK}_{Mode x}$ – emissions per passenger kilometre for transportation mode mix *x* [$gCO_2e\cdot(p\cdot km)^{-1}$]; $S_{Mode x}$ – distance (km) replaced from transportation mode *x*.

Scooter emissions can be calculated:

$$CO_2e_{Scooer}^{PPK} = \left\lfloor \frac{CO_2e_M^{PV} + CO_2e_T^{PV} + CO_2e_I^{PV}}{S_L \cdot n_p} \right\rfloor + CO_2e_U^{PPK} + CO_2e_O^{PPK}, \quad (3)$$

where:

$CO_2e_M^{PV}$ – emissions per vehicle created to manufacture the scooter (gCO_2) = 355 807 gCO_2;

$CO_2e_T^{PV}$ – emissions per vehicle to transport the scooter from manufacturer (gCO_2) = 18 195 gCO_2;

$CO_2e_I^{PV}$ – emissions per vehicle to create scooter infrastructure (gCO_2) = 0 (no special infrastructure exists);

$[CO_2e_M^{PV} + CO_2e_T^{PV} + CO_2e_I^{PV}]$ is an amount of fixed CO_2 emissions, which must be amortised over distance driven per scooter lifetime, to obtain emissions per km, divided by:

S_L – distance driven during scooter lifetime, km;

n_p – average number of passengers per ride (p), which in case of scooters is 1.

Two variable components of emissions are:

$CO_2e_U^{PPK}$ – CO_2 emissions for scooter use [$gCO_2e\cdot(p\cdot km)^{-1}$];

$CO_2e_O^{PPK}$ – CO_2 emissions $gCO_2e\cdot(p\cdot km)^{-1}$ for scooter operator services.

The fixed values for $CO_2e_M^{PV}$, $CO_2e_T^{PV}$, $CO_2e_I^{PV}$ and $CO_2e_O^{PPK}$ have not changed since 2021 and are taken from previous research [15]. Eq. (3) can be rewritten as:

$$CO_2e_{Scooter}^{PPK} = \frac{374\,002}{\bar{s}_{Scooter}^{Day} \cdot \bar{N}_{Scooter}} + CO_2e_U^{PPK} + CO_2e_O^{PPK}, \quad (4)$$

where:

$\bar{N}_{Scooter}$ – average scooter lifetime in days;

$\bar{s}_{Scooter}^{Day}$ – average scooter trip per day.

2.3. PV Energy Calculation

There are two possible impacts of using locally produced solar energy, which can help decreasing overall CO_2 emissions of shared electric scooters.

The direct impact will come from using solar energy with 0 CO_2 emissions to charge the batteries and decrease the scooter use emissions. To evaluate the CO_2 emission reduction, we will compare the emissions from using PV energy with emissions from using the typical sources of electricity.

$$\Delta CO_2e_U^{PPK} = CO_2e_{PV}^{PPK} - \overline{CO}_2e_U^{PPK} \quad (5)$$

The CO_2 emissions for scooter use per km are

$$CO_2e_U^{PPK} = E_{El}^{GHG} \cdot C_{Scooter}^{PK}, \quad (6)$$

where

E_{El}^{GHG} – greenhouse gas emission intensity of electricity generation ($gCO_2\cdot kWh^{-1}$);

$C_{Scooter}^{PK}$ – scooter energy consumption per kilometre ($kWh\cdot km^{-1}$).

The emissions of average energy mix of countries are available at European Energy Agency, and case of Latvia it is 106.5 $gCO_2 \cdot kWh^{-1}$ [18]. The average scooter energy consumption per kilometre in 2021 was 12.3 Wh/km [15], however that could change as trip characteristics change in time.

The indirect emission savings come from reduction of need to move scooters or batteries back and forth to charge their batteries, as they can be charged locally. It is hard to determine precisely the amount that can be saved. One way to do it is to calculate the average distances travelled by scooter collecting vehicles and their emissions. Rubenis *at al.* [15] calculated that the average CO_2 emissions per km travelled by scooters are $CO_2e_O^{PPK}$ = 23.5 $gCO_2 \cdot km^{-1}$.

Other way to calculate the emissions are to use publicly available information from scooter operators. Bolt notes that installing the docks on both public and private land in high-demand spots eliminates 50–60 battery swap operations per day, which reduces CO_2 emissions by over 400 kg CO_2 emissions per month[19], thus we can calculate:

$$CO_2e_O^{PPK} = \frac{CO_{2month}^{GHG} \cdot 1000}{n_{days} \cdot n_{operations} \cdot \overline{n}_{trips} \cdot \overline{s}_{trip}}, \tag{7}$$

where

CO_{2month}^{GHG} – CO_2 emissions saved per month, kg;

n_{days} – number of days per month;

$n_{operations}$ – number of swap operations replaced a day;

$\overline{n}_{trips}$ – average number of trips between battery swap operations;

$\overline{s}_{trip}$ – average distance of scooter trip, km.

Substituting the data for Riga, Eq. (7) can be rewritten:

$$CO_2e_O^{PPK} = \frac{242.4}{n_{trips} \cdot s_{trip}}. \tag{8}$$

3. Results

3.1. Scooter Trip Data

There was significant increase in shared scooter use in Riga in 2022, compared to 2021. If in 2021 there were 750 thousand scooter trips logged from April to November, then in 2022 there were already three times more, resulting in 2.28 million scooter trips, with average daily number of trips reaching 15 thousand in August 2022 (Fig. 1).

While there was a significant increase in the number of scooter trips, the parameters of the trips changed significantly – the scooter trips become shorter both in distance and in the time sense. The average trip distance decrease from 1.7 km in 2021 to 1.5 km in 2022, and the average trip duration came down from 22.3 minutes to 18.2 minutes (Fig. 2).

This was just slightly affected by decrease in average trip speed from 5.46 km/h to 5.35 km/h as depicted in Fig. 3. Interestingly, this decrease was more due to the speed decrease in extreme (very slow and very fast) speed ranges, as standard deviation decreased from 3.05 to 2.97 km/h which compensated for speed increase in "normal" middle ranges around 5 km/h.

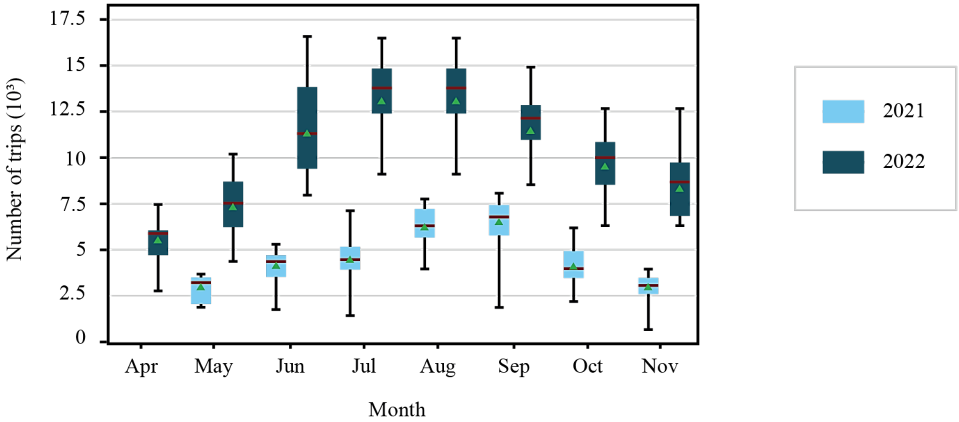

Fig. 1. Number of scooter trips in Riga, years 2021 and 2022.

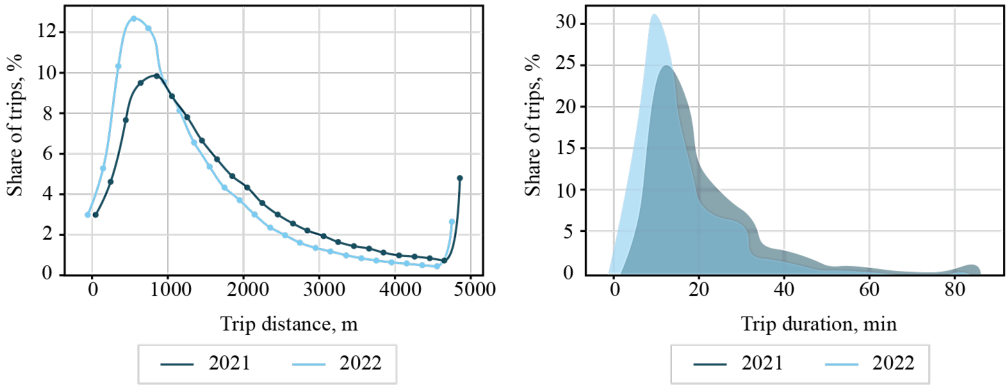

Fig. 2. Scooter trip distance and duration distribution in Riga, years 2021 and 2022.

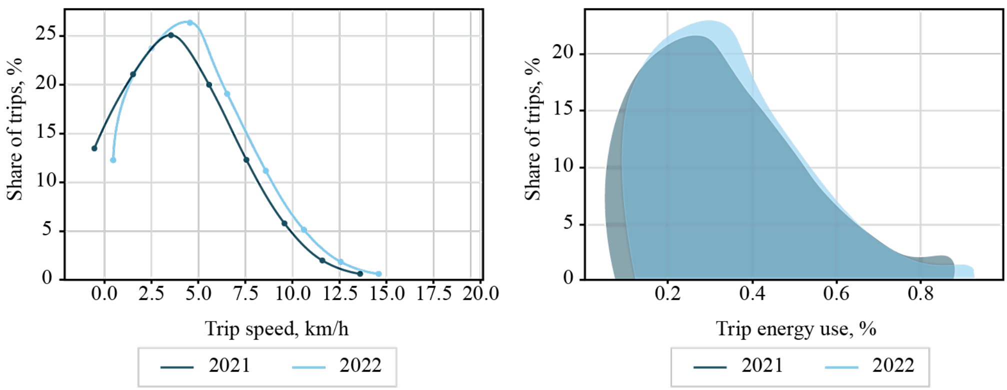

Fig. 3. Scooter trip speed and energy consumption distribution in Riga, years 2021 and 2022.

The scooter usage characteristics had not changed significantly during these years (Fig. 4); early morning peak being at 8 am, and evening peaking at 7 pm.

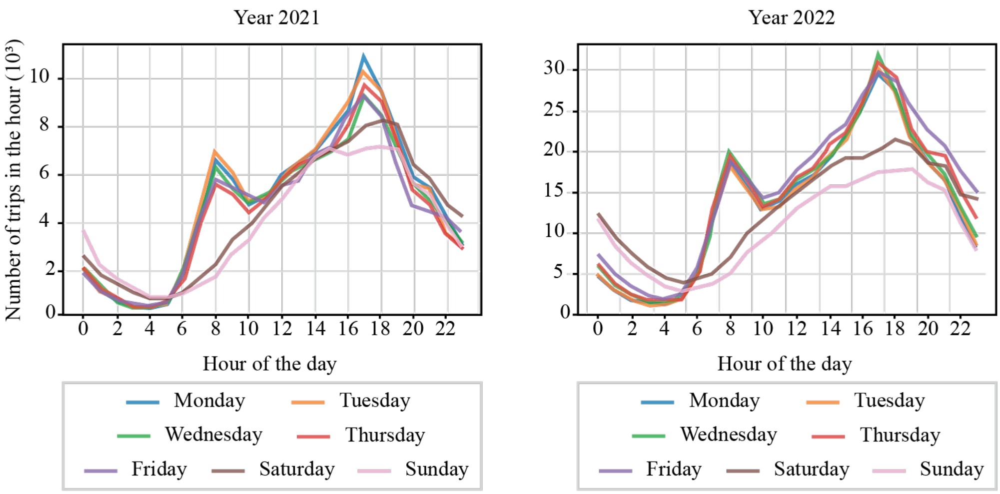

Fig. 4. Number of scooters trips by hours in weekdays in Riga, years 2021 and 2022.

The increase in scooter trips was reflected in the number of scooters on the streets. The average number of scooters in 2021 was 1642, while in 2022 the average number of scooters had risen 2.6 times to 4315 (Fig. 5).

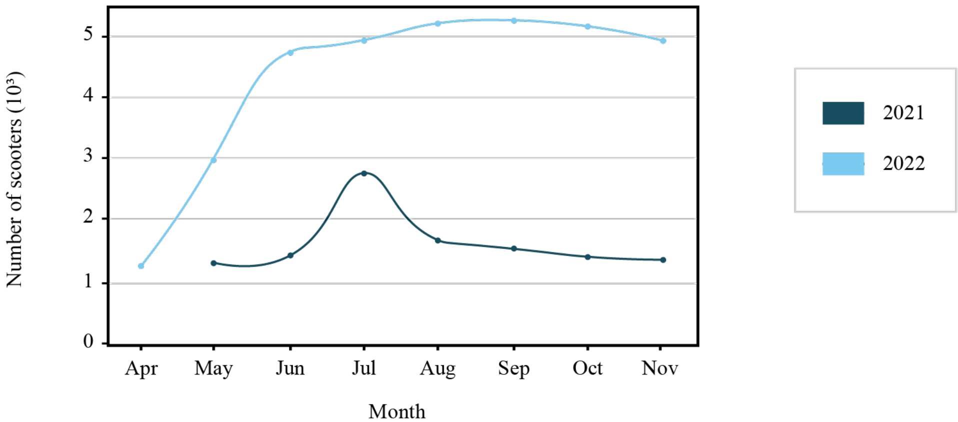

Fig. 5. Number of scooters on street in Riga, years 2021 and 2022.

This increase had impact on average use of the scooters – the average number of trips per day per scooter decreased from 3.71 to 3.11 and the average time spent riding was down from 1.48 hours a day to 0.94 hours a day (Fig. 6), which demonstrates the simultaneous decrease in average trip distance and trip duration, as mentioned above (see Fig. 2).

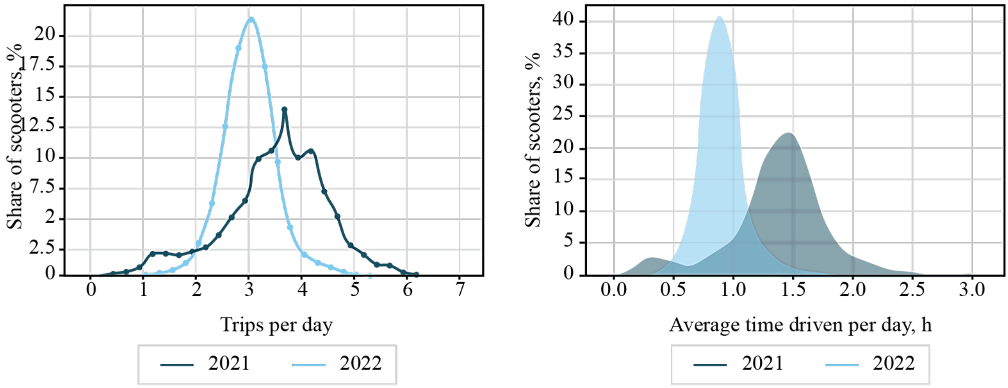

Fig. 6. Individual scooter usage in Riga in 2021 and 2022: daily trips and hours of operation.

This all culminates in a significant decrease in scooter's average daily travel distance – from 12.2 km per day in 2021 to just below 7 km per day in 2022 (Fig. 7). Combined with decrease in energy use this increases the average trips between charging from 6.7 in 2021 to 9.5 in 2022.

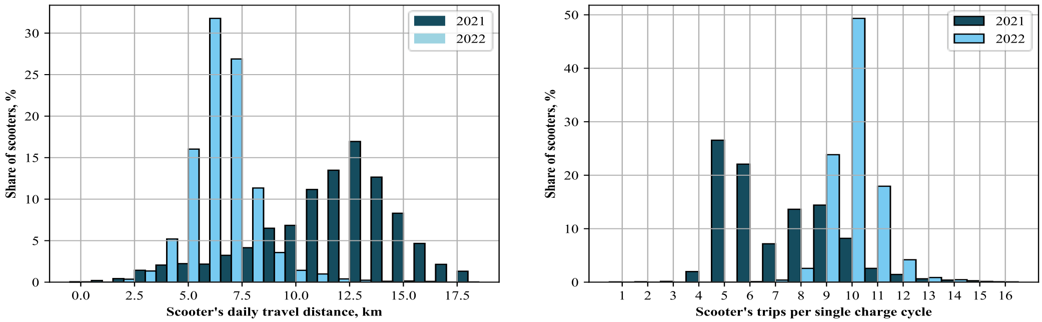

Fig. 7. Individual scooter usage in Riga, years 2021 and 2022: daily distance and trips per charging cycle.

3.2. CO_2 Emissions

While the increase in number of trips per one charging cycle decreases the operational CO_2 emissions per trip, it increases both operational and fixed emissions per km. This indirectly is the main factor calculating the total emissions as the km per scooter lifetime also will decrease unless the scooter lifetime is increased proportionally.

This, however, does not seem to be the case. While, of course, we do cannot have the empirical evidence of the expected lifetime, because scooters have not been long-enough on the streets to validate any assumption, indirect indications show that the lifetime of scooters might be less than 5 years. One indication of this being true is, that there have already been six scooter generations since 2019, averaging in less than a year for a generation [20].

Based on scooter identification numbers, during 2021 and 2022 sessions 2653 scooters have been discontinued and 5624 are still in operation, as seen in Fig. 8. Looking at scooter lifetime, the lifetime of scooters that are in operation are reaching 500 days in the best case (those, operating whole 2 seasons). While those that are discontinued, have been done so before 400-day limit. The total driving distance for discontinued scooters have been below 1000 km, while for those still in operation it mostly ranges from 750 to 1250 km. This short distance over the lifetime is explained by the short average trips and low utilisation rates, which do not bode well for emission ppm calculations.

Extrapolating from the current scooter odometers, considering that many of them have been in operation for less than a year, an average expected distance for a scooter is 2071 km a year.

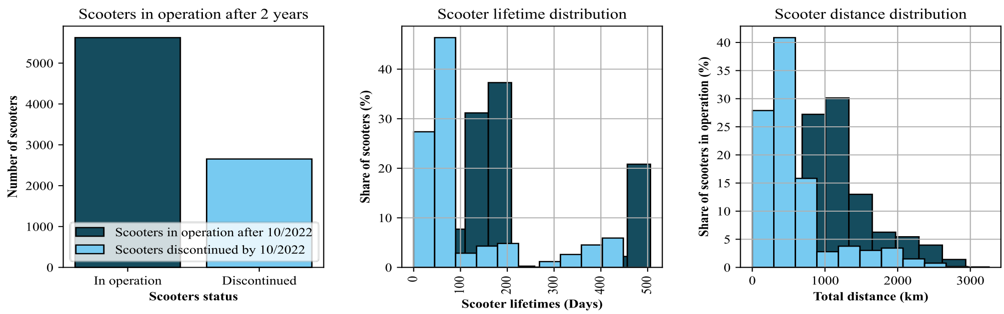

Fig. 8. Scooter lifetime and distances in Riga in 2021–2022 seasons.

The fixed CO_2 emissions according to International Transport Forum (ITF) data [14] are: $CO_2e_M^{PV}$ – emissions created to manufacture the scooter (gCO_2) = 355 807 gCO_2, $CO_2e_T^{PV}$ – emissions created to transport the scooter from manufacturer (gCO_2) = 18 195 gCO_2.

In total, there are 372 kg of CO_2 emissions that need to be depreciated over each scooter's lifetime. Generously assuming the 5-year scooter lifetime, the total expected scooter trip distance would reach 10 000 km and the fixed emissions would come to 36.11 gCO_2 ppkm (Fig. 9).

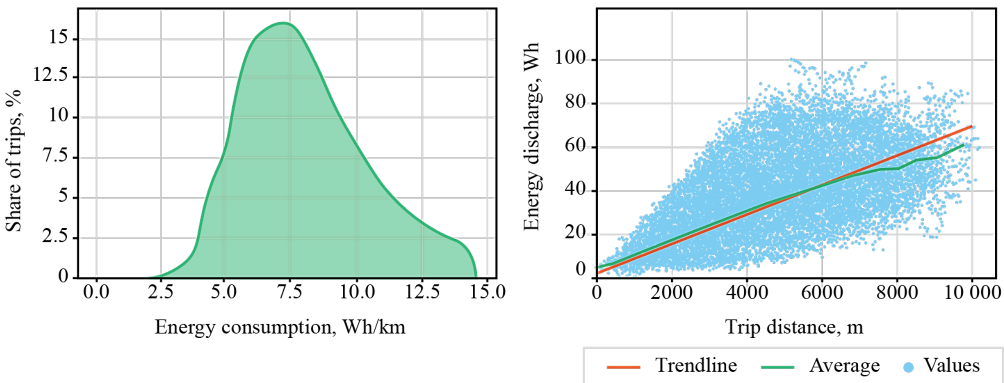

Fig. 9. Distribution of scooter energy consumption in Riga, years 2021–2022.

The variable CO_2 emissions on top of that would come to:

- $CO_2e_{Op}^{PKm}$ – operational emissions from scooter. With 242 gCO_2 per cycle (8), on average 9.5 trips between charging and 1486 m of average trip, the operational emissions come to 17.15 gCO_2 ppkm;
- $CO_2e_U^{PKm}$ – emissions from energy used for scooter trips. Using average data from trip

distance and energy consumption calculations (Fig. 9), the average energy consumption during years 2021 and 2022 has been 8.45 W/km, with R^2 value: 0.745. The energy emissions being 106 gCO_2/kWh, the energy for scooter use results in minuscule 0.9 gCO_2 ppkm.

Thus, the total $CO_2e_{Total}^{PKm}$ for electric scooters would amount to 54.16 gCO_2 ppkm.

Using the replacement emission Table 1 from Methods section and scooter trip distance distribution, we can calculate that the replacement emissions for the case of Riga, and the results show, that the scooter emissions including replacement emissions are still higher than zero (Fig. 10), and only trips between 1500 and 2500 m provides a decrease in emissions.

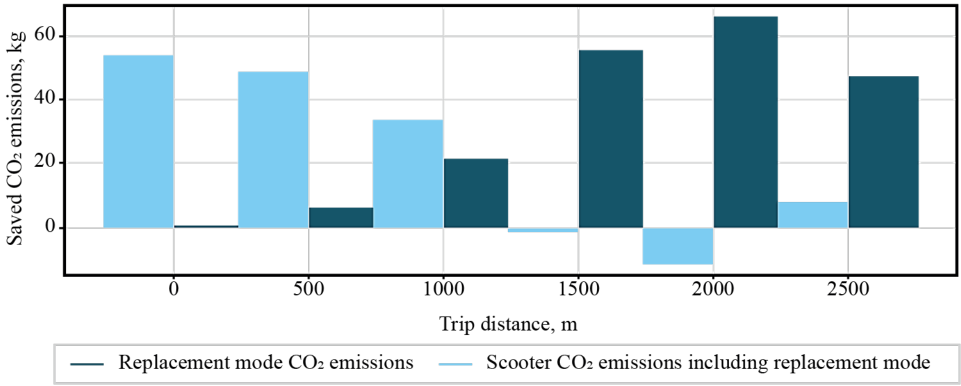

Fig. 10. Replacement mode and total CO_2 emissions in Riga by trip distances, years 2021–2022.

There was an increase of scooter rides in 2021, which has led to increase in additional CO_2 emissions from shared scooter use in Riga. The escalation in trips was not uniform across all distance categories, reflecting a shift in both the structure of trip distances and the volume of scooter usage (Fig. 11). The most substantial growth occurred in the 500 m – 1 km distance category, whereas the 2000–2500 m range saw a comparatively smaller increase in trips relative to the overall rise in ride numbers.

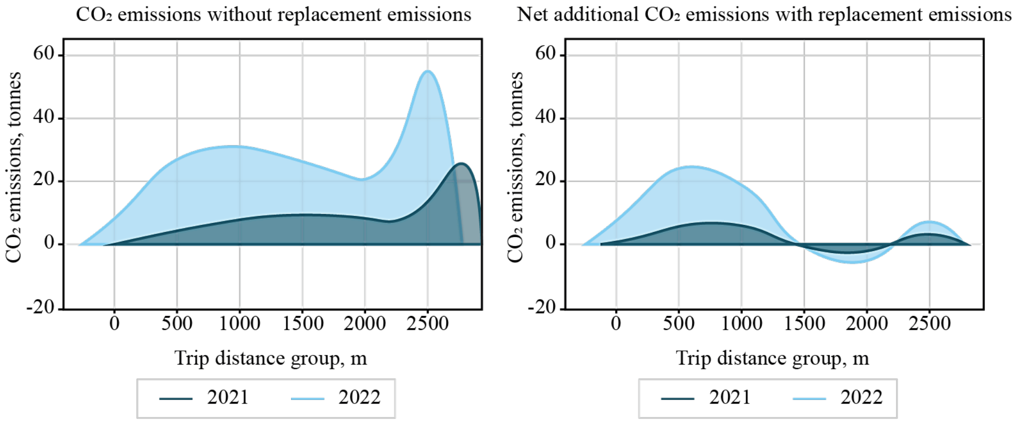

Fig. 11. CO_2 emissions from scooter rides in Riga with and without replacement emissions, years 2021 and 2022.

3.3. PV Energy

By using solar panels to generate energy locally it would be possible to decrease the scooter operation emissions and scooter trip energy emissions.

Implementing these measures could cut CO_2 emissions by 18.95 gCO_2 ppkm, amounting to a reduction of nearly 35 % – a substantial reduction. As scooter journeys become more frequent over time, such a strategy has the potential to significantly lower Riga's overall CO_2 emissions (Fig. 12).

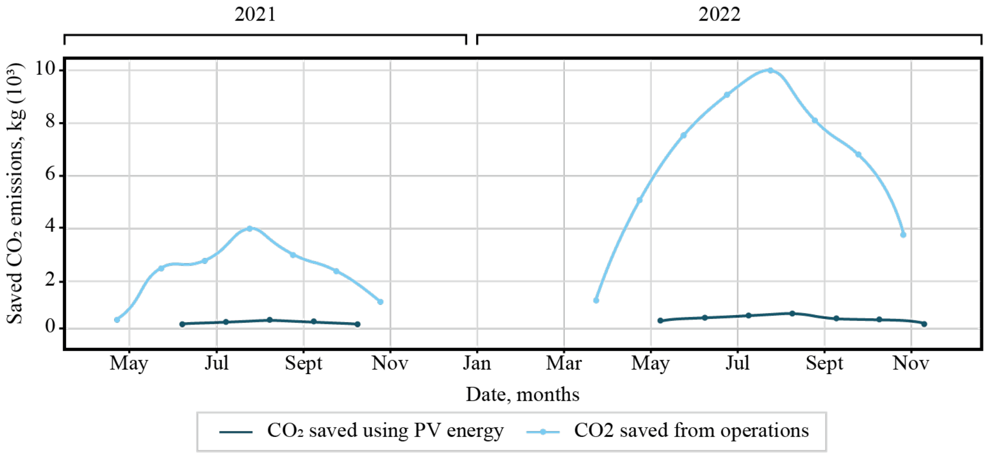

Fig. 12. Potential CO_2 emission savings in Riga, years 2021–2022.

As presented in Table 2, over the whole period the potential emission savings could have been 71 tonnes CO_2, most of which would come from avoiding operational CO_2 emissions.

TABLE 2. POTENTIAL CO_2 EMISSIONS SAVED BY USE OF LOCAL PV ENERGY

Year	**Operational CO_2 emissions, t CO_2**	**Energy CO_2 emissions, t CO_2**	**Total saved emissions, t CO_2**
2021	15.81	0.98	16.78
2022	51.92	2.47	54.40
Total	67.73	3.45	71.18

3.4. PV Charger Infrastructure

In our calculations, however, we now need to add a new component, that arises from a requirement to develop an infrastructure for local PV charging. Such an infrastructure would consist of PV panels and a storage battery, to be able to provide energy to scooters all day, not just during the hours of sunshine.

$$CO_2e_{\text{Infr}}^{\text{PV}} = CO_2e_{\text{PV}}^{\text{PV}} + CO_2e_{\text{Batt}}^{\text{PV}} \tag{9}$$

Rubenis *et al.* [21] created a model, which demonstrated, that in case of Latvia, 0.2 m^2 PV cells with 20 % efficiency and integrating a 200 Wh energy storage system at charging stations and employing an optimized energy flow algorithm, it is possible to power 98 % of all scooter days in Riga using PV energy.

The lifetime emissions of PV modules range from 115.04 to 201.4 $kgCO_2 \cdot m^{-2}$, depending on the technology used [22].

The CO_2 emissions from batteries used in energy storage vary widely, ranging from 38 to 356 $kgCO_2 \cdot kWh^{-1}$ [23]. Excluding the worst-performing options, this equates to approximately 7.6 kg CO_2 per charging station.

$$CO_2 e_{\mathrm{Infr}}^{\mathrm{PV}} - (gCO_2) = 18\ 195\ gCO_2 \tag{10}$$

Solar panels are typically guaranteed to last 25 years, though some systems have operated effectively for over 30 years [24]. Assuming a shorter lifespan of 10 years, a 0.2 m^2 PV panel used for a charger would contribute 2.3 to 4.0 kg of CO_2 annually, or 1.8 to 3.2 $gCO_2 \cdot km^{-1}$, based on an annual scooter travel distance of 1250 km.

Battery lifespan is affected by several factors, including charging parameters, state of charge, C-rate, and temperature [25]. Here, we assume a lifespan of 8 years, aligning with the warranty period offered by most electric vehicle manufacturers [26]. For EVs, a battery is typically considered to have reached its end of life when its capacity declines to 80 % of its original level – a standard not commonly applied to storage batteries. Even with this assumption, the battery would add an extra 0.8 $gCO_2 \cdot km^{-1}$, bringing the total CO_2 emissions from the scooter charging infrastructure to 3.6–4.0 g $CO_2 \cdot km^{-1}$, which is less than a quarter of the emissions currently produced by relocating shared electric scooters for charging.

4. DISCUSSION

Between the 2021 and 2022 seasons, there was a notable rise in the number of scooter trips. Ordinarily, this uptick could be expected to lead to a reduction in CO_2 emissions per kilometre. However, the simultaneous surge in the total number of electric scooters in circulation negated these potential benefits, so that the average CO_2 emissions 54.16 gCO_2 per kilometre are still higher than that of the transportation modes scooters replace.

As highlighted in existing studies and corroborated by our research, the most critical determinant of scooter sustainability is their lifespan. Fixed CO_2 emissions, which encompass both manufacturing and transportation, constituted 66 % of the total emissions over a two-year data collection period (Fig. 13).

Comparison of data from our research and the information published by scooter operators is depicted in Table 3.

TABLE 3. SCOOTER CO_2 EMISSION COMPARISON

Source	Riga, this research	VOI	Lime (Paris)	Lime (Stockholm)	Tier	Dott
Total CO_2 emissions (gCO_2e ppkm)	51.4	18 [10]	19[11]	22.6	42.8 [12]	30 [12]

Data from Voi and Lime indicate that the total emissions per kilometre are comparable to the emissions from energy use and operations. Even if we reduce the operational and energy emissions to zero, the residual emissions are still half of those identified in this study. This suggests that for scooters in Riga to achieve comparably low CO_2 emission levels, either their lifespan or their annual usage distance would need to double – a prospect that does not appear viable for Riga.

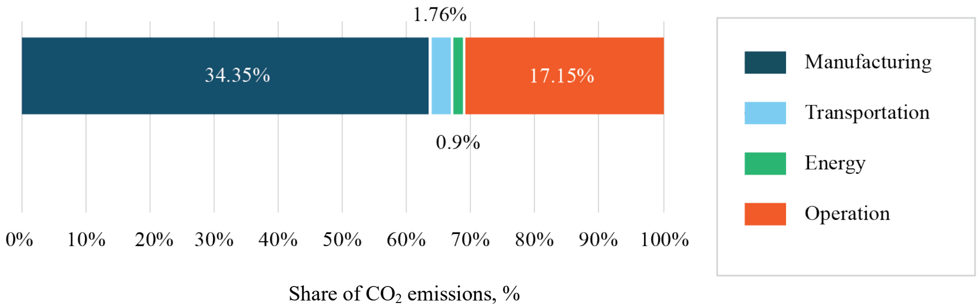

Fig. 13. CO_2 emission structure.

Nevertheless, this may not be necessary. By recalculating the total CO_2 emissions from scooters including the potential reductions in energy and operational emissions gained from integrating local PV generation, the net additional emissions including the transportation modes that the scooters would replace, effectively become negative as illustrated in the Fig. 14.

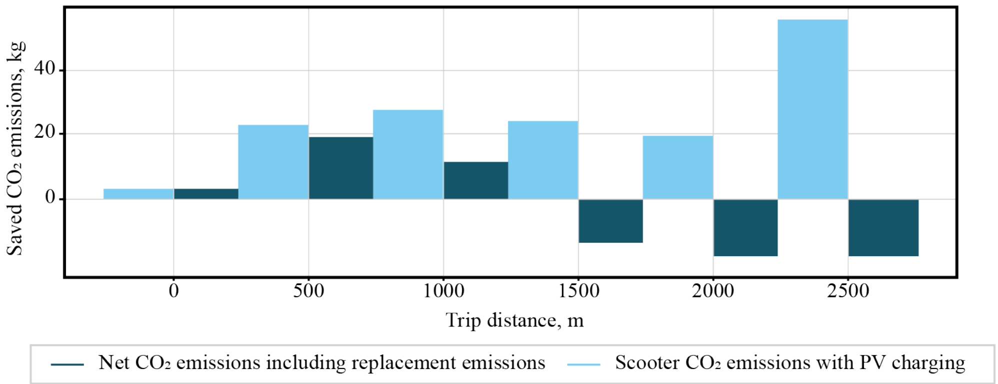

Fig. 14. CO_2 emissions from scooter rides in Riga with hypothetical reductions from local PV generation.

The implementation of local photovoltaic (PV) energy production is projected to lower Riga's total CO_2 emissions from 222 tonnes to 148 tonnes. Moreover, the net impact of scooters on the city's transportation-related CO_2 emissions would shift from an increase of 63 tonnes to a reduction of 11 tonnes, effectively rendering electric scooters a net positive contributor to reducing Riga's transport emissions.

5. Conclusions

In conclusion, our observations of shared electric scooter usage in Riga reveal several trends:

– there was a threefold increase in the number of trips, escalating from 750 000 in 2021 to 2.28 million in 2022.
– the pattern of scooter usage has remained consistent, with the distribution of trips throughout the day showing remarkable stability over years – only the volume of trips has increased. However, the average journey has slightly shortened in both duration and distance, dropping from 1.7 km to 1.5 km.

The surge in scooter utilization was accompanied by a rise in the scooter fleet size from 1642 to 4315, leading to a decrease in individual scooter usage from 3.7 to 3.11 hours per day and a reduction in average daily travel distance from 12.2 km to just 7 km. This also resulted in less frequent charging needs, raising the average number of trips between charges from 6.7 in 2021 to 9.5 in 2022.

These shifts in trip distance distribution and the expansion of the scooter fleet contributed to CO_2 emissions from scooter usage in Riga to 54.16 gCO_2 per passenger kilometre, causing a rise in total emissions both in absolute terms (from 59.0 to 163.3 tonnes) and in net impact on transportation CO_2 emissions. As most scooter trips became shorter, the substitution of CO_2-neutral transportation modes (like walking and cycling) increased disproportionately compared to emissions-intensive modes such as cars, resulting in a net increase from 13.8 to 49.2 tonnes of CO_2.

The investigation into local PV generation indicated that two significant sources of CO_2 emissions could be negated – the emissions from the energy used for scooter operation, and the operational emissions from transporting scooters or batteries to and from charging stations. The analysis estimated a potential reduction in CO_2 emissions by 34 %, or by 18.05 gCO_2 per passenger kilometre. Such a decrease could have saved 71 tonnes of CO_2 during the 2021–2022 period, potentially positioning electric scooters as a net positive force in diminishing Riga's transportation emissions by 11 tonnes.

These findings justify a more detailed examination of the practical viability of local PV generation, to understand the technical and economic feasibility of such a system's development, which will be the focus of subsequent publications.

ACKNOWLEDGEMENT

This paper has been published within the research project "Use of PV energy for e-scooter charging" carried out within grant program by European Regional Development Fund and Central Finance and Contracting Agency in the research program "Competency Centre for Energy and" Project number: 5.1.1.2.i.0/1/22/A/CFLA/001.

REFERENCES

[1] Hall M. Bird scooters flying around town. Santa Monica Daily Press, 2017. [Online]. [Accessed 06.12.2023] Available: https://smdp.com/2017/09/26/bird-scooters-flying-around-town/

[2] National Association of City Transportation Officials. Shared Micromobility in 2018. *Nacto* 2019:1–16.

[3] Rubenis A., Celms A., Ratkevičs A. Analysis of Shared Electric Scooter Use in Riga. *Environmental and Climate Technologies* 2022:26(1):930–940. https://doi.org/10.2478/rtuect-2022-0070

[4] Yanatma S. Paris officially the first city in Europe to ban e-scooters. What are the rules in other countries? Euronews. [Online]. [Accessed 01.09.2023]. Available: https://www.euronews.com/next/2023/09/01/electric-scooters-what-are-the-rules-across-europe-and-where-are-injuries-highest

[5] Koch M.-C. Gelsenkirchen enforces e-scooter ban: Bolt and Tier face 350 vehicle removal. Heise Online. [Online]. [Accessed 18.06.2024]. Available: https://www.heise.de/en/news/Gelsenkirchen-enforces-e-scooter-ban-Bolt-and-Tier-face-350-vehicle-removal-9688867.html

[6] Reuters. Madrid moves to ban app-rented e-scooters over safety concerns. Guardian. [Online]. [Accessed 04.10.2024]. Available: https://www.theguardian.com/world/article/2024/sep/05/madrid-moves-to-ban-app-rented-e-scooters-over-safety-concerns

[7] Suhartono H., Phakdeetham J., Church S. Scooter Company Bird Global Files Bankruptcy to Sell Itself. [Online]. [Accessed 20.12.2023]. Available: https://www.bloomberg.com/news/articles/2023-12-20/scooter-company-bird-global-files-for-chapter-11-bankruptcy

[8] Eurostat. Air emissions accounts for greenhouse gases by NACE Rev. 2 activity – quarterly data. [Online]. [Accessed 04.10.2024]. Available: https://ec.europa.eu/eurostat/databrowser/view/env_ac_aigg_q/default/table?lang=en&category=env.env_air.env_air_aa

[9] European Environment Agency. Greenhouse gas emissions from transport in Europe. Greenhouse gas emissions from transport in Europe. [Online]. [Accessed 24.10.2023]. Available: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport
[10] Eurostat Air emissions accounts for greenhouse gases.
[11] Feldman H., Bunte B. Life cycle assessment of Generation 4.0 Lime e-bikes and e-scooters Final. 2022. [Online]. [Accessed 01.02.2024]. Available: https://cdn.li.me/content/uploads/placeholder/RESULTS-Lime_Gen4_eBike_eScooter_Paris_LCA_Results_v4.0.pptx.pdf
[12] Bilboe C. How green are Europe's escooter startups? Sifted. [Online]. [Accessed: Dec. 07, 2023] Available: https://sifted.eu/articles/electric-scooter-green-comparison-2021
[13] Hollingsworth J., Copeland B., Johnson J. X. Are e-scooters polluters? the environmental impacts of shared dockless electric scooters. *Environmental Research Letters* 2019:14(8). https://doi.org/10.1088/1748-9326/ab2da8
[14] International Transport Forum, 'Good to Go? Assessing the Environmental Performance of New Mobility', Paris, 2020. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/environmental-performance-new-mobility.pdf
[15] Rubenis A., Laizāns A., Zvirbule A. Effect of Shared Electric Scooters on Urban Green House Gase Emissions: Case of Riga. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, 2022:247–258. https://doi.org/10.5593/sgem2022V/4.2/s19.31
[16] Advertising Standards Authority, *ASA Ruling on TIER Operations Ltd Ad description A21-1118832*. 2022. [Online]. [Accessed 20.12.2023]. Available: https://www.asa.org.uk/rulings/tier-operations-ltd-a21-1118832-tier-operations-ltd.html
[17] Knot, 'Docking and charging stations for scooters', Mobility Innovation Marketplace. [Online]. [Accessed 07.02.2024.] Available: https://www.knotcity.com/en/
[18] European Environment Agency. Greenhouse gas emission intensity of electricity generation by country. [Online]. [Accessed 14.05.2022]. Available: https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-9/#tab-chart_2
[19] Bolt. Bolt's charging docks: here's what we've learned'. [Online]. [Accessed 20.12.2023]. Available: https://bolt.eu/en/blog/bolts-charging-docks-heres-what-weve-learned/
[20] Bolt. In a league of its own – the first impressions of Bolt 6'. [Online]. [Accessed 20.12.2023]. Available: https://bolt.eu/en/blog/bolt-6-electric-scooter-reviews/
[21] Rubenis A., Adrian L. R., Garkevics M. Sun-Powered Wheels: PV Chargers for Shared E-Scooters to Mitigate Urban CO_2 Emissions. In *Engineering for Rural Development*, Latvia University of Life Sciences and Technologies, 2024:999–1007. https://doi.org/10.22616/ERDev.2024.23.TF202
[22] Yıldız G., Çalış B., Gürel A. E., Ceylan İ. Investigation of life cycle CO_2 emissions of the polycrystalline and cadmium telluride PV panels. *Environmental Nanotechnology, Monitoring & Management* 2020:14:100343. https://doi.org/10.1016/j.enmm.2020.100343
[23] Ellingsen L. A. W., Hung C. R., Strømman A. H. Identifying key assumptions and differences in life cycle assessment studies of lithium-ion traction batteries with focus on greenhouse gas emissions. *Transp Res D Transp Environ* 2017:55:82–90. https://doi.org/10.1016/j.trd.2017.06.028
[24] Aghaei M. *et al.* Review of degradation and failure phenomena in photovoltaic modules. *Renewable and Sustainable Energy Reviews* 2022:159:112160. https://doi.org/10.1016/j.rser.2022.112160
[25] Woody M., Arbabzadeh M., Lewis G. M., Keoleian G. A., Stefanopoulou A. Strategies to limit degradation and maximize Li-ion battery service lifetime – Critical review and guidance for stakeholders. *J Energy Storage* 2020:28:101231. https://doi.org/10.1016/j.est.2020.101231
[26] Gorzelany J. By The Numbers: Comparing Electric Car Warranties. Forbes. [Online]. [Accessed: 29.04.2024]. Available: https://www.forbes.com/sites/jimgorzelany/2022/10/31/by-the-numbers-comparing-electric-car-warranties/