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*Review*

# Research on Micro-Mobility with a Focus on Electric Scooters within Smart Cities

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**Abstract:** In the context of the COVID-19 pandemic, an increasing number of people prefer individual single-track vehicles for urban transport. Long-range super-lightweight small electric vehicles are preferred due to the rising cost of electricity. It is difficult for new researchers and experts to obtain information on the current state of solutions in addressing the issues described within the Smart Cities platform. The research on the current state of the development of long-range super-lightweight small electric vehicles for intergenerational urban E-mobility using intelligent infrastructure within Smart Cities was carried out with the prospect of using the information learned in a pilot study. The study will be applied to resolving the traffic service of the Poruba city district within the statutory city of Ostrava in the Czech Republic. The main reason for choosing this urban district is the fact that it has the largest concentration of secondary schools and is the seat of the VŠB-Technical University of Ostrava. The project investigators see secondary and university students as the main target group of users of micro-mobility devices based on super-lightweight and small electric vehicles.

**Keywords:** micro-mobility; charger; electric scooter; Smart Cities; management; sharing; Smart Home

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## 1. Introduction

The main objective of the article is to investigate the current state of the research, analysis, and design of a solution for the maximally efficient and comprehensive concept of urban E-mobility based on small lightweight passenger vehicles (including the possibility of transporting smaller loads). This would bring a qualitatively new level both in terms of the design and in terms the parameters of the vehicles themselves and, at the same time, in terms of their operation, charging, and management.

With the transition to the urban Micro-Mobility (MM) model in Smart-Cities (SCs)-as-a-service with sharing systems, Personal Lightweight Electric Vehicles (PLEVs) are becoming a popular means of transport in cities [1]. Micro-mobility affects first- and last-mile travel in urban areas [2]. In the aftermath of the emergency caused by the COVID-19 pandemic, it has become clear that urban mobility plans need to be modified to reduce the use of public transport and the crowding of people in traffic and, at the same time, avoid traffic congestion by, among other things, encouraging urban residents to stop using private motor vehicles. From this perspective, a reorganization of cities (e.g., Milan) is recommended, both in view of unpredictable environmental sustainability requirements and new mobility needs that require the promotion of bicycles and PLEVs, e.g., electric scooters [3]. PLEVs are a phenomenon that can be currently observed in cities and are intended to be an environmentally friendly form of transport. Analyses conducted show that the dynamic growth of PLEVs in cities will result in an increased demand for electricity distribution, which cities that are developing according to the concept of sustainable development must take into account [4]. Ciociola proposed an approach that uses open data to create a demand model for e-scooter sharing and charging (a flexible, data-driven demand model using modulated Poisson processes for time estimation and Kernel Density Estimation (KDE) for spatial estimation). This approach uses, together with a configurable e-scooter sharing simulator, other input information such as the effect of the number of scooters and the cost of managing their charging in the cities of Minneapolis and Louisville, USA [1]. However, E-Scooters (ESs) face challenges in urban management, such as traffic regulations, public safety, parking regulations, and liability issues for their operation [2]. The rapid infiltration of stand-up ESs as a mobility option has left cities in a quandary, as they must deal with regulating them and planning for their sudden abandonment at unreserved locations [5]. Garikapati introduced a new paradigm for evaluating mobility options in an urban area using the Mobility and Energy Productivity (MEP) metric. The MEP measures accessibility and appropriately weighs it against the travel time, cost, and energy of each mode of transportation that provides access to options in a given location [6]. In the face of new "disruptive" mobilities, there is a need to (a) build on existing evidence to develop new regulations that address the "who, when, and where" rules for the introduction of new mobilities (such as e-bikes and e-scooters), whose health impacts can be easily predicted [7] Goli proposed a two-stage methodology based on the energy savings gained by optimal network reconductoring was developed for the sizing and allocation of electric vehicle (EV) charging load at the residential locations in urban distribution systems. [8]. Diaz-Parra proposed a mathematical approach for resolving the electric School Bus Routing Problem (SBRP), which aims at minimizing the cost and optimizing the time and cost of transporting students [9]. Holyoak et al. scrutinized what it would take to turn a city into a world-class sustainable city through specific measures that would accelerate the use of active transportation, with a high number of households and industries equipped with solar and photovoltaic smart fast-charging station systems at strategic locations for electric-assisted non-motorized transportation and for low-power transportation [10].

The content of the article is organized as follows: Section 2 describes the materials and methods for conducting the research. Section 3 presents the results obtained from the research. Section 4 provides a discussion of the findings, and Section 5 provides the conclusions of the research.

## 2. Materials and Methods

The PRISMA method and the Kofod-Petersen method were used to extract useful information from the systematic review. The PRISMA 2020 statement includes reporting guidance that reflects advances in methods to identify, select, appraise, and synthesize studies. The structure and presentation of the items were modified to facilitate implementation with a 27-item checklist [11]. A systematic review has three main phases: planning, conducting, and reporting. Each of these phases is divided into several steps. The first phase involves planning the review and can be broken down into the following steps: identification of the need for a review, commissioning a review, specifying the research question(s), developing a review protocol, and evaluating the review protocol. This second phase is the actual review of the literature and consists of the following steps: identification of research, selection of primary studies, study quality assessment, data extraction and monitoring, and data synthesis. The last phase deals with how to disseminate the newly acquired knowledge and consists of three steps: specifying the dissemination strategy, formatting the main report, and evaluating the report [12]. In addition, the authors asked the research questions, determined the search process, identified the inclusion and exclusion criteria for the publications, selected individual studies, performed the data extraction and synthesis, and determined the risk of bias, as outlined in the following subsections [13].

### *2.1. Research Questions*

The aim of this systematic review is to determine the possible solutions for the development of long-range super-lightweight small electric vehicles for the intergenerational urban E-mobility in Smart Cities concept. The steps to determine the current status of the solution are as follows:

- Analyze the requirements and solutions of the needs for the development of a micro-mobility concept in Smart Cities;
- Analyze the requirements and solutions of the needs for the development of the concept of electric vehicle charging while driving;
- Analyze the requirements and solutions of the needs for the development of the electric scooter charger concept;
- Analyze the requirements and solutions of the needs for the development of the management and sharing of the electric scooter concept;
- Analyze the requirements and solutions of the needs for the development of the concept of E-mobility within Smart Cities (Smart Homes).

A number of questions were identified for this systematic review:

- RQ1: What technological solutions and innovations can be used to develop the concept of micro-mobility in Smart Cities?
- RQ2: What technological solutions and innovations can be used for the development of the concept of electric vehicle charging while driving?
- RQ3: What technological solutions and innovations can be used to develop the electric scooter charger concept?
- RQ4: What technological solutions and innovations can be used to develop the management and sharing of the electric scooter concept?
- RQ5: What technological solutions and innovations can be used to develop the E-mobility within Smart Cities (Smart Homes) concept?

### *2.2. Search Process*

The Web of Science scientific database [13] was used for the search. The search process started on 16 March 2022 and ended on 4 July 2022. The search results were stored in the Web of Science database, and the selected publications were uploaded and imported into the Endnote online reference manager. The main search keywords were "Smart Cities", "micro-mobility", "electric vehicle charging while driving", "charger for electric scooter", "management and sharing of electric scooters", and "E-mobility within Smart City (Smart Home)".

### *2.3. Inclusion and Exclusion Criteria*

In order to refine the search and select relevant literature, inclusion and exclusion criteria were used in the search (Table 1).

**Table 1.** Inclusion and exclusion criteria.

| | Inclusion Criteria | Exclusion Criteria |
|---|---|---|
| IC1 | The publication contains the keywords "Mobility", "Smart Cities", and "Micro-mobility" in the title, abstract, and topic. | No match with the described criteria, duplicate publication. |
| IC2 | Articles that contain the keywords and match the keywords "charger for electric scooter". | No match with the described criteria, duplicate publication. |
| IC3 | Articles that contain the keywords and match the keywords "management and sharing electric scooter" and "E-mobility within Smart City (Smart Home)". | No match with the described criteria, duplicate publication. |
| IC4 | The publication contains the keywords "electric vehicle charging while driving" and "Smart Cities". | No match with the described criteria, duplicate publication. |
| IC5 | The publication contains the keywords "electric mobility", "Smart Home", and "Smart Cities" in the title, abstract, and topic. | No match with the described criteria, duplicate publication. |

### *2.4. Study Selection*

The criteria for article selection included a review of the document title, abstract, and skimming of the article. In addition, the inclusion and exclusion criteria were also used in accordance with the PRISMA flowchart (Figure 1).

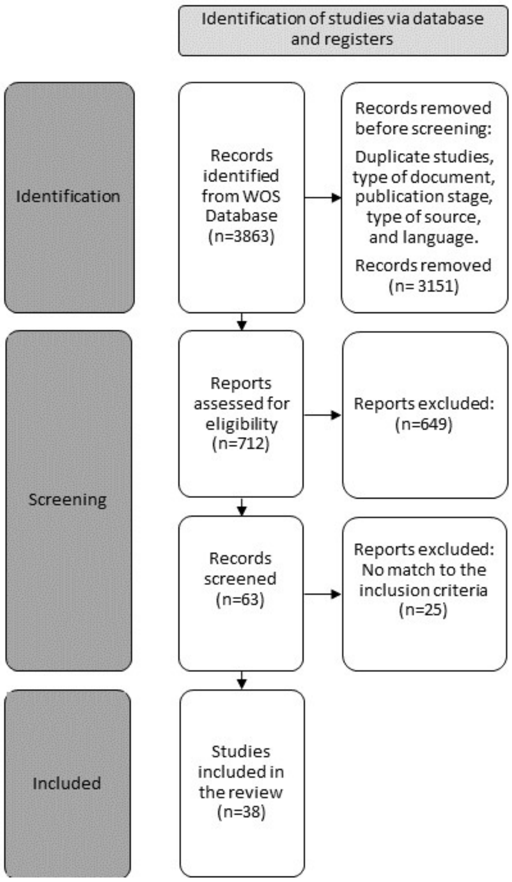


**Figure 1.** Flowchart for the selection of relevant publications and articles, processed for the selection of studies based on PRISMA.

Specifically, 3693 publications were found for the keywords "Smart Cities mobility". After specifying "electric mobility", 712 publications were found. After entering the keywords "micro-mobility", 63 publications were chosen, from which 38 publications (Table 2) were selected for the study of the "Smart Cities micro-mobility" topic.

**Table 2.** Inclusion and exclusion criteria.

| Query No. | Query Strings | Results | Selected |
|---|---|---|---|
| 1 | Key (Smart Cities all fields) AND (mobility all fields) AND (micro-mobility all fields) | 63 | 38 |
| 2 | Key (Smart Cities all fields) AND (Electric Vehicles driving charging all fields) AND (micro-mobility all fields) | 108 | 33 |
| 3 | Key (Charger all fields) AND (electric Scooter all fields) | 29 | 28 |
| 4 | Key (electric Scooter all fields) AND (Management and sharing all fields) | 21 | 19 |
| 5 | Key (Smart Cities all fields) AND (Electric mobility all fields) AND (Smart Home all fields) | 24 | 16 |
| | Total | 245 | 134 |

### *2.5. Data Extraction and Synthesis*

General information for the evaluation of the articles should include information on a needs analysis and innovative solutions in the areas of:

1. Smart Cities and micro-mobility.
2. Smart Cities and electric vehicle charging while driving.
3. Charger for an electric scooter.

4. Management and sharing of electric scooters.
5. E-mobility within Smart Cities (Smart Homes).

For each of the identified topics, the necessity to address the needs and individual requirements of the above-described area is described in the context of the current state of the solution in the development of super-lightweight small electric vehicles with a long range for intergenerational urban E-mobility concepts within Smart Cities. Furthermore, a table was created in the text—an overview of the tasks addressed within each topic in the development of super-lightweight small electric vehicles with a long range for intergenerational urban E-mobility concepts within Smart Cities.

The data obtained from the selected literature were tabulated in Excel according to the following structure:

- Title
- Authors
- Corporate Authors
- Editors
- Book Editors
- Source Title
- Publication Date
- Publication Year
- Volume Issue Part Number
- Supplement
- Special Issue
- Beginning Page
- Ending Page
- Article Number
- DOI
- Conference Title
- Conference Date
- Total Citations
- Average per Year

### *2.6. Risk of Bias*

The risk of the distortion of the objective information obtained from the retrieved publications may be influenced by the specified years of the selected literature in the interval between 2008 and 2022. Another possible factor influencing the distortion is the subjective view of the authors of the article on the area addressed and the chosen selection process. Last but not least, the effect of the bias of selecting literature only from the Web of Knowledge scientific database should also be mentioned.

## **3. Results**

This section presents the results from the data collected from RQ1 to RQ5 listed in Section 2. RQ1 and RQ2 provide a general perspective on the issues analyzed. The focus on the analyzed area of technological solutions and innovations for the development of the charger for electric scooters and management and sharing of electric scooter concepts is established by RQ3 and RQ4. The context of E-mobility solutions within Smart Homes in Smart Cities is asked by question RQ5.

In the following text, the technical terms PHEV, PLEV, BEV, EV, and HEV are used: “PHEV—Plug-in Hybrid Electric Vehicle”, “PLEV—Personal Light Electric Vehicle”, “BEV—Battery Electric Vehicle”, “EV—Electric Vehicle “, “HEV—Hybrid Electric Vehicle”. Electric Vehicles (EVs) move using an electric motor instead of using an Internal Combustion Engine (ICE). Electric vehicles require a charging port and outlet to charge their batteries fully (BEVs). In other vehicles, such as conventional hybrids (HEVs), the engine requires both fuel and electricity to run. This is the same for Plug-in Hybrid Electric Vehicles (PHEVs) [14].

### 3.1. Smart Cities and Micro-Mobility

Interest in publishing on the topic of Smart Cities and micro-mobility according to the number of publications began in 2011. The highest number of publications, 12, was reached in 2019 (Figure 2).

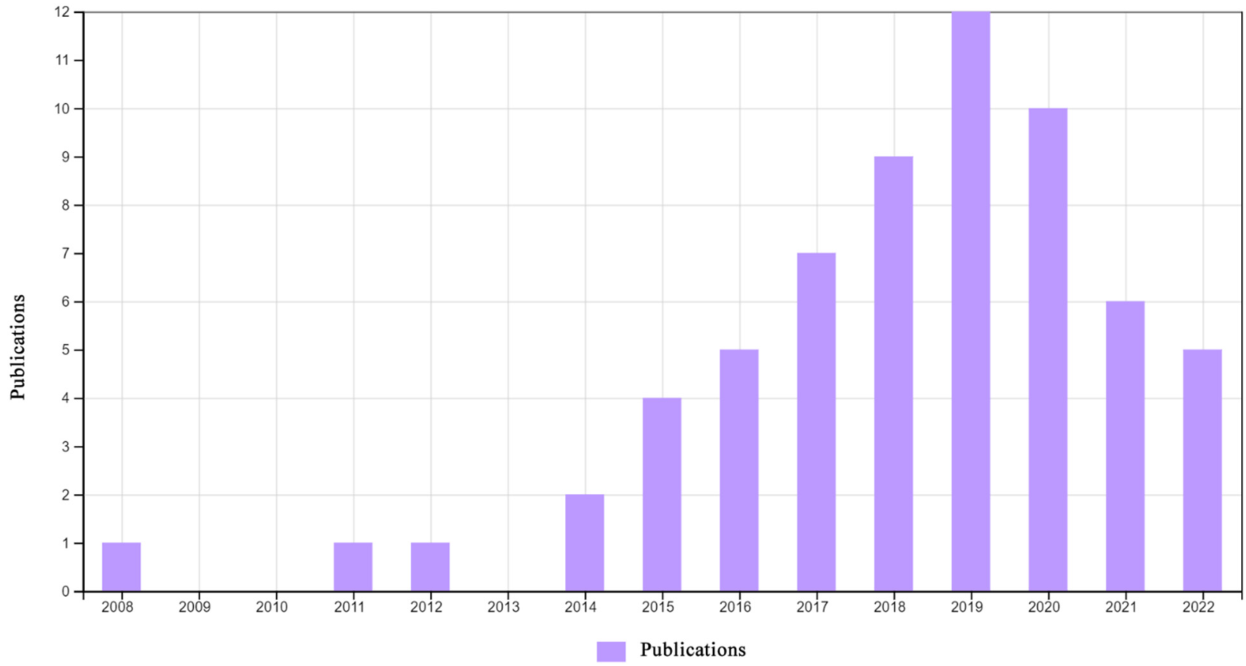


**Figure 2.** The number of publications in individual years on the Smart Cities and micro-mobility topics.

The total number of 63 publications covering the research area that focus on the described topic includes, among others, the following disciplines: Computer Science, Engineering, Transportation, Telecommunications, Environmental Sciences Ecology, Science Technology Other Topics, and others (Table 3).

**Table 3.** The research areas that focus on the topic "Smart Cities and micro-mobility".

| Research Areas | Record Count | % of 63 |
|---|---|---|
| Computer Science | 25 | 39.7 |
| Engineering | 17 | 27.0 |
| Transportation | 14 | 22.2 |
| Telecommunications | 12 | 19.1 |
| Environmental Sciences Ecology | 10 | 15.9 |
| Science Technology Other Topics | 10 | 15.9 |

In terms of affiliations, the topic is, among others, addressed by: Delft University of Technology, Universidad de Malaga, Czech Technical University Prague, Enzo Ferrari Engn Dept, Univ Nacl Patagonia Austral, Universidad Publica de Navarra (Table 4).

**Table 4.** In terms of affiliations which are dealing with the topic "Smart Cities and micro-mobility".

| Affiliations | Record Count | % of 63 |
|---|---|---|
| Delft University of Technology | 3 | 4.7 |
| Universidad de Malaga | 3 | 4.7 |
| Czech Technical University Prague | 2 | 3.2 |
| Enzo Ferrari Engn Dept | 2 | 3.2 |
| Univ Nacl Patagonia Austral | 2 | 3.2 |
| Universidad Publicad de Navarra | 2 | 3.2 |

Countries/regions that support research on the topic include Spain, the USA, Germany, Italy, England, Mexico, The Netherlands, and others (Table 5).

**Table 5.** Countries/regions that support research on the topic "Smart Cities and micro-mobility".

| Countries/Regions | Record Count | % of 63 |
| --- | --- | --- |
| Spain | 12 | 19.0 |
| USA | 11 | 17.5 |
| Germany | 10 | 15.9 |
| Italy | 10 | 15.9 |
| England | 4 | 6.4 |
| Mexico | 4 | 6.4 |
| The Netherlands | 4 | 6.4 |
| Brazil | 3 | 4.7 |

An overview of the solved tasks within the topic "Smart Cities and micro-mobility" is as follows:

- Sharing electric scooters in SCs [1];
- Resolving problems in city administration, such as traffic regulations, public safety, parking regulations, and liability issues of running MM in SCs [2,3,5];
- Adequate distribution of electrical energy for MM in SCs [4];
- Metrics for evaluating Mobility and Energy Productivity (MEP) in SCs [6];
- Assessment of the health impact of operating electric scooters in SCs [7];
- Optimization of electric car charging in residential SHs in SCs [8];
- Sharing MM resources in SCs [15,16];
- Analyses of the use of PLEVs in public transport using quantitative and qualitative indicators in SCs [17,18];
- Sustainability of PLEVs in SCs [19];
- The use of mobile phones during PLEV [20] operations for tracing and localization in SCs [21];
- Electric carsharing and micro-mobility [22];
- Environment Friendly booster bike [23];
- Optimization of the PLEV driving solution in SCs [24];
- Legislation and legitimization of the conflict within the framework of the operation of MM in SCs [25];
- The Infrastructure for Sustainable Mobility [26];
- Assignment of a Synthetic Population for Activity-Based Modeling Employing Publicly Available Data [27]
- Visualization and analysis of MM in SCs [28];
- The use of the IoT [29] in the operation of MM [30] using the LoRaWAN platform in SCs [31];
- The use of PLEVs to resolve noise in SCs [32];
- Machine Learning-Based Radio Access Technology Selection in the Internet of Moving Things [33];
- On-board unit to connect personal mobility vehicles to the IoT [34];
- Evaluation of alternative battery charging schemes for one-way electric vehicle smart mobility sharing systems based on real urban trip data [35];
- Consumers' innovativeness and conspicuous consumption orientation as predictors of environmentalism [36];
- The use of MM operation to improve the environment in SCs [37];
- Data collection from sensors deployed in the urban environment in SCs [38];
- Resolving the problem of traffic loads using MM in SCs [39];
- OSU SMOOTH in a Smart City [40];
- The use of MM to support the independent life of disabled persons or seniors in SCs or SHs [41,42].

- Two-Layer Model Predictive Battery Thermal and Energy Management Optimization for Connected and Automated Electric Vehicles [43];

### 3.2. Smart Cities and Electric Vehicle Charging while Driving

The first article on Smart Cities and electric vehicle charging while driving was published in 2011. The number of publications peaked in 2020 (Figure 3).

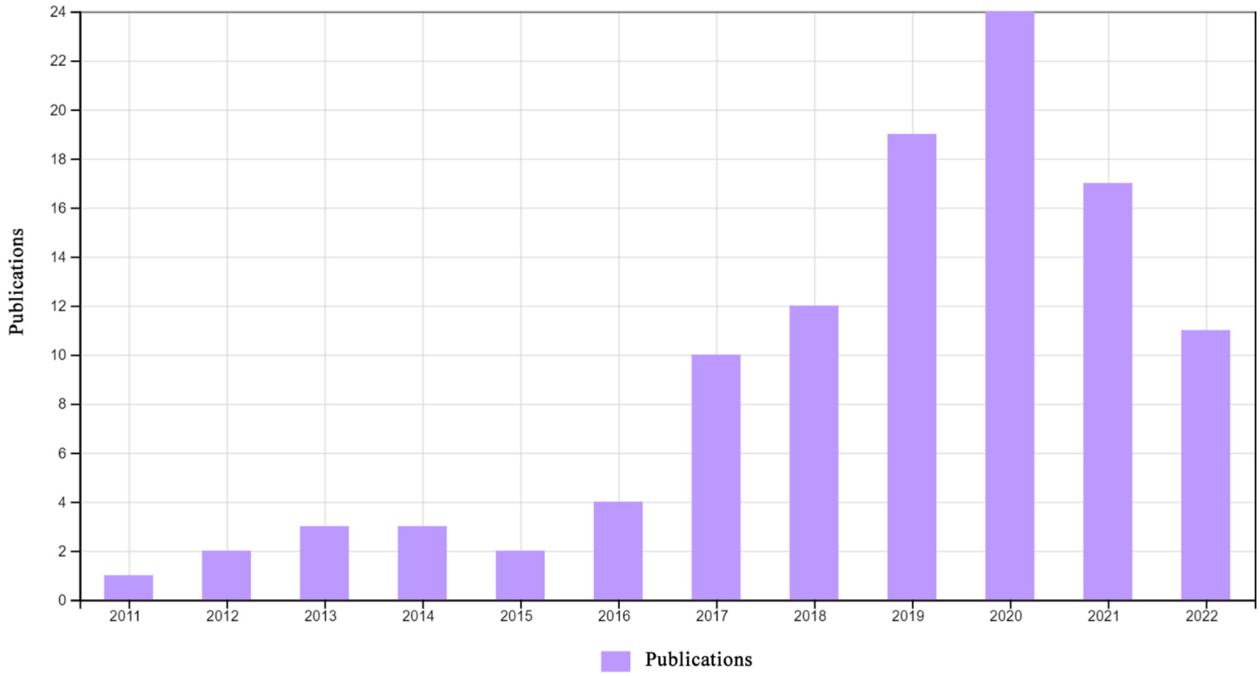


**Figure 3.** Number of publications in individual years for Smart Cities and electric vehicle charging while driving.

Out of the total number of 108 publications covering the research area that focuses on the described topic are included the areas: Engineering, Computer Science, Energy Fuels, Transportation, Telecommunications, Science Technology Other Topics, Environmental Sciences Ecology, Automation Control Systems (Table 6).

**Table 6.** The research areas that focus on the topic "Smart Cities and Electric Vehicles driving and charging".

| Research Areas | Record Count | % of 108 |
|---|---|---|
| Engineering | 63 | 58.3 |
| Computer Science | 33 | 30.6 |
| Energy Fuels | 25 | 23.1 |
| Transportation | 22 | 20.4 |
| Telecommunications | 18 | 16.7 |
| Science Technology Other Topics | 8 | 7.4 |
| Environmental Sciences Ecology | 7 | 6.5 |
| Automation Control Systems | 6 | 5.6 |

In terms of affiliations, the topic is, among others, addressed by the United States Department of Energy, Polytechnic University of Turin, University of Zagreb, American University of Sharjah, Chinese Academy of Sciences, Concordia University Canada (Table 7).

**Table 7.** Affiliations that support research on the topic "Smart Cities and Electric Vehicles driving and charging".

| Affiliations | Record Count | % of 108 |
|---|---|---|
| United States Department Oof Energy (DOE) | 5 | 4.6 |
| Polytechnic University of Turin | 4 | 3.7 |
| University of Zagreb | 4 | 3.7 |
| American University of Sharjah | 3 | 2.8 |
| Chinese Academy of Sciences | 3 | 2.8 |
| Concordia University Canada | 3 | 2.8 |

Countries/regions that support research on the topic include the People's Republic China, the USA, India, Italy, Canada, England, Japan, and South Korea (Table 8).

**Table 8.** Countries/regions that support research on the topic "Smart Cities and Electric Vehicles driving and charging".

| Countries/Regions | Record Count | % of 108 |
|---|---|---|
| People's Republic of China | 27 | 25.0 |
| USA | 22 | 20.4 |
| India | 11 | 10.2 |
| Italy | 9 | 8.3 |
| Canada | 8 | 7.4 |
| England | 8 | 7.4 |
| Japan | 6 | 5.6 |
| South Korea | 6 | 5.6 |

Figure 4 shows the keywords of selected publications for the topic of Smart Cities and electric vehicle charging while driving.

The automotive industry is currently shifting from traditional fossil fuels to electrification. There is a growing need in the EV industry to provide new infrastructures, services, tools, and solutions to support the use of EVs [44]. It is expected that future EVs will increasingly be able to use a connected driving environment for efficient, comfortable, and safe driving. Due to the relatively slow dynamics associated with the state of charge and temperature response in large battery-electrified vehicles, a long prediction/planning horizon is required to achieve better energy efficiency benefits [45]. The deployment of a Battery Management System (BMS) unit is a key element for monitoring the battery status of an electric car. In turn, the development and assessment of electric vehicle models form the basis for BMS design, as it provides a fast and inexpensive solution for testing optimal battery control logic in the Loop software environment [46]. In modern Smart Cities, mobility is based on EVs and it is considered a key factor in reducing carbon emissions and pollution. However, despite worldwide interest and investment, user adoption is still low, mainly due to a lack of support for charging services [47].

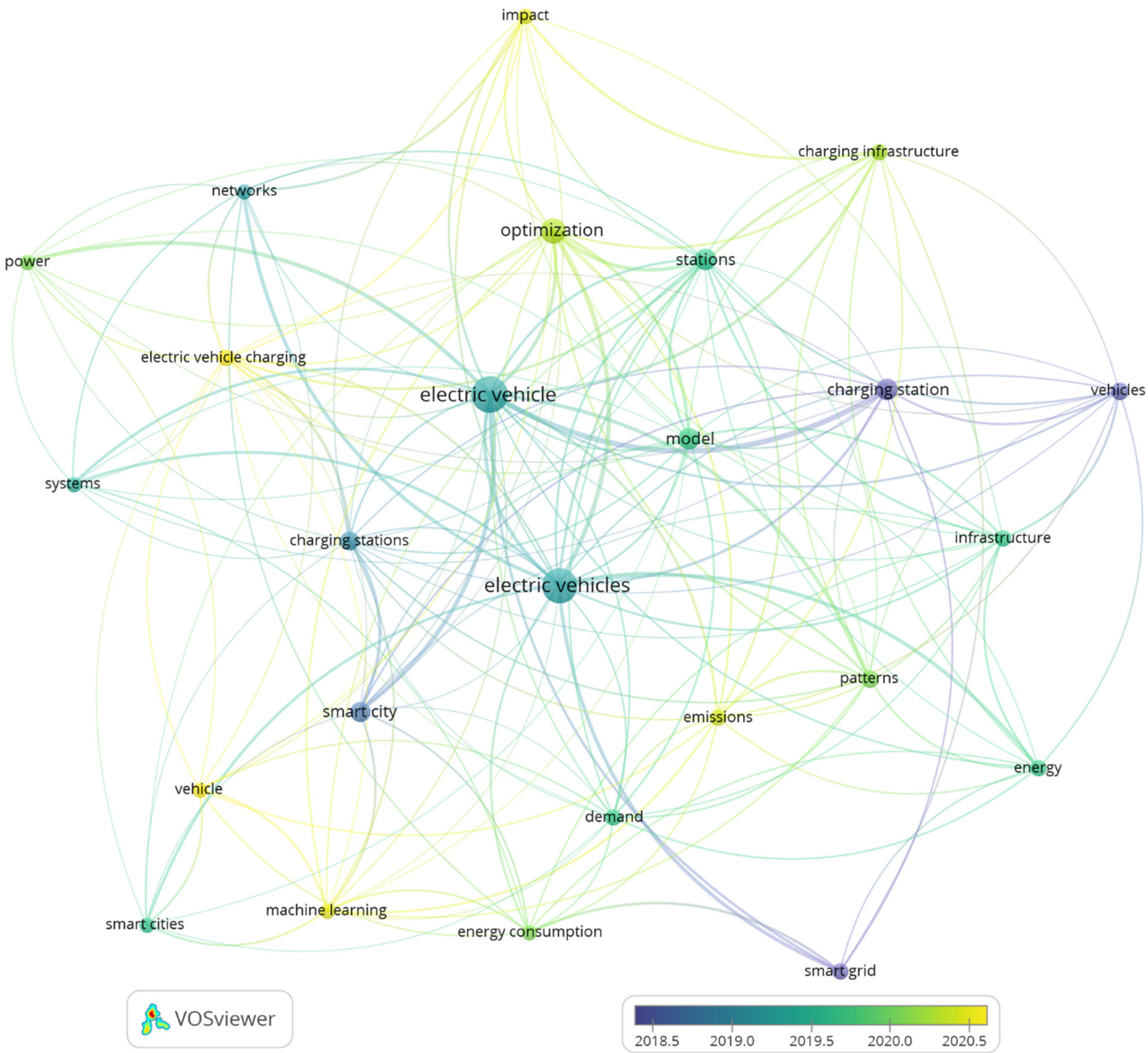


**Figure 4.** Individual keywords for the Smart Cities and electric vehicle charging while driving topic (created in SW Tool VOSviewer) [48].

Lithium ion batteries play a key role in powering electric cars. The battery's Remaining Useful Life (RUL) is fundamentally important to ensure the safety and reliability of vehicles. Due to the complex aging mechanism, RUL prediction for Battery Management Systems (BMSs) is challenging [49]. An accurate prediction of the Remaining Available Energy (E-RAE) of lithium ion batteries is still a challenging problem for electric vehicles, which is of fundamental importance for predicting the remaining range of EVs [50]. Solid and Liquid Electrolyte Lithium ion Batteries (SLELBs) have good commercial applicability in electric vehicles because they combine the safety of solid electrolyte lithium ion batteries with the high ionic conductivity of Liquid Electrolyte Lithium ion Batteries (LELBs) [20]. Feng et al. presented a plug-in hybrid electric vehicle supervisory control strategy based on energy demand prediction and route preview with an adaptive fuel Consumption Minimization Strategy (ECMS) in real-time operation using neural networks [51]. For the implementation of the electrochemical–thermal model in the BMS of electric cars, Gao et al. introduced a control-oriented electrochemical model of lithium ion batteries and its real-time implementation in the EV BMS by simplifying partial differential equations using the Laplace transform and Pade approximation [52].

Gong et al. focused on the study of the performance of Lithium ion (Li ion) batteries depending on the ambient temperature with respect to the available range of electric cars (electrochemical impedance spectroscopy test, dynamic driving plan test, and others) for the prediction of the available range and also for the development of vehicle control for electric cars and PHEVs [53]. Gozukucuk et al. used the Monte Carlo method to probabilistically predict the optimal energy to reach a given route obtained from Google Maps incorporating location and road topology [54]. Guo et al. developed an energy consumption control strategy for an extended-range electric vehicle based on a predictive control model [55]. In order to accurately predict the SOC value of an electric vehicle, He et al. developed a battery state space model suitable for pure EVs [56]. Hoekstra et al. proposed a real-time active cell balancing strategy derived from model-based predictive control [57]. Hu et al. proposed an optimization control strategy for a parallel hybrid electric vehicle with multiple excitation sources to improve torsional stability using the established simplified two-mass nonlinear dynamic model of the HEV powertrain [58]. To improve the energy efficiency and adaptability of pure EV driving conditions in a complex traffic environment, simulation conditions that can dynamically update traffic information based on measured data have been proposed [59]. Huber et al. resolved the problem of the shortest path with a constraint that makes it possible to treat uncertainty—especially the risks resulting from imperfect predictions of energy consumption using an energy reserve from a certain part of the battery capacity provided as such an energy reserve [60]. Jin et al. proposed the parameter estimation of an electrochemistry-based lithium ion battery model using a two-step procedure and parameter sensitivity analysis [61]. Lee et al. presented an adaptive optimal control strategy for SOC balancing based on Pontryagin's minimum principle that can be applied to real vehicles and does not require the prediction of driving patterns using an adaptive SOC balancing concept [62]. Li et al. provided an electrochemical model of a lithium ion battery with variable solid-state diffusion and the identification of parameters over a wide temperature range [63]. To increase the accuracy of E-RDE, Liu et al. introduced a Battery Energy (EB) prediction method based on predictive control theory, in which the combined prediction of the future change of the battery state, the change of the battery model parameters, and the voltage response is implemented on the E-RDE prediction horizon, and the E-RDE is then accumulated and optimized in real-time [64]. Falai et al. focused on assessing the performance and electric range of a two-wheel pure electric scooter in a real driving cycle, where the drive system of the device includes a set of LIBs with an Electric Energy Storage System (EESS) [46].

An overview of the solved tasks within the topic "Smart Cities and Electric Vehicles driving and charging" is given as follows:

- Thermal and energy management of Electric Vehicle (EV) batteries to ensure consumption savings through real-time prediction and optimization [45];
- Planning EV mobility routes also on medium and long routes [47];
- Indication of battery degradation using information obtained from discharge voltage on energy from voltage signals to reveal degradation characteristics [49];
- Determination of the energy state of the battery for the realization of the prediction of the future EV load [50];
- Supervisory management of plug-in hybrid electric vehicles based on the prediction of energy demand and route overview with the aim of minimizing energy consumption in real operation [51];
- Realization of the electrochemical–thermal model in the Battery Management System (BMS) in EVs [52];
- Verification of the performance of lithium ion batteries in EVs depending on the temperature [53];
- Resolution of the equation of EV dynamics for the generalization of energy consumption management issues using a large-capacity battery [54];
- Energy consumption management strategy based on Model Predictive Control (MPC) [55];
- Accurate predictions of the SOC EV value using the created battery model [56];

- Maximization of the EV range in RT by means of active balancing of cells using MPC [57];
- Elimination of HEV torsional vibrations to optimize energy consumption management [58];
- Optimal energy-efficient control of EVs based on the dynamic flow of traffic information [59];
- Solution of the optimization of the shortest EV path by ensuring the energy reserve [60];
- LIB model parameter estimation [61];
- Adaptive optimal control strategy for SOC balancing with application to real vehicles [62];
- Description of the LIB electrochemical model with variable diffusion in the solid phase and identification of parameters in a wide range of temperatures [63];
- Increasing the accuracy of $E_{-RDE}$ in RT [64];
- Optimal range of a two-wheeled electric scooter in a real driving cycle using an LIB—EESS [65].
- Optimal estimation of SOC battery status for HEVs [65];
- Range extension, system energy consumption forecast, range estimation, and control of the car's battery charge status [66];
- Efficient optimization of fast charging protocols to maximize battery cycle life [67];
- Forecasts and optimization of the range of electric cars [68];
- Use of a high-energy density battery and a high-power density supercapacitor to predict power demand within seconds [69];
- Accurate estimation of the state of charge of the battery in order to reduce estimation errors [70];
- Parameterization of a typical model of the Equivalent Electric Circuit (EEC) LIPB [71];
- Predictive control of circulating current with improvement of capacitor voltage behavior in real-time for modular multilevel converters [72];
- AER (All-Electric Range) adaptive energy management strategy based on the equivalent consumption minimization strategy (ECMS) and the forthcoming energy consumption prediction [73];
- Determination of the importance of HVLIB internal losses for EV range estimation algorithms [74];
- Forecasts of the need to charge an electric car driven by a specific user to make a predefined journey using Information Technology (IT) with Virtual Sensors (VSs) [44];
- Safe and efficient EV operation using accurate knowledge of battery behavior under various influencing factors with the creation of a battery simulation model [75];
- Estimation of SOC during HEV operation in RT [76];
- Optimization of the energy consumption management of electric vehicles with an extended range in RT [77];
- Use of ANN for PHEV energy prediction within the AER adaptive control strategy [78];

### *3.3. Chargers for Electric Scooters*

According to the number of publications, the interest in the charger topic for electric scooters is increasing (Figure 5). The largest number of publications so far was in 2021.

The total number of 28 publications covering the research area that focus on the described topic include the areas: Engineering, Energy Fuels, Computer Science, Science Technology, Telecommunications, Transportation, and others (Table 9).

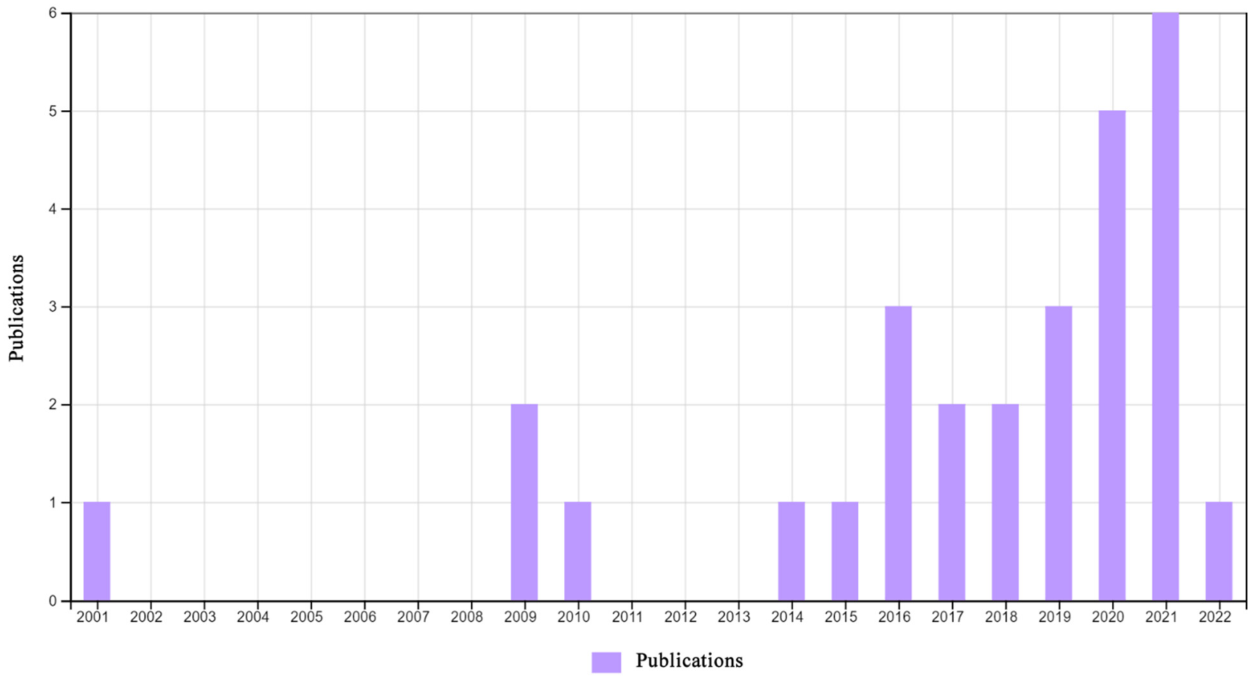


**Figure 5.** The number of publications in individual years on the topic of chargers for electric scooters.

**Table 9.** The research areas that focus on the topic "Chargers for Electric Scooter".

| Research Areas | Record Count | % of 28 |
|---|---|---|
| Engineering | 23 | 82.1 |
| Energy Fuels | 10 | 35.7 |
| Computer Science | 6 | 21.4 |
| Science Technology Other Topics | 4 | 14.3 |
| Telecommunications | 4 | 14.3 |
| Transportation | 4 | 14.3 |

In terms of affiliations, the topic is, among others, addressed by the Osaka Institute of Technology, Imperial College London, Polytechnic University of Turin, Universiti Malaya, Fuzhou University, King Saud University, and others (Table 10).

**Table 10.** Affiliations that support research on the topic "Chargers for Electric Scooter".

| Affiliations | Record Count | % of 28 |
|---|---|---|
| Osaka Institute of Technology | 4 | 14.3 |
| Imperial College London | 3 | 10.7 |
| Polytechnic University of Turin | 3 | 10.7 |
| Universiti Malaya | 3 | 10.7 |
| Fuzhou University | 2 | 7.1 |
| King Saud University | 2 | 7.1 |

Countries/regions that support research on the topic include Italy, Japan, England, Malaysia, Taiwan, Australia, the Czech Republic, India, and others (Table 11).

Ando et al. dealt with a super-fast ES pulse charging system, based on an Electric Double-Layer Capacitor (EDLC) [79]. Devendra et al. focused on the design and production of ES charging devices [80]. Hicham et al. implemented Space Vector Modulations for a Direct Torque Control (SVM-DTC) unit of a BLDC three-wheel ES with two BLDC motors that drove the rear wheels [81]. Hsu et al. presented an ES with grid-to-vehicle/Vehicle-to-Home (V2H)/Vehicle-to-Grid (V2G) and energy harvesting functions using Photovoltaic panels (PV) [82]. Joseph et al. tried to optimize Series–Series-Wireless Power Transmission

(SS-WPT) based on a current converter to achieve higher coupling separation, higher power transfer efficiency, and higher misalignment tolerance than conventional WPT designs with a transmission efficiency of 94% at a 200 mm link distance [83]. Kaneko et al. focused on an electric scooter powered by a powerful electronic motor and its associated new EDLC [84–86]. Kwan et al. presented a wireless charging solution for 600 W electric scooters operating at a frequency of 6.78 MHz with a battery charging efficiency of 84% [87] and 65.5% [88]. In order to realize emission-free solutions and clean transportation alternatives, Lin presented a novel frequency-controlled pulsed-DC converter for EVs' or Light Electric Vehicles' (LEVs) battery chargers [89]. Martinez-Navarro et al. designed, built, and commissioned a sustainable e-scooter charging dock using photovoltaic panels and a battery system in Valencia, Spain [90]. Masoud et al. developed a Mixed-Integer Linear Programming (MILP) model for the real-world ESCA charger allocation problem. The proposed model allocates e-scooters to chargers with an emphasis on minimizing the average distance traveled by chargers to pick up e-scooters [91,92]. Monteiro et al. presented a mobile battery network for electronic devices via power banks in the city and proposed an optimization model to find the optimal location and layout of the network considering customer demand, logistics components, battery degradation, and terminal charging mode [93]. The aim of Tai et al. was to develop a battery charger with remote monitoring and an intelligent active equalizer with NCR18650PF batteries, which have a nominal voltage of 3.6 V and a nominal capacity of 2900 mAh [94].

**Table 11.** Countries/regions that support research on the topic "Chargers for Electric Scooter".

| Countries/Regions | Record Count | % of 28 |
|---|---|---|
| Italy | 6 | 21.4 |
| Japan | 4 | 14.3 |
| England | 3 | 10.7 |
| Malaysia | 3 | 10.7 |
| Taiwan | 3 | 10.7 |
| Australia | 2 | 7.1 |
| Czech Republic | 2 | 7.1 |
| India | 2 | 7.1 |

An overview of the solved tasks within the topic "Chargers for Electric Scooter" is given as follows:

- Fast charging of ESs [79];
- HW and SW solution of the charging station for ESs [80];
- DC motor torque control for ES drive [81];
- ES with the function of energy transfer from the grid to the vehicle/from the Vehicle to the House (V2H)/from the Vehicle to the Grid (V2G) and energy collection using PV [82];
- Use of a charger with EC [84–86];
- Use of a wireless charger for Wireless Power Transfer (WPT) within ES operation [83,87,88,95–98];
- Use of a DC–DC converter with frequency control for LEV applications [89];
- Realization of a charging dock with PV for ESs [90];
- Resolving the problem of allocating chargers for ESs [91];
- Optimal assignment of E-scooter to chargers [92];
- Optimization of the mobile network for energy storage [93,99,100];
- Battery charger design for ESs [94,101–105];
- Solution to the design and implementation of a fast charger with high efficiency for lead acid batteries [106].

*3.4. Management and Sharing of Electric Scooters*

Interest in publishing on the management and sharing of electric scooters topic started in 2012. The largest number of publications produced so far was in 2021 (Figure 6).

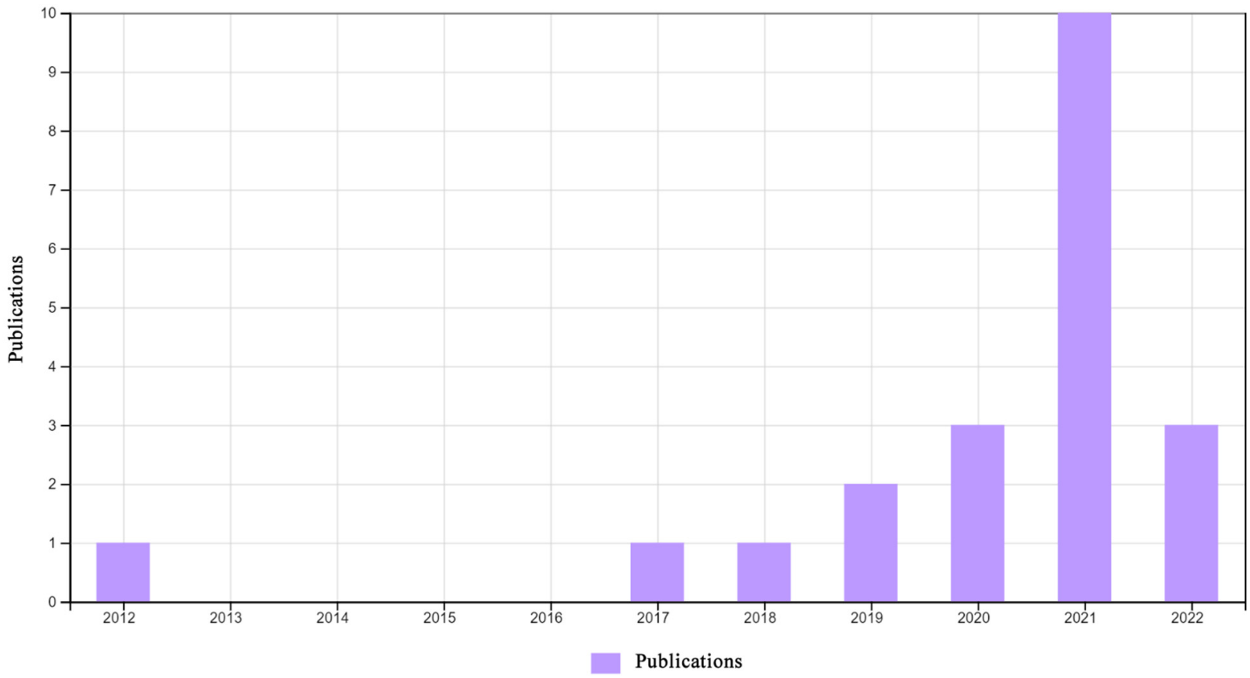


**Figure 6.** Number of publications in individual years on the topic of the management and sharing of electric scooters.

The total number of 21 publications covering the research area that focus on the described topic include the areas: Transportation, Business Economics, Computer Science, Environmental Sciences Ecology, Telecommunications, and others (Table 12).

**Table 12.** The research areas that focus on the topic "Management and sharing electric scooter".

| Research Areas | Record Count | % of 21 |
|---|---|---|
| Transportation | 9 | 42.9 |
| Business Economics | 4 | 19.1 |
| Computer Science | 4 | 19.1 |
| Environmental Sciences Ecology | 3 | 14.3 |
| Telecommunications | 3 | 14.3 |
| Energy Fuels | 2 | 9.5 |

In terms of affiliations, the topic is, among others, addressed by the University of California System, Asia University Taiwan, Barcelona Supercomputer Center BSC CNS, Beijing Institute of Technology, Chalmers University of Technology, China Medical University Hospital Taiwan, and others (Table 13).

**Table 13.** Affiliations that support research on the topic "Management and sharing electric scooter".

| Affiliations | Record Count | % of 21 |
|---|---|---|
| University of California System | 2 | 9.5 |
| Asia University Taiwan | 1 | 4.8 |
| Barcelona Supercomputer Center BSC CNS | 1 | 4.8 |
| Beijing Institute of Technology | 1 | 4.8 |
| Chalmers University of Technology | 1 | 4.8 |
| China Medical University Hospital Taiwan | 1 | 4.8 |

Countries/regions that support research on the topic include the USA, Taiwan, Germany, Italy, the People's Republic of China, Poland, Sweden, and Australia (Table 14).

**Table 14.** Countries/regions that support research on the topic "Management and sharing electric scooter".

| Countries/Regions | Record Count | % of 21 |
|---|---|---|
| USA | 5 | 23.8 |
| Taiwan | 4 | 19.1 |
| Germany | 2 | 9.5 |
| Italy | 2 | 9.5 |
| People's Republic of China | 2 | 9.5 |
| Poland | 2 | 9.5 |
| Sweden | 2 | 9.5 |
| Australia | 1 | 4.8 |

Current mobility trends suggest that the popularity of private cars will decline in the near future. One of the reasons for this development is the proliferation of mobility services such as car or bicycle sharing or Mobility-packages-as-a-Service (MaaS) [107]. Electric micro-mobility is becoming increasingly popular as an urban transport option. It could help reduce transport externalities and provide last-mile solutions and complementary ways to access public transport [108]. Micro-mobility can alleviate many of the problems facing large cities today and offer a path to more sustainable urban transport [109]. Micro-mobility is shaping first- and last-mile journeys in urban areas. Recently, shared dockless electric scooters (e-scooters) have emerged in major cities as an everyday alternative to driving for short-distance commuters due to their affordability, ease of app accessibility, and zero emissions [110]. On-demand mobility services such as bike-sharing, scooter-sharing, and transportation network companies (TNCs, also known as ride-sourcing and ride-hailing) are changing the way people travel by providing dynamic on-demand mobility that can complement public transport and passenger car use [111]. Electric scooter (e-scooter) sharing services have redefined the concept of urban transport and urban development around the world. However, these services have raised concerns about information privacy due to allegations that they are used by companies and even government agencies to collect information [112]. Through the IoT and cloud computing technologies, the marketing and availability of electric motorcycles can be increased [113]. It is also necessary to ensure the management of traffic and traffic lights in connection with the operation of EC [114].

Scorrano et al. found that the purchase price, fuel consumption, annual road tax, insurance costs, range, motor power, country of manufacture, and replaceable battery were consistently statistically significant across different specifications in the application of ES operation [115]. Other important parameters for the wider use of ESs are providing an increase in the lifetime of products, ensuring the exchangeability of batteries, alternative logistics of data collection, as well as ensuring a suitable charging concept that takes into account the protection of the environment [116]. Another important factor in ES operation is the provision of information on the interactions of ES operations with existing transport systems, such as modeling the interaction of e-scooters and bus transit services [117].

An overview of the solved tasks within the topic "Management and sharing electric scooter" is given as follows:

- Car or bicycle sharing or mobility-packages-as-a-service [107];
- Last-mile solutions and complementary ways of accessing public transport from the point of view of the private operator based on cost effectiveness, guaranteeing access to these services in a sustainable and safe way, and from the user's point of view by increasing the availability of the network through more mobility options [108];
- Sustainability of urban transport [109];

- Solving urban governance issues such as traffic regulations, public safety, parking regulations, and liability issues, analyses of the causes of injuries associated with shared e-scooters [110];
- ES operation flexibility and affordability [111];
- Privacy of information obtained in the sharing economy of e-scooters within the framework of development with the use of IT [112];
- Improving the appearance design and service of ESs to attract the attention of consumers [113];
- Management of operation, traffic, and traffic lights [114];
- Analyses of the impact of the purchase price, fuel consumption, annual road tax, and insurance premium costs, range, motor power, country of manufacture, and replaceable battery for extending ES operation [115];
- Analyses of the impact on the environment in connection with the lifetime of products, replaceable batteries, alternative collection logistics, and charging concepts compared to alternative means of transport [116];
- Resolving the problem of modelling the interaction of e-scooters and bus transit services [117].
- Use of hybrid energy systems of fuel cells and batteries with increased efficiency [118];
- Increasing the efficiency of the Fuel Cell (FC) in partial load conditions, improvement and protection of the environment [119,120];
- Elimination of accidents and injuries [121,122];
- Analyses of safety risks (alcohol, non-use of head, hand, foot protection, etc.) in ES operation [122];
- Monitoring of e-scooter routes during the delivery of goods (elimination of delays in the delivery of goods) [123];
- Measuring the quality of shared mobility [124]; Visualization, analysis, and comparison of the impacts of Smart City policies based on innovative mobility concepts in urban areas [125];

### *3.5. E-Mobility within Smart Cities (Smart Homes)*

Interest in publishing on the topic of E-mobility within Smart Cities (Smart Homes) began in 2015. The largest number of publications so far was in 2018 (Figure 7).

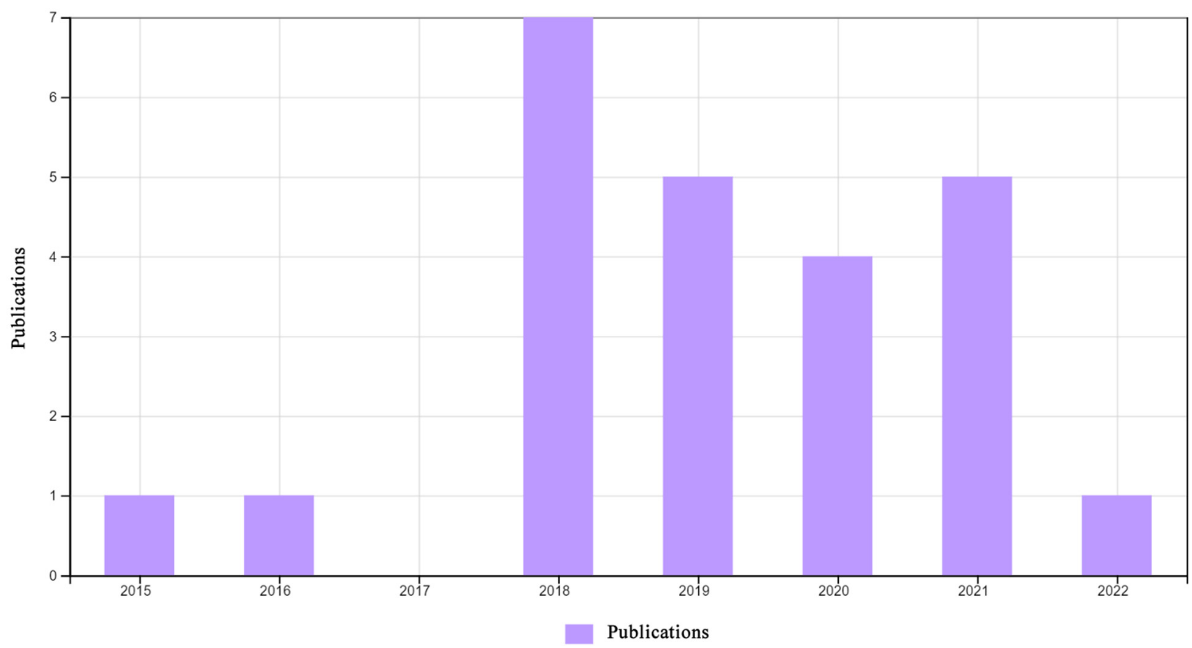


**Figure 7.** Number of publications in individual years on the subject of E-mobility within Smart Cities (Smart Homes).

The total number of 24 publications covering the research area that focus on the described topic include the areas: Computer Science, Engineering, Energy Fuels, Telecommunications, Automation Control Systems, and others (Table 15).

**Table 15.** The research areas that focus on the topic "E-mobility within Smart Cities (Smart Home)".

| Research Areas | Record Count | % of 24 |
|---|---|---|
| Computer Science | 11 | 45.8 |
| Engineering | 9 | 37.5 |
| Energy Fuels | 7 | 29.2 |
| Telecommunications | 3 | 12.5 |
| Automation Control Systems | 2 | 8.3 |
| Chemistry | 2 | 8.3 |

In terms of affiliations, the topic is, among others, addressed by the Eindhoven University of Technology, Ku Leuven, Abdus Salam International Center for Theoretical Physics ICTP, AGH University of Science Technology, Alma Digit Res Labs, Beijing Jiaotong University, and others (Table 16).

**Table 16.** Affiliations that support research on the topic "E-mobility within Smart Cities (Smart Home)".

| Affiliations | Record Count | % of 24 |
|---|---|---|
| Eindhoven University of Technology | 2 | 8.3 |
| Ku Leuven | 2 | 8.3 |
| Abdus Salam International Centre For Theoretical Physics ICTP | 1 | 4.2 |
| AGH University of Science Technology | 1 | 4.2 |
| Alma Digit Res Labs | 1 | 4.2 |
| Beijing Jiaotong University | 1 | 4.2 |

Countries/regions that support research in the given topic include, among others: People's Republic of China, the USA, India, Italy, The Netherlands, Belgium, and others (Table 17).

**Table 17.** Countries/regions that support research on the topic "E mobility within Smart Cities (Smart Home)".

| Countries/Regions | Record Count | % of 24 |
|---|---|---|
| People's Republic of China | 7 | 29.2 |
| USA | 6 | 25.0 |
| India | 4 | 16.7 |
| Italy | 4 | 16.7 |
| The Netherlands | 3 | 12.5 |
| Belgium | 2 | 8.3 |
| England | 2 | 8.3 |
| Germany | 2 | 8.3 |

Ideas about what the cities of the future will look like are currently met by the Smart Cities concept, which is an effective platform that ensures the optimization of resources and services through monitoring and communication technologies [126,127]. By 2030, the number of urban areas is expected to triple, housing 60% of the world's population [128]. The Internet of Things (IoT) is expected to provide the basic infrastructure for Smart Cities and make ICT a technology to address major challenges related to climate change, energy efficiency, mobility, and future services [129]. Urban mobility is a multidimensional characteristic of cities, which is seen as layers of interconnected infrastructures, places, people, and information. Therefore, the study of networks such as electrical and transportation systems should go beyond the individual network and connect with other networks in the SC [130].

There are six possible tools to make urban mobility more environmentally friendly: stricter rules for urban transport policy solutions, taking advantage of shared vehicles, improving the urban fabric, proposing alternatives to car use, new financial resources to change driver behavior, and a business model for those cities that want to have a green image [131]. To resolve poor air quality and greenhouse gas emissions in cities, it is proposed that the use of electric cars, electric bicycles, and electric scooters be established [132]. For that reason, it is necessary to focus on new methods of electricity production and storage (photovoltaics, fuel cells, battery storage systems) [133] using the current structure of SH solutions within building automation [134]. With the transition to the Internet of Things (IoT), there is a significant increase in stationary and mobile IoT sensing and computing devices that continuously generate a huge amount of contextual information [135]. Based on the obtained data, it is possible to more easily provide information modeling the behavior of residents on the scale of Smart Cities [136]. The emerging paradigm of the Internet of Things is based on intelligent objects that will be able to communicate with the surrounding environment using ubiquitous connectivity [137]. An overview of the solved tasks within the topic "E-mobility within Smart Cities (Smart Home)" is given as follows:

- Secure data collection using the IoT within SCs [128,138];
- Sending data over long distances using a wireless network and archiving data [137];
- Localization of people and objects in cities [139];
- Prediction of the consumption of electricity in connection with e-transport in SCs [130];
- Monitoring and modelling the behavior of residents for realistic suggestions for predicting electricity consumption [136];
- Financing of electricity infrastructures within the framework of electricity regulation and E-mobility [132];
- Support, development, and use of environmentally friendly vehicles [131];
- Development of domestic battery systems within SHs [134];
- Use of SH automation and innovations (Smart Meters) within SCs [129];
- Innovative approaches to solving ways of producing photovoltaic energy for smart charging stations for e-bikes and e-scooters, together with energy stored in a local battery [126,127];
- Photovoltaic energy supply for smart charging stations for e-scooters together with energy stored in a local battery [133];
- Identification of electricity consumption model devices in households in connection with SG [140];
- Smart Metering in Smart Homes [141,142].

## 4. Discussion

The main objective of the article was to investigate the current state of research, analysis, and design of a solution for the maximally efficient and comprehensive concept of urban E-mobility to bring a qualitatively new level both in terms of the design and in terms of the parameters of the ESs themselves and, at the same time, in terms of their operation, charging, and management within SCs.

The aim of the systematic review was to determine the possible solutions for the development of long-range super-lightweight small electric vehicles for intergenerational urban E-mobility in the SC concept. The steps to determine the current status of the solution were to analyze the requirements and solutions needed for the development of the: "MM concept in SC, the concept of EV charging while driving, the ES charger concept, the management and sharing of the ES concept, of the concept of E-mobility within SC (SH)".

A number of questions were identified for this systematic review: "RQ1 What technological solutions and innovations can be used to develop the concept of micro-mobility in Smart Cities?", "RQ2 What technological solutions and innovations can be used for the development of the concept of electric vehicle charging while driving?", "RQ3 What technological solutions and innovations can be used to develop the electric scooter charger concept?", "RQ4 What technological solutions and innovations can be used to develop the management and sharing of the electric scooter concepts?", "RQ5 What technological solutions and innovations can be used to develop the E-mobility within Smart Cities (Smart Home) concept?".

The PRISMA studies and the Kofod-Petersen method were used to extract useful information from the presented systematic review.

To answer RQ1 related to the solution of the "Smart Cities and micro-mobility" concept requires addressing the following needs, which are listed in Table 18. The most mentioned tasks for solving are "traffic regulations, public safety, PLEVs parking", "MM and PLEV shared micro-mobility", "PLEVs analysis for urban public transport", "IoT, LoRaWAN, SC", "connection of MM with traffic load in SC and configuration and provision of SC infrastructure", and "support for seniors and disabled people for an active life with the help of MM".

**Table 18.** Overview—topics addressed within the "SC and MM" concept.

| Topic of the Article | Reference Number | Observations |
|---|---|---|
| PLEVs demand in cities, Micro-Mobility (MM) | [4] | SC, PLEV, Poland |
| Sharing PLEVs | [1] | SC, PLEV, USA |
| Tracking EVs | [9] | SC, EV |
| Traffic regulations, public safety, PLEVs parking | [2,3] | SC, PLEV |
| Regulation of the use of PLEVs | [5] | SC, PLEV, Australia |
| Mobility and Energy Productivity (MEP) assessment methodology | [6] | SC, PLEV, MEP |
| Health impacts and injuries | [7] | SC, PLEV, health |
| EV charging methodology—optimization | [8] | SC, SH, EV, charging optimization |
| MM and PLEV shared micro-mobility | [15,23,26,31,36,43] | SC, PLEV MM sharing |
| Use of ANN to predict PLEV sharing | [16] | SC, Predikce, sdílení, PLEV, USA |
| PLEVs analysis for urban public transport | [17,18] | SC, PLEV sustainability, Uruguay |
| Charging station—Photovoltaics (PV)—households (Smart Homes), PLEVs | [19] | SC, SH, PV, PLEV, SH |
| Smart mobile, PLEV driving intention | [20] | SC, Mobile, PLEV |
| Localization of PLEVs, data processing | [21] | SC, PLEV, data processing, USA |
| A sustainable alternative for moving around the city—PLEVs | [22] | SC, sustainability, PLEVs, Italy |
| PLEVs, Brushless DC motor (BLDC) | [24] | PLEV, BLDC motor |
| PLEVs' conflicts, legitimization | [25] | SC, PLEV, conflicts |
| Infrastructure for sustainable mobility | [27] | SC, PLEV, infrastructure |
| SW tool, simulation, and analysis of micro-mobility | [28] | SC, MM, Talin, Estonia |
| IoT, LoRaWAN, Smart Cities | [29,33–35,42], | SC, MM, IoT |
| A comprehensive PLEV sharing solution—Dockless Shared Electric Scooters (DSESs) | [30] | SC, MM, DSES |
| Resolving noise in cities using PLEVs | [32] | SC, PLEV, noise |
| Ensuring data collection within micro-mobility | [36,38] | SC, MM, data collection |
| Internet of Moving Things (IoMT), PLEVs | [34] | SC, MM, IoMT |
| Micro-mobility for environmental improvement | [37] | SC, MM, environment |
| Connection of MM with traffic load in SCs and configuration and provision of SC infrastructure | [39,40] | SC, MM, traffic load, infrastructure |
| Disabled people + seniors' support for an active life with the help of MM | [41,42] | SC, MM, seniors, disabled people |

To answer RQ2 related to the solution of the "SC and EV driving and charging" concept requires addressing the following needs, which are listed in Table 19. The most mentioned tasks are "Battery charging with MPC of EV in RT", "Battery SOC Estimation Optimization Model", "Prediction, EV range optimization", and "Battery behavior model".

**Table 19.** Overview—resolved topics within the “SC and EV driving and charging” concept.

| Topic of the Article | Reference Number | Observations |
|---|---|---|
| Battery charging MPC of Electric Vehicles (EVs) in RT | [45,69] | Battery, EV, MPC, HESS |
| Battery State Of Charge (SOC) estimation optimization model | [65,66,70] | SOC, HEV, OML-SOCE, |
| Fast charging optimization to maximize battery cycle life | [67] | ML, fast charging |
| Prediction, EV range optimization | [47,68] | EV, range |
| Indication of battery degradation during battery charging | [49] | RUL, FRGM |
| E-RCE battery energy state determination, EV remaining range prediction | [50] | SOE, SRUKF, ECE, $E_{\text{-RCE}}$, $E_{\text{-RAE}}$, range |
| Parameterization of EEC, LIPB—a combination of the EIS method and analysis of charge/discharge curves with the prediction of the behavior of Li ion batteries | [71] | EEC, LIPB, EIS, SOE/SOC, battery parameterization |
| Modular Multilevel Converters (MMCs)—quick charge | [73] | MMC, quick charge, NMPC |
| Determining the importance of HVLIB internal losses to EV range estimation algorithms | [74] | EV, range, HVLIB, SOC, SOH |
| Demand prediction—EV range solution—virtual sensors | [44] | EV, VS, prediction, IT |
| Accurate knowledge of battery behavior, creation of battery simulation model | [75] | SLELB, EIS, EV, SECM, SOC |
| Battery behavior model | [51–55] | EV, MPC, battery model |
| SOC prediction in EVs using a battery model | [56] | SOC, EV, battery model |
| Maximizing EV range in RT using active cell balancing with MPC | [57] | EV, RT, MPC |
| Torsional vibration removal of HEVs to optimize energy management | [58] | HEV energy optimization |
| Optimal energy-efficient EV control based on the dynamic flow of traffic information | [59] | EV, control optimization |
| Estimation of SoC during HEV operation in RT | [76] | HEV, SOC, RT |
| Optimizing EV shortest distance estimation | [60] | EV, shortest distance range |
| Lithium ion battery model parameter estimation | [61] | LIB model estimation |
| Adaptive SOC balancing control with application to real vehicles | [62] | SOC, EV |
| Description of the electrochemical model of the lithium ion battery | [63] | Estimation of the LIB model |
| Optimization of EV energy management with extended range in RT | [77] | EV, RT |
| ANN for PHEV energy prediction under AER adaptive control strategy | [78] | ANN, PHEV, AER |
| Ensuring the accuracy of $E_{\text{-RDE}}$ | [64] | $E_{\text{-RDE}}$ |
| Optimization of battery management within BMS for ERP | [46] | ES, BMS, EESS, LIB, ERP |

To answer RQ3 related to the solution of the “Chargers for Electric Scooter” concept requires addressing the following needs, which are listed in Table 20. The most mentioned tasks are “Wireless Power Transfer (WPT) using Wireless Charger”, “EDLC charger solution (Electric Double Layer Capacitor)”, “Optimization of MESN solutions for ES”, “Design and solution of BC for ES”, and “FC with high efficiency for LAB”.

To answer RQ4 related to the solution of the “Management and sharing of electric scooters” concept requires addressing the following needs, which are listed in Table 21. The most mentioned tasks are “The connection between EC operation and environmental protection”, “Elimination of accidents and injuries”, and “EC traffic problems, traffic regulations”.

**Table 20.** Overview—resolved topics within the "Chargers for ES" concept.

| Topic of the Article | Reference Number | Observations |
|---|---|---|
| Super-fast-charging ES, Electric Double-Layer Capacitor (EDLC) | [79] | EDLC, ES, |
| HW and SW solutions of EVCS using the OCPP standard | [80] | EVCS, OCPP |
| Reduction of THD in BLDC | [81] | THD, BLDC, ES |
| ES with V2H and V2G energy transfer function using PV | [82] | ES, V2H, V2G, PV |
| Wireless Power Transfer (WPT) using wireless charger | [83,87,88,95–98] | WPT, ES |
| EDLC charger solution | [84–86] | ES, EDLC |
| DC–DC converter with frequency control for LEV | [89] | LEV, DC-DC converter |
| Photovoltaic charging dock for electric scooters | [90] | PV, ES |
| Solving ES charging dock allocation problem (ESCA) | [91] | ES, ESCA, MILP, charging docks |
| Optimizing ES assignment solutions to chargers | [92] | ES, allocation, charging docks |
| Optimization of MESN solutions for ES | [93,99,100] | ES, MESN |
| Design and solution of BC for ES | [94,101–105] | ES, BC |
| FC with high efficiency for LAB | [106] | ES, FC, LAB |

**Table 21.** Overview—topics resolved in the "Management and sharing ES" concept.

| Topic of the Article | Reference Number | Observations |
|---|---|---|
| Car or bicycle sharing or mobility-packages-as-a-service | [107] | ES, sharing, MaaS |
| Last-mile operation solutions from the point of view of the private operator and from the point of view of the user | [108] | ES, mobility, sharing |
| Use of hybrid energy systems of fuel cells and batteries with increased efficiency | [118] | ES, electric batteries |
| The connection between EC operation and environmental protection | [119,120] | ES, sharing, environment |
| Sustainability of urban transport in connection with the operation of ESs | [109] | ES, sustainability of transport |
| EC traffic problems, traffic regulations, public safety, parking regulations, liability issues, accident, and injury analysis | [110] | ES, rules of the road |
| Elimination of accidents and injuries | [121,122] | ES, elimination of injuries |
| Monitoring of e-scooter routes during goods delivery | [123] | ES, route monitoring |
| ES shared mobility quality measurement, MMQUAL | [124] | ES, shared mobility quality |
| Ensuring ES operation flexibility and affordability | [111] | ES, TNC, flexibility, price |
| EC operation, IT development, data protection | [112] | ES, IT, data secure |
| Ensuring safety risk analysis of ES operation | [122] | ES, safety, analysis |
| Ensuring visualization, analysis, and comparison of the impacts of SC policies based on innovative mobility concepts in urban areas | [125] | ES, visualization, traffic impact analysis |
| Ensuring service and maintenance of batteries and charging stations for ESs | [113] | ES, service and maintenance, IoT, cloud computing |
| Ensuring the control of operation, traffic, and traffic lights | [114] | ES, traffic control |
| Provision of analysis of possibilities for expansion of ES operation | [115] | ES, expansion of operation, impact analysis |
| Ensuring the analysis of the impact of ES operations on the improvement of the environment | [116] | ES, operation, environment |
| Providing a solution to the problem of modeling the interaction of e-scooters and bus transit services. | [117] | ES, interaction with the operation of electric buses |

To answer RQ5 related to the solution to the development of the concept of "E-mobility within Smart Cities (Smart Homes)" requires addressing the following needs, which are listed in Table 22 The most mentioned tasks are "Secure data collection using IoT within SC", "Optimization of resources and services through monitoring and IT in SC", and "Implementation of Smart Metering in Smart Homes".

**Table 22.** Overview—topics addressed within the "E-mobility within SC (SH)" concept.

| Topic of the Article | Reference Number | Observations |
|---|---|---|
| Secure data collection using IoT within SCs | [128,138] | IoT, SC, data |
| Wireless networks, long-distance data transmission in SCs | [137] | SC, Wireless networks, data |
| Localization of persons and objects in SCs | [139] | Localization, SC |
| Electricity consumption prediction in connection with e-transport in SCs | [130] | SC, consumption of electricity, prediction, e-transport |
| Monitoring and modeling the behavior of residents for realistic proposals for predicting electricity consumption; energy in SCs | [136] | SC, behavior monitoring, prediction of electricity consumption; energy |
| Financing of electric power infrastructures within the framework of the regulation of electric power and E-mobility in SCs | [132] | Financing of electric power, E-mobility |
| Ensuring the support, development, and use of environmentally friendly vehicles in SCs | [131] | SC, support |
| SH automation, dynamic tariffs for demand response shaping | [134] | SH, dynamic tariffs |
| Smart Meters within SCs | [129] | SC, smart meters |
| Optimization of resources and services through monitoring and IT in SCs | [126,127] | SC, IT, monitoring |
| PV energy supply for smart charging stations for e-scooters + a local battery | [133] | ES, SH, PV, BEV |
| Identification of electricity consumption models facilities in SHs in connection with SG | [140] | SH, SG |
| Implementation of Smart Metering in Smart Homes | [141,142] | SM, SH |

Some limitations of the EV use in SCs (SHs) [140] arise from the dependence of electricity generation on weather conditions and the utility of EVs [139] depending on the range of vehicle use with respect to the following [138]:

- The variation in vehicle energy consumption by season (winter/summer);
- The actual charging profile of the EV;
- The parking periods required to achieve the target range for the user.

The analyses showed that the most important factors in the operation of the electric shared mobility market are prices, the condition of the fleet, the replacement of vehicles, rental area, legal requirements, the location of parking spaces, and operational safety [139].

## 5. Conclusions

The main contribution of the article was a systematic overview and discussion related to the research on the current status of the development of long-range super-lightweight small electric vehicles for intergenerational urban E-mobility within the Smart Cities concept for a pilot study of a new way of resolving the traffic management of the urban district of Poruba within the statutory city of Ostrava in the Czech Republic. Another of the goals was to help researchers and other workers dealing with the described area to identify the most feasible solution for the use of electric scooters as part of micro-mobility solutions in Smart Cities.

After applying the above-described inclusion and exclusion criteria to articles generated from the scientific research database Web of Science on the subject of the "Smart Cities and micro-mobility", "Smart Cities and Electric Vehicles charging while driving", "chargers for electric scooters", "Management and sharing of electric scooters", and "E-mobility within Smart Cities (Smart Homes)", 134 articles in the period from 2008 to 2022 were selected. The selected articles made it possible to achieve the set goals and answer the research questions of this systematic review. Most of the mentioned studies were conducted in the USA (44), followed by contributions by the People's Republic of China (36), Italy (31), India and England (15), Germany (12), Canada (11), Japan (10), The Netherlands (7), South Korea (6), Mexico (4) and the Czech Republic (4).

A summary of the findings of this research review is provided for each research question:

RQ1:

As part of the search for an answer to RQ1, the largest number of articles dealt with the issue of shared PLEV micro-mobility (6). Other articles dealt with the provision of the IoT in connection with the operation of MM in Smart Cities (5), resolving traffic regulations and public safety together with ensuring the provision of parking (4), and providing data collection within MM (2) in connection with solving traffic loads (2). Supporting the active life of seniors and disabled people with the help of MM (2) is also an important topic to address.

RQ2:

In response to RQ2, the articles dealt with topics describing the solution of the battery behavior model (5) and the optimization of the estimation of the battery SOC (3). The topics of Model-Predictive-Control-based battery charging control (MPC) of Electric Vehicles (EVs) in Real-Time (RT) (2) and EV range optimization solutions (2) were also important topics.

RQ3:

In the search for answers to RQ3, most of the articles dealt with the issue of wireless charger solutions for Wireless Power Transfer (WPT) (7) and solutions for the design of an EDLC (3). Other articles dealt with the optimization of the MESN solution for ESs (3) and the design of the battery charger for electric scooters (6).

RQ4:

In order to find the answer to RQ4, articles were examined that dealt with the connection between the operation of electric scooters and environmental protection (2), as well as the elimination of accidents and injuries during the operation of ESs (2), ES operation, IT development, data security, the provision of visualization within ES operation (service and maintenance), the IoT, and cloud computing

RQ5:

In the search for answers to RQ5, articles were found describing the optimization of resources and services through monitoring and communication technologies in SCs (2), the implementation of Smart Metering in Smart Homes (2), the use of wireless networks and long-distance data transmission in SCs, the localization of persons and objects in SCs, and the prediction of electricity consumption in connection with e-transportation in SCs using monitoring and modelling of the behavior of residents for realistic suggestions for predicting electricity consumption in SCs.

Future research should focus on the development of charging stations and the investigation of models of the behavior of conventional and wireless batteries in connection with the operation of PLEVs in SCs, their sharing, visualization, and monitoring using long-term measured data, and their analysis using SW tools within the IoT to ensure the long-range certainty.

In spite of all the answers obtained, there are also limitations in the present study. The defined inclusion and exclusion criteria limited the scope of this study. Consequently, this systematic review does not provide the details of the described technological systems that do not include environmental parameters. Additionally, publications were retrieved from only one database (Web of Science) [136], and the search was limited to publications between 2008 and 2022.

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## Abbreviations

| | |
|---|---|
| AEMS | Adaptive Energy Management Strategy |
| AER | All-Electric Range |
| ANN | Artificial Neural Network |
| BC | Battery Charger |
| BEV | Battery Electric Vehicle |
| BLDC | Brushless DC electric motor |
| BMS | Battery Management System |
| CEV | Compact Electric Vehicle |
| CS | Charging Station |
| DC–DC | Direct Current–Direct Current |
| DFN | Doyle–Fuller–Newman |
| DSES | Dockless Shared Electric Scooters |
| EC | Electric Capacitor |
| ECE | Energy Conversion Efficiency |
| ECM | Electronically Commutated Motor |
| ECMS | Equivalent Consumption Minimization Strategy |
| EDLC | Electric Double-Layer Capacitor |
| EEC | Electronic Engine Control |
| EESS | Electrical Energy Storage System |
| EIS | Electrochemical Impedance Spectroscopy |
| ERAE | accurate Remaining Available Energy |
| ERCE | battery Remaining Chemical Energy state |
| ERDE | Remaining Discharge Energy |
| ERP | Electric Range Prediction |
| ES | Electric Scooter |
| ESCA | E-Scooter Chargers' Allocation |
| EV | Electric Vehicle |
| EVCS | Electric Vehicle Charging Station |
| FC | Fast Chargers |
| FPA | Flower Pollination Algorithm |
| FRGM | Fractional Grey Model |
| HESS | Hybrid Energy Storage System |
| HEV | Hybrid Electric Vehicles |
| HVLIB | High-Voltage Lithium Ion Battery |
| ICT | Information and Communication Technologies |
| IoT | Internet of Things |
| IT | Information Technology |
| KDE | Kernel Density Estimation |
| KF | Kalman Filter |
| LAB | Lead Acid Batteries |
| LELB | Liquid Electrolyte Lithium ion Batteries |
| LEV | Light Electric Vehicle |
| LIB | Lithium Ion Battery |
| LIPB | Lithium Ion Phosphate Battery |
| LoRaWAN | Long-Range Wide Area Network |
| MaaS | Mobility-as-a-Service |
| MEP | Mobilita a Energetická Produktivita |
| MESN | Mobile Energy Storage Network |
| MILP | Mixed-Integer Linear Programming |
| ML | Machine Learning |
| MM | Micro-Mobility |
| MMC | Modular Multilevel Converters |
| MMQUAL | Micro-Mobility QUALity |
| MPC | Model Predictive Control |
| NMPC | Nonlinear Model Predictive Control |

| | |
|---|---|
| NN | Neural Network |
| OCPP | Open Charge Point Protocol |
| OML-SOCE | Optimal Machine-Learning-based SOC Estimation |
| OMS | Open Metering Specification |
| P2P | Peer-to-Peer |
| PLEV | Personal Light Electric Vehicle |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PV | Photovoltaic Panel |
| RT | Real-Time |
| RUL | Remaining Useful Life |
| SBRP | School Bus Routing Problem |
| SC | Smart Cities |
| SECM | Simplified Equivalent Circuit Model |
| SG | Smart Grids |
| SH | Smart Home |
| SLELB | Solid–Liquid Electrolyte Lithium ion Battery |
| SM | Smart Metering |
| SOC | State Of Charge |
| SOE | State Of Energy |
| SOH | State Of Health |
| SRUKF | Square-Root Unscented Kalman Filter |
| SSA | Salp Swarm Algorithm |
| SSAE | Stacked Sparse Auto Encoder |
| SS-WPT | Series–Series Wireless Power Transmission |
| SVM-DTC | Space Vector Modulation for Direct Torque Control |
| TEM | Transactive Energy Management |
| THD | Total Harmonic Distortion |
| TNC | Transportation Network Companies |
| UPF | Unscented Particle Filter |
| V2G | Vehicle to Grid |
| V2H | Vehicle to Home |

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