

FEASIBILITY OF INTEGRATING INTERNET OF THINGS (IoT) - ENABLED DOCKED ELECTRIC SCOOTER SYSTEMS WITH PUBLIC TRANSPORT: A CASE STUDY OF SOFIA, BULGARIA

Tsvetan Iliev

The Institute of Robotics, Bulgarian Academy of Science (IR-BAS), Sofia, Bulgaria

Abstract: Urban transport systems face increasing challenges related to congestion, emissions, and inefficient first- and last-mile connectivity. This study proposes a methodological framework for evaluating the integration of Internet of Things (IoT)-enabled docked electric scooter systems with urban public transport through a composite index combining travel time, emissions, and cost. A case study based on the transport network of Sofia, Bulgaria, compares a conventional public transport scenario with an integrated metro and shared e-scooter scenario. The results demonstrate that the integrated approach can reduce travel time by approximately 27% and transport-related emissions by approximately 29%, while providing improved overall mobility performance despite slightly higher direct user cost. The proposed framework offers a simple and adaptable methodology for evaluating integrated micromobility solutions in sustainable urban transport systems.

Keywords: micromobility, electric scooters, urban mobility, public transport integration, IoT, sustainable transport

1. INTRODUCTION

Transport is a fundamental component of modern societies, enabling economic activity, social interaction, and access to essential services [1]. However, transportation is also a major contributor to environmental degradation and public health challenges. In the European Union (EU), transport accounts for approximately 29% of total greenhouse gas emissions and remains the only major economic sector where emissions have consistently increased since 1990 [1]. Road transport represents the largest share of these emissions, accounting for 73.2% of total transport-related emissions in the EU [2]. The growing volume of passenger and freight transport has intensified congestion, air pollution, noise, and other negative urban impacts [1, 3].

To address these challenges, the EU aims to reduce transport-related emissions by 90% by 2050 under the European Green Deal framework [1]. Achieving this objective requires a transition towards more sustainable urban mobility systems, including public transportation and micromobility solutions [1, 4]. Urban areas are particularly important in this transition, as they accommodate over 70% of EU citizens and generate approximately 23% of transport-related greenhouse gas emissions [4].

Micromobility solutions, particularly electric scooters, have emerged as a promising approach for improving first- and last-mile connectivity and reducing reliance on private vehicles [7]. However, many existing shared scooter systems rely on dockless operational models, which often suffer from unreliable vehicle availability, urban clutter, and

inconsistent service quality, limiting their suitability for regular commuting applications [7-10].

In Sofia, the transport system includes private cars, buses, trolleybuses, trams, metro, and shared micromobility services [11]. Despite this diversity, the city remains highly dependent on private vehicles and experiences significant air quality and congestion challenges, particularly during peak commuting periods [11]. While Sofia's public transport network provides integration between metro, bus, and tram systems, effective integration with environmentally friendly individual transport modes such as shared electric scooters remains limited. At the same time, high-activity urban corridors, including the Tsarigradsko Shose area, experience concentrated traffic flows and mobility demand [11].

Despite the growing adoption of micromobility systems, there remains a lack of simple and applicable evaluation frameworks capable of simultaneously assessing travel time, environmental impact, and cost within integrated public transport scenarios. This study addresses this gap by proposing a methodological framework for evaluating the integration of shared electric scooters with urban public transport systems. The framework introduces a composite index combining travel time, emissions, and cost and applies it to a case study in Sofia.

2. LITERATURE REVIEW

2.1. Micromobility Systems - Docked vs. Dockless Approaches

Micromobility solutions, particularly electric scooters, have gained significant attention as a sustainable alternative to conventional urban



transportation modes, primarily due to their ability to alleviate congestion, reduce pollution, and offer convenient short-distance travel. Electric scooters are currently available through two primary deployment methods - docked systems, featuring dedicated parking stations, and dockless systems, allowing scooters to be freely parked within designated zones. Dockless solutions, despite their flexibility, face issues regarding scooter clutter, uncertain availability, and vandalism, all of which significantly diminish their attractiveness for regular commuting [8, 9]. Conversely, docked systems have demonstrated higher reliability for commuters by ensuring predictable scooter availability and consistent service quality, thus addressing common barriers to habitual adoption [8, 10].

In European cities like Paris and Berlin, the preference is shifting towards docked or semi-docked systems, integrating dedicated docking stations into public infrastructure to manage urban space more effectively and reduce visual and environmental impacts [10, 12, 13]. Furthermore, the presence of physical docking stations enhances the safety and reliability perception of micromobility systems, which in turn positively influences commuter behaviour and acceptance [10, 13].

2.2. The Role of IoT in Micromobility Management and Optimization

IoT (Internet of Things) technology is essential in optimizing micromobility solutions by providing real-time monitoring, fleet management, and predictive maintenance capabilities [14, 15]. IoT enables continuous tracking of scooter locations, battery statuses, and mechanical conditions, facilitating proactive maintenance and efficient redistribution strategies [14]. Furthermore, IoT integration supports optimized charging cycles, ensuring scooters are readily available for users while maximizing battery life and overall operational efficiency [15, 16].

A critical advantage of IoT is the ability to deliver real-time data to both users and system operators through mobile applications and centralized management systems. This capability enhances user convenience by providing real-time navigation, reservation options, and instant service notifications, significantly improving the commuting experience and promoting regular use [14, 16, 17].

2.3. European Examples and Practices in Micromobility Integration

Several European cities have successfully implemented integrated micromobility systems,

highlighting both opportunities and challenges. For instance, in Paris, the integration of micromobility docking stations with public transport hubs has notably improved first-mile and last-mile connectivity, thereby enhancing public transport attractiveness and reduced private car usage [10, 18]. Berlin has adopted similar practices, strategically placing docking stations near public transport stations to facilitate multimodal commuting, resulting in positive shifts in commuter preferences towards micromobility [13, 18].

However, not all attempts have been uniformly successful. Copenhagen faced significant challenges with dockless scooters, prompting regulatory interventions and eventual transition to regulated docking systems to curb sidewalk clutter and improve user reliability [8, 12]. Such examples underline the necessity for careful planning and integration strategies, emphasizing the critical role of local regulatory frameworks and public acceptance in determining system effectiveness [12, 19].

2.4. Commuter Behaviour and Adoption Barriers

Understanding commuter behaviour is pivotal in evaluating the feasibility of integrating micromobility solutions into existing public transportation frameworks. Commuters prioritize reliability, affordability, and convenience when adopting new modes of transport. Existing research suggests that unpredictable availability, high costs, and perceived safety risks significantly deter regular use of dockless scooter systems among daily commuters [8, 10]. Surveys conducted in European urban centres indicate a strong preference for integrated micromobility options that complement public transport infrastructure, providing seamless transfers and predictable service availability [13, 20].

Additionally, environmental awareness among commuters positively correlates with willingness to adopt sustainable transport modes, including electric scooters. However, practical issues, particularly regarding availability and service reliability, remain significant barriers that must be addressed through effective system design and management [20, 21].

2.5 Research Gap and Contribution

While the integration of micromobility solutions with public transport is recognized as beneficial, literature consistently highlights a lack of comprehensive studies explicitly focusing on the feasibility and effectiveness of integrating IoT-enabled, docked scooter stations within existing

public transportation infrastructure [16, 19, 22]. Most current studies and pilot projects address micromobility either independently or in parallel with public transport, without explicit operational integration, thereby limiting potential benefits of seamless multimodal commuting [16, 23].

This literature review highlights the existing body of knowledge surrounding micromobility systems and commuter behaviours in urban contexts. While micromobility solutions clearly demonstrate potential for sustainable commuting improvements, considerable gaps remain, particularly concerning direct integration with public transport infrastructure. Addressing this gap, particularly within the context of Sofia, Bulgaria, could provide valuable insights and practical guidance for urban mobility planning and policy development, potentially serving as a benchmark for similar urban areas aiming to achieve sustainable commuting practices [23, 24].

Despite the extensive body of research on micromobility systems, existing studies primarily focus on either system design, user behavior, or standalone deployment models. There remains a lack of simple, quantitative, and applicable evaluation frameworks that integrate micromobility directly into public transport systems while simultaneously accounting for travel time, environmental impact, and cost.

This gap is particularly relevant for cities such as Sofia, where high reliance on private vehicles and significant air quality challenges necessitate integrated and scalable mobility solutions.

3. PROPOSED SYSTEM CONCEPT

To support the evaluated scenario, a conceptual system architecture is considered, consisting of shared electric micromobility vehicles and modular docking stations integrated with public transport infrastructure.

The conceptual system evaluated in this study consists of two primary components: an electric micromobility vehicle and a modular docking station integrated with public transport infrastructure. Figure 1 presents the electric scooter considered as the reference vehicle for the feasibility assessment, while Figure 2 illustrates the conceptual docking station configuration intended for deployment at transport nodes such as metro stations.

As illustrated in Figures 1 and 2, the proposed system is based on docked electric vehicles positioned at key transport nodes, such as metro stations, enabling predictable availability and

structured fleet management. Modular docking stations allow flexible deployment and scalability depending on demand patterns.

Such systems can be enhanced through IoT-based monitoring and management, enabling real-time tracking, usage optimization, and integration with digital mobility platforms. This approach addresses common limitations of dockless systems, such as vehicle clutter, inconsistent availability, and operational inefficiencies.

The proposed system serves as a representative model for evaluating the integration of micromobility into public transport networks, without being limited to a specific commercial implementation.



Fig. 1: The figure illustrates the core vehicle considered for this feasibility study – an electric scooter Vinghen

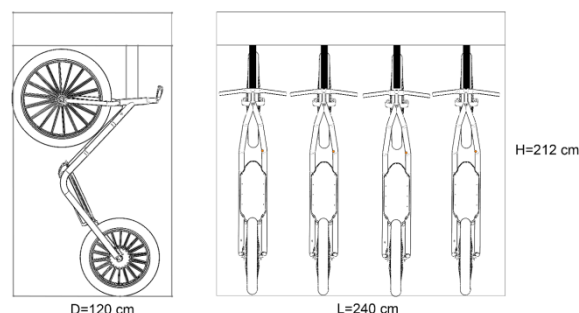


Fig. 2. A side and front view scheme of the vertical docking station in configuration for four scooters, illustrating the general packaging and dimensions with depth of 120 cm, length of 240 cm, and height of 212 cm.

4. MATERIALS AND METHODS

4.1. Scenario Definition

The study evaluates the integration of shared electric scooters within the public transport system in Sofia through a comparative scenario-based approach.

A representative commuting route is defined, reflecting typical urban mobility patterns during peak hours:

- Origin: Opalchenska Metro Station
- Metro segment: Opalchenska - G.M. Dimitrov Metro Station (~7.5 km)
- Last-mile segment: G.M. Dimitrov - The Mall (~1.8 km)

Total route length: ~9.3 km.

The selected corridor corresponds to a high-activity urban axis associated with business and commercial zones and elevated traffic intensity.

Two scenarios are defined:

- **S1 (Baseline):** Metro + feeder public transport (bus) / walking
- **S2 (Integrated):** Metro + shared e-scooter (last mile)

4.2. Evaluation Metrics

Three key performance indicators are defined:

Travel Time TTT

Total door-to-door travel time:

$$T = T_{\text{access}} + T_{\text{wait}} + T_{\text{in vehicle}} + T_{\text{last mile}}$$

Representative values are derived from urban mobility studies and route analyses using publicly available transport information and travel time estimates obtained from Google Maps.

Emissions E

Total carbon dioxide (CO₂) emissions per trip:

$$E = \sum_i (d_i \cdot e_i)$$

where:

- d_i - segment distance
- e_i - emission factor (gCO₂/passenger-km)

Cost C

Two pricing schemes are considered:

- **S1:** single public transport ticket (0.80 EUR)
- **S2:** integrated daily pass (2.00 EUR),

including e-scooter access

4.3. Emissions Factors

Emission factors were determined based on published transport emission data and measured vehicle energy consumption.

For metro transport, an emission factor of 35 g CO₂/passenger-km was adopted based on published emissions data for electrified urban rail transport systems in the United Kingdom [26]. Due to the absence of publicly available operational emission factors for the Sofia Metro system, this value was considered representative for the purposes of the present study.

For bus transport, an emission factor of 80 g CO₂/passenger-km was adopted based on reported emissions for urban bus operations in London [27]. This value was used as a representative estimate for conventional urban bus transport.

For the electric scooter, emissions were calculated using the measured energy consumption of the Vingen electric scooter and the average carbon intensity of electricity generation in Bulgaria. Based on an electricity carbon intensity of 305 g CO₂/kWh for Bulgaria in 2025 [28] and measured vehicle energy consumption, the resulting emission factor was calculated as approximately 15 g CO₂/km.

4.4. Index Formulation

A composite evaluation index is defined:

$$I = \omega_T \cdot T_n + \omega_E \cdot E_n + \omega_C \cdot C_n$$

where:

- T_n, E_n, C_n are normalized values
- $\omega_T, \omega_E, \omega_C$ are weighting coefficients

Subject to:

$$\omega_T + \omega_E + \omega_C = 1$$

The study adopts environmentally weighted coefficients:

- $\omega_T = 0.3$
- $\omega_E = 0.5$
- $\omega_C = 0.2$

4.5. Normalization

Min-max normalization is applied according to:

$$X_n = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

where X is the evaluated parameter (travel time, emissions, or cost), $X_{\min}$ is the lower reference value, and $X_{\max}$ is the upper reference value. The lower and upper limits are selected based on representative urban mobility conditions and are used to enable comparison between different transport scenarios.

For the purposes of this study, the following reference ranges are adopted:

- Travel time: $X_{\min} = 15$ min, $X_{\max} = 45$ min
- Emissions: $X_{\min} = 0$ g CO₂, $X_{\max} = 500$ g CO₂
- Cost: $X_{\min} = 0$ EUR, $X_{\max} = 5$ EUR

This approach provides a continuous normalization scale between 0 and 1 and allows comparison beyond the specific scenarios considered in the case study.

4.6. Calculation Procedure

- 1) Define route and transport modes
- 2) Estimate T, E, C for each scenario
- 3) Normalize indicators

- 4) Compute index I
- 5) Compare scenarios

5. CASE STUDY

The defined route is evaluated under peak-hour conditions, consistent with observed traffic patterns in Sofia (08:00–09:00 and 17:00–18:00). Return trip assumed.

The travel time for each scenario was calculated as the sum of access, waiting, in-vehicle, and last-mile travel components. The resulting total travel times are presented below.

Scenario S1: Metro + Bus

- Metro travel time: ~13 min
- Waiting time (metro + bus): ~10 min
- Bus last mile (~1.8 km @ 18 km/h): ~6 min
- Transfers and walking: ~4 min

Total time:

$$T_{s1} \approx 33 \text{ min}$$

Total emissions were calculated by multiplying the distance travelled by each transport mode by its corresponding emission factor and summing the results for the complete journey.

Emissions CO₂:

- Metro: $7.5 \cdot 35 = 262.5 \text{ g}$
- Bus: $1.8 \cdot 80 = 144 \text{ g}$

$$E_{s1} \approx 406.5 \text{ g CO}_2$$

Travel costs were estimated based on the pricing schemes defined for each scenario. For the baseline scenario, two single public transport tickets were assumed to account for a return trip, while the integrated scenario considered a daily pass including access to the shared e-scooter system.

Cost:

$$C_{s1} = 0.80 \cdot 2 = 1.60 \text{ EUR}$$

Scenario S2: Metro + E-scooter

- Metro travel time: ~13 min
- Waiting time (metro only): ~4 min
- E-scooter (~1.8 km @ 20 km/h): ~5 min
- Transition time: ~2 min

Total time:

$$T_{s2} \approx 24 \text{ min}$$

Emissions (CO₂):

- Metro: $7.5 \cdot 35 = 262.5 \text{ g}$
- E-scooter: $1.8 \cdot 15 = 27 \text{ g}$

$$E_{s2} \approx 289.5 \text{ g CO}_2$$

Cost:

$$C_{s2} = 2.00 \text{ EUR}$$

6. RESULTS

6.1. Raw Comparison

Metric	S1	S2
Time (min)	33	24
Emissions (g CO ₂)	406.5	289.5
Cost (EUR)	1.6	2.0

6.2. Normalized Values

Metric	S1	S2
T_n	0.600	0.300
E_n	0.813	0.579
C_n	0.320	0.400

Normalization was performed using representative urban mobility reference ranges rather than relative scenario extrema, enabling more scalable and continuous comparison between mobility alternatives.

6.3. Index Calculation

- **S1:**

$$I_{S1} = \omega_T \cdot T_n + \omega_E \cdot E_n + \omega_C \cdot C_n = 0.3 \cdot 0.600 + 0.5 \cdot 0.813 + 0.2 \cdot 0.320 = 0.651$$

- **S2:**

$$I_{S2} = \omega_T \cdot T_n + \omega_E \cdot E_n + \omega_C \cdot C_n = 0.3 \cdot 0.300 + 0.5 \cdot 0.579 + 0.2 \cdot 0.400 = 0.460$$

6.4. Interpretation

The integrated e-scooter scenario (S2) demonstrates a significantly lower index value, indicating superior overall performance.

Key findings:

- ~27% reduction in travel time
- ~29% reduction in emissions
- Higher direct cost, but improved system efficiency

The results align with the need for sustainable mobility solutions in Sofia, where high traffic density and air pollution remain critical challenges.

7. DISCUSSION

The results of the case study demonstrate that the integration of shared electric scooters into the public transport system can significantly improve the overall performance of urban mobility. The proposed scenario (S2), combining metro and e-scooter transport, achieves notable reductions in both travel time and emissions compared to the baseline scenario (S1), which relies on conventional feeder transport.

The reduction in travel time is primarily driven by the elimination of waiting times associated with secondary public transport modes, such as buses, as well as the increased flexibility of point-to-point movement provided by e-scooters. This is particularly relevant in urban environments like Sofia, where peak-hour congestion and irregular service intervals can significantly affect travel reliability.

From an environmental perspective, the results indicate a substantial decrease in emissions when replacing bus-based last-mile transport with electric micromobility. Given the broader context of air quality challenges in Sofia, this reduction is of particular importance. The findings are consistent with the need for sustainable mobility solutions that reduce the environmental footprint of urban transport systems.

The cost analysis shows that the integrated scenario has a higher direct cost when based on a daily transport pass. However, this difference should be interpreted in the context of system-level benefits. In practical scenarios, many users already rely on daily or monthly public transport passes, which effectively reduces the marginal cost of e-scooter usage to near zero when integrated into the system. This highlights the importance of considering pricing models and policy design when evaluating mobility solutions.

The proposed index-based methodology proves effective in capturing trade-offs between different performance criteria. By assigning higher weight to environmental impact, the model aligns with policy priorities in cities facing air pollution challenges. At the same time, the framework remains flexible and can be adapted to different weighting schemes depending on specific policy objectives.

The obtained results are consistent with findings reported in previous studies on micromobility integration and multimodal urban transport systems. Olabi et al. [18] identify micromobility solutions as an effective approach for reducing transport-related

emissions and improving urban mobility efficiency. Similarly, Li et al. [7] report that shared e-scooter systems can provide an attractive alternative for short-distance urban trips and first- and last-mile connections. The observed reduction in travel time and emissions in the present study is therefore aligned with broader trends reported in the literature, supporting the potential benefits of integrating shared electric scooters with public transport systems.

It should be noted that the analysis is based on representative values derived from literature and urban mobility studies rather than detailed empirical datasets. While this approach is suitable for demonstrating the applicability of the methodology, future work could enhance accuracy through the integration of real-time transport data and user behavior analysis.

8. CONCLUSION

This study proposes a methodological framework for evaluating the integration of shared electric scooters with urban public transport systems. The framework is based on a composite index that combines travel time, emissions, and cost, allowing for a structured comparison of alternative mobility scenarios.

The application of the methodology to a case study in Sofia demonstrates that integrating e-scooters as a last-mile solution can lead to significant improvements in both travel efficiency and environmental performance. Despite a higher direct cost under certain pricing schemes, the integrated approach offers clear system-level advantages, particularly when considering existing public transport usage patterns.

The main contribution of this work lies in the development of a simple and applicable evaluation framework that can support decision-making in the context of sustainable urban mobility. The methodology is adaptable and can be applied to different cities, transport configurations, and policy scenarios.

From a practical perspective, the results suggest that the integration of micromobility services into public transport systems represents a viable strategy for reducing traffic congestion and improving air quality in urban environments. This is particularly relevant for cities such as Sofia, where transport-related environmental challenges remain significant.

Future research directions include the incorporation of real-world mobility data, the analysis

of user behavior and adoption patterns, and the extension of the model to include additional factors such as reliability, safety, and infrastructure availability.

REFERENCES

1. European Environment Agency. Transport and mobility. 2025 Feb 10. Available from: <https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility>
2. European Environment Agency. Greenhouse gas emissions from transport in Europe. 2024 Oct 31. Available from: <https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport>
3. Airly. Clean Air Day: Airly reveals where the most polluted air is in Europe. 2021 Jun 17. Available from: <https://airly.org/en/clean-air-day-airly-reveals-where-the-most-polluted-air-is-in-europe/>
4. European Commission. Sustainable urban mobility. 2024. Available from: https://transport.ec.europa.eu/transport-themes/urban-transport/sustainable-urban-mobility_en
5. Eurostat. Main place of work and commuting time statistics. 2024. Available from: <https://ec.europa.eu/eurostat/statisticsexplained/>
6. European Commission. The reasons behind our congested cities. Urban Mobility Observatory. 2022 May 13. Available from: https://urban-mobility-observatory.transport.ec.europa.eu/news-events/news/reasons-behind-our-congested-cities-2022-05-13_en
7. Li A., Zhao P., Liu X., Mansourian A., Axhausen K.W., Qu X. Comprehensive comparison of e-scooter sharing mobility: Evidence from 30 European cities. *Transp. Res. Part D: Transp. Environ.*, 2022, 105, 103229.
8. Edenred Benefits. What's best for commuters: Docked or dockless? 04 Feb 2021. Available from: <https://www.edenredbenefits.com/blog/whats-best-for-commuters-docked-or-dockless>
9. Waldman N. Battle of the bikes: docked vs. dockless. *Here.com*. 10 Mar 2020. Available from: <https://www.here.com/learn/blog/dockless-scooters-bikes>
10. McKenzie G. Docked vs. Dockless Bike-sharing: Contrasting Spatiotemporal Patterns. In: *Proc. of GIScience* 2018. DOI: 10.4230/LIPIcs.GIScience.2018.46
11. Vitanova, L.L., Shirinyan, E., Trendafilova, T., Petrova-Antonova, D., 2025. Understanding Sofia's travel dynamics: Study of private traffic patterns and urban mobility. *Transp. Res. Interdiscip. Perspect.* 30, 101352. <https://doi.org/10.1016/j.trip.2025.101352>.
12. Hassam S., Alpalhão N., Neto M.C. A Spatiotemporal Comparative Analysis of Docked and Dockless Shared Micromobility Services. *Smart Cities*, 2024, 7(2), 880–912.
13. Jaller M., Niemeier D., Qian X., Hu M. Dock-based and Dockless Bikes sharing Systems: Analysis of Equitable Access for Disadvantaged Communities. National Center for Sustainable Transportation, Research Report, Dec 2021.
14. Zamir K.R., Bondarenko I., Nasri A., Brodie S. Comparative Analysis of User Behavior of Dock-Based vs. Dockless Bikes share and Scooters share in Washington, D.C. *arXiv*, 2019. DOI: 10.48550/arXiv.1907.11526
15. JHK Infotech. The Role of IoT in Transforming Micromobility. 2024 Sep 25. Available from: <https://topsoftwarecompanies.co/internet-of-things/the-role-of-iot-in-transforming-micromobility>
16. Fernandes E. IoT Solutions for Micromobility Market: Key Challenges, Growth and Opportunities 2025. *LinkedIn*. Available from: <https://www.linkedin.com/pulse/iot-solutions-micromobility-market-key-challenges-cwsbf/>
17. Kabakuş N., Eyüboğlu M. Factors Affecting the Integration of Micromobility into Smart Cities and Effects on Urban Transport. *J. Intell. Transp. Syst. Appl.*, 2025. DOI: 10.51513/jitsa.1603010
18. Olabi A.G., Wilberforce T., Obaideen K., Sayed E.T., Shehata N., Alami A.H., Abdelkareem M.A. Micromobility: Progress, benefits, challenges, policy and regulations, energy sources and storage, and its role in achieving sustainable development goals. *Int. J. Thermofluids*, 2023, 17, 100292.
19. Ma X., Ji Y., Yuan Y., Van Oort N., Jin Y., Hoogendoorn S. A comparison in travel patterns and determinants of user demand between docked and dockless bike-sharing systems using multi-sourced data. *Transp. Res. Part A: Policy Pract.*, 2020. DOI: 10.1016/j.tra.2020.06.022
20. Heineke K. The two-wheeled commute: Micromobility and your future. *McKinsey & Company*. 2022 Sep 8. Available from: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-two-wheeled-commute-micromobility-and-your-future>

21. Lahoti N. How to Overcome Challenges in Micromobility with IoT. Mobisoft Infotech. 2023 Mar 1. Available from: <https://mobisoftinfotech.com/resources/blog/iot-in-micro-mobility-industry>

22. Kalašová A., Čulík K. The Micromobility Tendencies of People and Their Transport Behavior. Appl. Sci., 2023, 13(19), 10559.

23. Asensio O.I., Chen E.W., Apablaza C.Z., Lawson M.C., Horner S.J. Impacts of micromobility on car displacement with evidence from a natural experiment and geofencing policy. Nat. Energy, 2022, 7, 1100–1108.

24. Le Boennec R., Salladarré F. Investigating the use of privately-owned micromobility modes for commuting in four European countries. J. Clean. Prod., 2023, 139760.

25. SofiaPlan. Териториален обхват и анализ на състоянието. 2021. Available from: https://sofiaplan.bg/wp-content/uploads/2021/09/I_%D0%A2%D0%B5%D1%80%D0%B8%D1%82%D0%BE%D1%80%D0%B8%D0%B0%D0%BB%D0%B5%D0%BD-%D0%BE%D0%B1%D1%85%D0%B2%D0%B0%D1%82-%D0%B8-%D0%B0%D0%BD%D0%B0%D0%BB%D0%B8%D0%B7-%D0%BD%D0%B0-%D1%81%D1%8A%D1%81%D1%82%D0%BE%D1%8F%D0%BD%D0%B8%D0%B5%D1%82%D0%BE-2.pdf

26. Office of Rail and Road. Rail emissions 2019-20. 2021. Available from: <https://dataportal.orr.gov.uk/media/1843/rail-emissions-2019-20.pdf>

27. Greater London Authority. London bus emissions. 2023 Jan 27. Available from: <https://www.london.gov.uk/who-we-are/what-london-assembly-does/questions-mayor/find-an-answer/london-bus-emissions-1>

28. Nowtricity. Bulgaria electricity carbon intensity (305 g CO₂/kWh). 2025. Available from: <https://www.nowtricity.com/country/bulgaria>

Eng. Tsvetan Iliev

PhD Candidate at The Institute of Robotics,
Bulgarian Academy of Science (IR-BAS), Sofia,
Bulgaria

M: +44 (0) 79 88 311 254

E: tsvetan.iliev@vinghen.com