Smart Charging and V2G Integration for Milan’s Shared Electric Mobility

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Abstract
This study investigates the potential of AI-enabled smart charging and Vehicle-to-Grid integration to support sustainable shared electric mobility because of their importance in reducing transport-related emissions, improving fleet availability, increasing charging efficiency, and strengthening data-driven urban energy management. The main objective is to evaluate how smart charging and V2G can enhance the environmental, functional, and technical performance of shared electric mobility through the case of Milan, Italy. To achieve this objective, the study combines a Litmap-based literature context with an analytical case-study model based on three indicators: transport-related emission reduction, improvement in urban-use efficiency, and intelligent data-processing capability. The results showed that Milan’s annual mean NO_2 concentration decreased from 34 µg/m³ in 2024 to approximately 32 µg/m³ in 2025, representing a 5.88% reduction. The average traffic congestion index also declined slightly from 27.68 to 27.58, corresponding to a 0.36% improvement in urban-use efficiency. The city demonstrated an advanced level of intelligent data-processing capability through integrated urban platforms, shared-mobility monitoring, MaaS services, electric-fleet analysis, and V2G decision-support applications. However, full citywide autonomous AI-controlled charging and bidirectional energy exchange were not verified during the study period. The analytical model recorded a final score of 40.00 out of 100, indicating an unsatisfactory overall impact. The findings indicate that Milan has strong digital, institutional, and infrastructural foundations for AI-enabled smart charging and V2G, but more integrated real-time control, direct carbon-emission monitoring, renewable-energy coordination, and operational bidirectional charging are required to achieve measurable environmental and mobility benefits at the citywide operational level.

Keywords: Smart charging, Vehicle-to-Grid, Shared electric mobility, Charging infrastructure, Urban sustainability, Mobility as a Service.

1. Introduction

Shared electric mobility has emerged as an important component of sustainable urban transportation, combining the environmental advantages of vehicle electrification with the operational and social benefits of shared mobility. Electric-vehicle sharing allows users to access electric cars for short periods without assuming the financial and operational responsibilities associated with private vehicle ownership. These services are generally managed through digital mobility platforms that coordinate vehicle reservations, user authentication, payment, parking, and charging operations. The rapid development of car-sharing services in major European cities reflects growing demand for flexible transport alternatives and the increasing role of digital platforms in urban mobility management [1], [2].

From an urban-planning perspective, shared electric vehicles can support reductions in private-car ownership, fossil-fuel consumption, local air pollution, carbon emissions, traffic noise, and parking demand. They can also improve access to mobility for users who do not own private vehicles and provide an additional transport option for short and occasional journeys. Nevertheless, these benefits depend on how shared services interact with public transport, walking, cycling, parking regulations, and travel behaviour. Shared electric mobility produces stronger sustainability outcomes when it replaces private vehicle use rather than public transport or active mobility [2].

The effectiveness of electric-vehicle sharing also depends on the availability, location, capacity, and reliability of charging infrastructure. Shared fleets require coordinated charging because vehicles must remain sufficiently charged and geographically available to meet changing user demand. Centralized fleet platforms can combine trip information, vehicle locations, battery states, charging-point availability, and electricity prices to determine when and where vehicles should charge. Intelligent fleet management therefore links vehicle dispatching, spatial rebalancing, and charging scheduling within a single operational process [3].

Artificial intelligence can further improve this process through mobility-demand forecasting, electricity-load prediction, battery monitoring, dynamic pricing, and automated charging decisions. Smart charging allows electricity consumption to be shifted away from peak-demand periods and aligned with periods of lower electricity prices or greater renewable-energy availability. Vehicle-to-Grid technology extends this model by enabling bidirectional electricity exchange, allowing electric vehicles to store energy and return part of it to the grid when required. This capability can improve grid flexibility, reduce peak loads, support distributed renewable generation, and create additional economic value for fleet operators [4].

Milan provides a relevant case for examining these relationships because the city combines shared electric-mobility services, an expanding charging network, smart-parking systems, low-emission zones, open-data platforms, and energy-management initiatives. The integration of these systems creates a suitable foundation for applying AI-enabled smart charging and future V2G services. Accordingly, this study evaluates how artificial intelligence and V2G integration could improve the environmental, operational, and technical performance of shared electric mobility in Milan.

2. Research Context Based on the Litmap

The Litmap analysis presented in Figure. 1 illustrates the chronological and thematic development of research on smart charging, Vehicle-to-Grid integration, shared mobility, and sustainable urban transport. The mapped literature is organised into five interrelated clusters: challenges and innovations in urban transportation, shared mobility and Mobility as a Service, smart-city strategies and social sustainability, sustainable urban mobility and charging infrastructure, and V2G and energy management. The map demonstrates a gradual transition from operational studies of ridesharing and fleet management toward integrated approaches combining transport electrification, digital platforms, renewable energy, and intelligent urban infrastructure. This development reflects the wider international transition toward sustainable cities and low-carbon mobility systems [5], [6], [7], [8].

The first cluster concerns the operational challenges and innovations associated with shared urban transportation. Agatz et al. (2010a) and Agatz et al. (2010b) investigated the role of optimisation in coordinating passenger requests, vehicle routes, and available capacity within dynamic ride-sharing systems [9], [10]. George and Xia (2011) examined the relationship between fleet size and service availability, while Li and Chung (2020) introduced robust optimisation and clustering methods for managing ridesharing under travel-time uncertainty [11], [12]. Other studies demonstrated that shared-mobility performance depends on appropriate fleet dimensions, tariff design, integration with public transport, and users' intentions to reuse the service [13], [14].

These operational challenges are directly relevant to Milan. Bruglieri et al. (2014) examined vehicle relocation in a one-way electric vehicle-sharing system and showed that uneven travel patterns can create spatial imbalances between vehicle supply and user demand [15]. Bignami and Rogel (2017) assessed condominium car sharing as a locally adapted model of sustainable mobility [16], while Realini et al. (2020) estimated the potential of ride sharing across the Milan metropolitan area [17]. Dispenza et al. (2017) also demonstrated how multipurpose infrastructure can connect electric mobility, energy systems, and smart-city services. These studies indicate that Milan has established experience in shared electric mobility, but continues to face challenges involving fleet balancing, charging-location planning, and service availability [18].

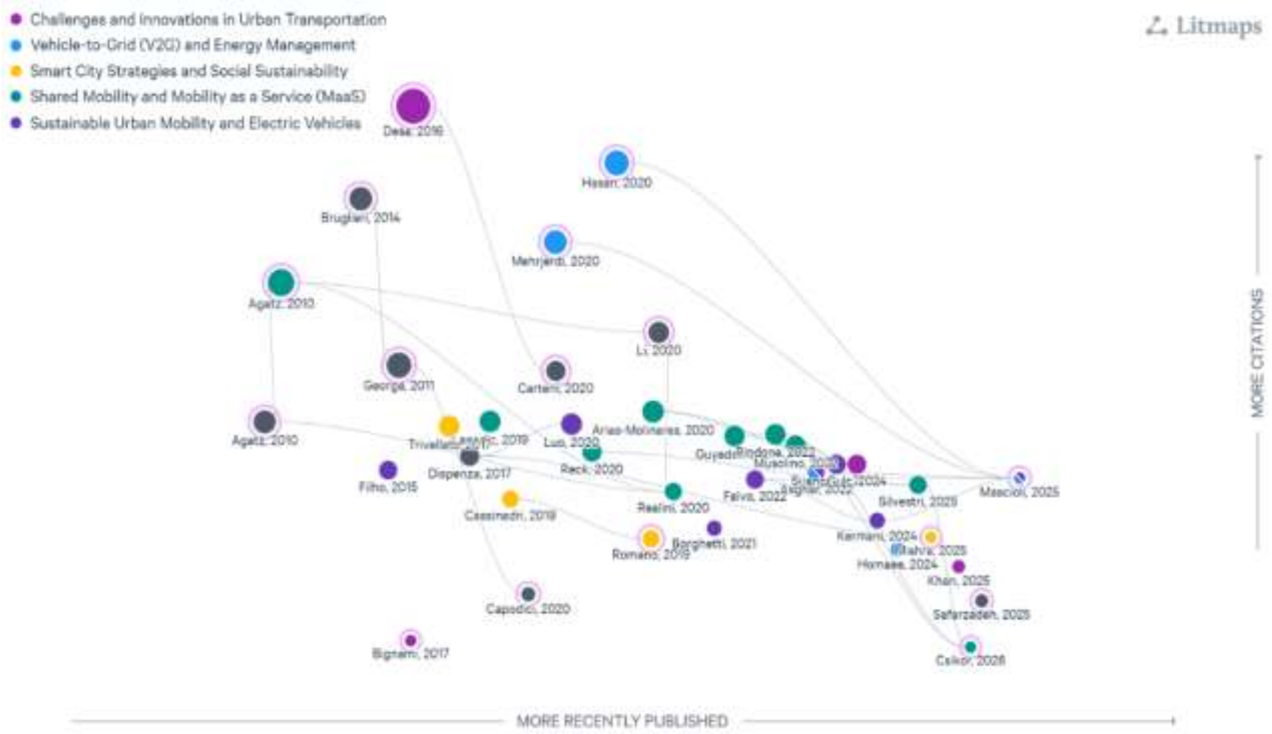

Figure . 1. Research Context [Author].

The second cluster addresses shared mobility and Mobility as a Service. The literature shows that shared mobility has developed from independent car-sharing and ride-sharing services into digitally integrated mobility systems combining public transport, cycling, shared vehicles, payment services, and journey-planning applications. Lagadic et al. (2019) highlighted the importance of financially viable business models and high fleet-utilisation levels [19], while Arias-Molinares and García-Palomares (2020) identified shared mobility as a central component of MaaS development [20]. Reck and Axhausen (2020) demonstrated that MaaS packages should reflect actual user preferences [21], whereas Guyader et al. (2021) argued that shared mobility supports sustainability when it complements public and active transport rather than generating additional motorised trips [22]. Supply- and demand-oriented studies further emphasised the need for coordination among service providers, public authorities, and users [23], [24].

Milan represents an important recent application within this cluster. Silvestri et al. (2025) examined the uptake of MaaS bundles in Milan and demonstrated the growing relevance of integrated mobility packages [25]. Nevertheless, most Milan-based studies concentrate on user behaviour, vehicle relocation, service design, and multimodal integration. They provide limited analysis of how shared electric fleets could simultaneously satisfy mobility demand and participate in electricity-system management.

The third cluster concerns smart-city strategies and social sustainability. Trivellato (2017) argued that Milan's smart-city development should combine technological innovation with social inclusion, institutional coordination, and citizen participation [26]. Cassinadri et al. (2019) developed this perspective through the Sharing Cities programme, which integrated shared e-mobility, smart parking, building renovation, environmental monitoring, and urban digital platforms [27]. Comparable smart-energy demonstrations showed that digital control and connected infrastructure can coordinate buildings, local energy generation, and consumption within wider urban systems [28]. These studies indicate that smart mobility should not be evaluated exclusively through technical efficiency, but also through accessibility, governance, public acceptance, and social value.

The fourth cluster focuses on sustainable urban mobility, electric vehicles, and charging infrastructure. Research indicates that transport electrification can reduce emissions and noise, although its environmental performance depends on the electricity mix, charging-station distribution, and integration with public and shared transport. Luo and Qiu (2020) identified charging-station location as an important urban-planning issue [29], while Cartenì et al. (2020) assessed the sustainability contribution of electric public-transport fleets [30]. Falvo et al. (2022) reviewed the technological development of electric vehicles and charging stations [31], whereas Kermani et al. (2024) identified regulatory, economic, spatial, and grid-capacity challenges affecting charging-infrastructure deployment [32]. Research conducted in the Italian context also emphasised the importance of advanced energy-storage solutions for maintaining fleet reliability and managing future electricity demand [33].

The fifth cluster examines V2G, Vehicle-to-Everything, and energy management. Mehrjerdi and Hemmati (2020) demonstrated that electric-vehicle batteries can be coordinated with renewable-energy resources to improve local energy management and system resilience [34]. Hasan et al. (2020) highlighted the cybersecurity and communication requirements of connected V2X platforms [35], while Asghar et al. (2022) reviewed the technical opportunities and limitations associated with integrating electric vehicles into smart grids [36]. Recent research has expanded this discussion from conventional V2G applications toward flexibility services at household, community, building, and electricity-grid levels [37], [38].

Within Milan, Borghetti et al. (2021) examined the potential application of V2G technology in ATM electric-bus depots [39]. This application is significant because scheduled electric fleets remain parked for predictable periods, enabling charging and discharging processes to be coordinated without necessarily disrupting transport services. The study demonstrates that electric fleets can operate as both mobility assets and distributed energy-storage resources when vehicle timetables, battery states, charging requirements, and grid conditions are jointly managed. However, its focus remains limited to public e-bus depots rather than the broader shared-mobility system.

The most recent literature introduces artificial intelligence and decentralised optimisation into electric-vehicle charging and grid integration. Suanpang and Jamjuntr (2024) applied multi-agent reinforcement learning to optimise charging recommendations [40], while Khan et al. (2025) proposed a decentralised framework integrating electric-vehicle charging, renewable-energy optimisation, and electricity-grid management. These approaches can process real-time information related to travel demand, vehicle location, battery state, energy prices, charger availability, and renewable-energy generation. They therefore provide a technical basis for coordinating the transport and energy functions of shared electric fleets [41].

Overall, Litmap reveals substantial development within the individual research clusters but limited integration among them. Milan-specific studies have addressed electric-vehicle relocation, condominium car sharing, ride-sharing potential, smart-city platforms, MaaS adoption, and V2G applications in electric-bus depots. However, limited research combines smart charging, bidirectional energy exchange, shared-fleet operation, and urban sustainability within a unified analytical framework.

3. Research Gap

The Litmap Figure .2shows that research on shared mobility, smart charging, V2G, MaaS and sustainable urban transport has developed through largely separate research streams. Shared-mobility studies mainly address fleet relocation, service availability and user behaviour, while V2G research focuses on grid flexibility, renewable-energy integration and battery management (Bruglieri, Colorni and Luè, 2014; Homaee et al., 2024; Mascioli et al., 2025). In Milan, previous studies have examined car sharing, ride sharing, MaaS, smart-city initiatives and V2G applications in electric-bus depots [17], [27], [25], [39]. However, limited research integrates smart charging, bidirectional energy exchange, artificial intelligence and shared-fleet management within one sustainability framework.

Figure . 2. Research Gap LITMAP [Author].

The present study addresses this gap by evaluating the potential contribution of smart charging and V2G integration to sustainable shared mobility in Milan. The environmental dimension considers carbon-emission reduction and renewable-energy utilisation. The functional dimension examines vehicle availability, charging accessibility, fleet balancing and responsiveness to mobility demand. The technical dimension evaluates real-time data processing, intelligent charging schedules, interoperability, battery management and bidirectional energy exchange. By connecting the five Litmap clusters, the study assesses whether Milan's mobility policies, smart-city platforms, charging infrastructure and electric fleets provide a suitable foundation for advanced AI-supported charging and V2G applications.

4. Methodology

4.1. Research Design

This study adopts an analytical case-study methodology to evaluate the potential contribution of smart charging and Vehicle-to-Grid integration to sustainable shared mobility in Milan. The analytical period covers 2024–2025, with 2024 treated as the baseline year and 2025 as the comparison year. This temporal structure enables the study to assess changes in environmental performance, mobility efficiency and technological capability during the selected period.

The study converts qualitative and quantitative evidence into comparable scores across three dimensions: environmental performance, functional efficiency and technological intelligence. Indicator-based assessment, weighting and score aggregation are commonly applied to evaluate the impacts of smart-city projects and compare their contribution to urban sustainability objectives [42].

Data are obtained from peer-reviewed studies, Milan mobility and energy reports, charging-infrastructure information and available urban datasets for 2024 and 2025. Project-level data are prioritized, while city-level indicators are used as proxies when direct data are unavailable. Evidence from different sources is compared to reducing the effect of data limitations and improving the reliability of the assessment.

4.2. Evaluation Indicators and Weights

The analytical model comprises three indicators:

1. Carbon-emission reduction, representing environmental performance
2. Urban-use efficiency improvement, representing functional performance
3. Intelligent data-processing capability, representing technological performance

Each indicator is scored from 0 to 4. Carbon-emission reduction and urban-use efficiency are assigned 35 points each, while intelligent data-processing capability is assigned 30 points. The maximum final score is therefore 100 points.

The weighting structure gives equal importance to environmental and functional outcomes. Technological intelligence receives slightly lower weight because it acts as an enabling factor that supports emission reduction, fleet coordination and efficient charging. Although the indicators are informed by smart-city and electric-mobility literature, their weights and thresholds were defined by the researcher for this comparative assessment.

4.3. Calculation of Indicator Scores

The weighted score for each indicator is calculated as follows:

$$\text{Weighted indicator score} = \left(\frac{\text{Indicator score}}{4}\right) \times \text{Indicator weight}$$

The final score is calculated by summing the three weighted scores:

Final score = Carbon-emission score + Urban-use efficiency score + Intelligent data-processing score

4.3.1. Carbon-Emission Reduction

This indicator measures the change in carbon emissions between 2024 and 2025. It considers emission reductions associated with electric shared mobility, smart charging, renewable-energy utilization and bidirectional energy exchange. Urban greenhouse gas assessments commonly estimate emissions by combining activity data, such as electricity consumption and vehicle kilometers', with relevant emission factors [43]. The scoring criteria used to evaluate the carbon-emission reduction are presented in Figure . 3.

The reduction percentage is calculated as follows:

$$\text{Reduction percentage} = \left[\frac{\text{Emissions in 2024} - \text{Emissions in 2025}}{\text{Emissions in 2024}}\right] \times 100$$

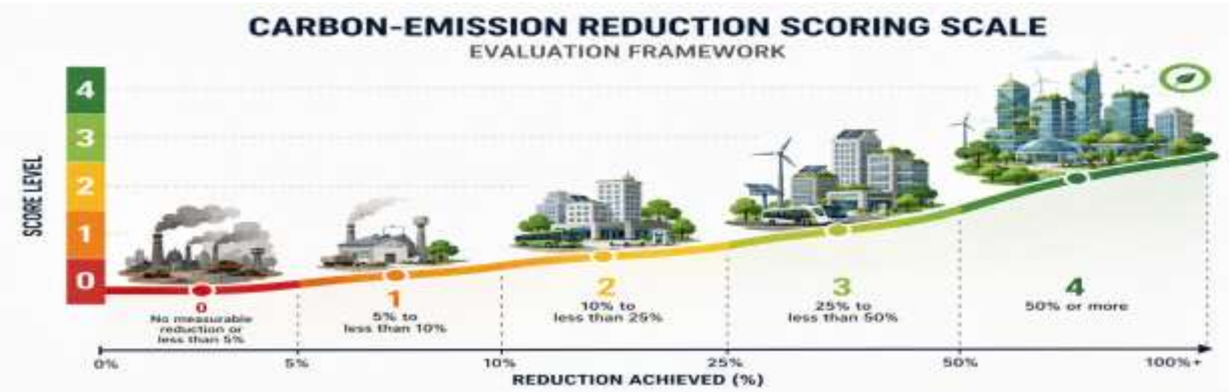

Figure . 3. Scoring scale for carbon-emission reduction [Author].

Electricity consumption, vehicle kilometres, fuel substitution, renewable-energy use and charging patterns are prioritised. City-level emission data may be used as contextual evidence when project-level information is unavailable.

4.3.2. Urban-Use Efficiency Improvement

This indicator evaluates changes in the functional performance of Milan's shared-mobility system between 2024 and 2025. It considers vehicle availability, charging accessibility, fleet utilisation, fleet balancing, charging downtime, service coverage and responsiveness to mobility demand.

For variables in which a decrease represents improvement, such as charging time, waiting time or vehicle shortages, the following equation is applied:

$$\text{Improvement percentage} = \left[\frac{\text{Value in 2024} - \text{Value in 2025}}{\text{Value in 2024}}\right] \times 100$$

The selected variable must be measured consistently in both years. The use of standardised indicators and baseline comparisons supports transparent evaluation of smart-city interventions [42]. Figure . 4 shows the scoring scale used to assess the percentage improvement in urban-use efficiency.

Figure . 4. Scoring scale for urban-use efficiency improvement [Author].

4.3.3. Intelligent Data-Processing Capability

This indicator evaluates the ability of Milan's smart charging and V2G system to collect, analyse and use mobility and energy data during 2024–2025. The assessment considers whether the system merely collects data or uses them for real-time decision-making, prediction and automated optimisation.

Relevant functions include monitoring vehicle locations, battery state of charge, charging-station availability, electricity prices, grid demand and renewable-energy generation. Advanced functions include mobility-demand prediction, automated charging schedules, battery-health management, fleet balancing and bidirectional energy exchange.

Smart charging systems depend on communication, real-time monitoring and optimisation methods to coordinate charging demand, reduce grid impacts and support renewable-energy integration [44], [45]. Figure . 5. shows score of 4 requires evidence that the system can predict mobility or energy demand and automatically optimise charging, discharging, vehicle availability and grid interaction.

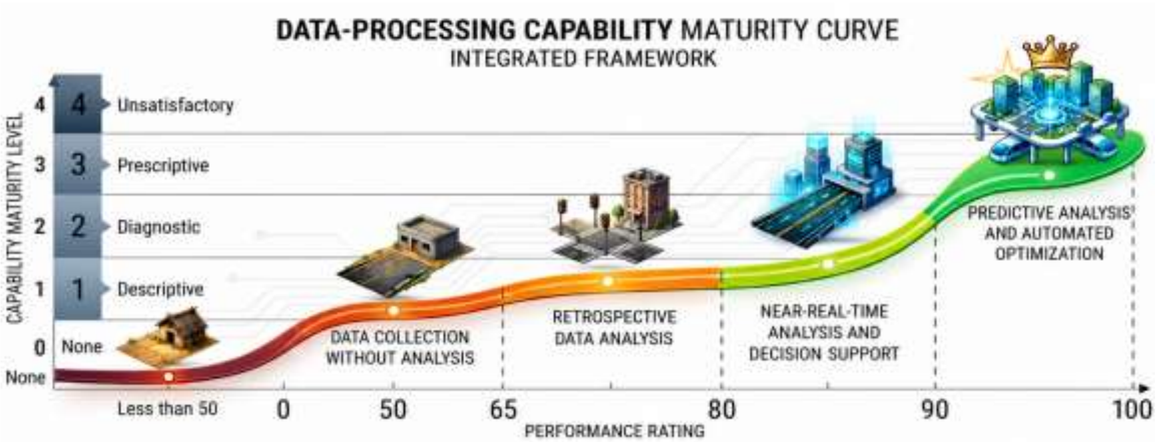

Figure . 5. Scoring scale for Intelligent Data-Processing Capability [Author].

4.4. Final Classification

The final score Figure . 6 represents Milan's combined environmental, functional and technological performance during 2024–2025.

These categories constitute a researcher-developed analytical scale rather than internationally standardised thresholds. They provide a structured method for evaluating whether Milan's electric fleets, charging infrastructure and smart-city platforms offer a suitable foundation for AI-supported smart charging and V2G integration.

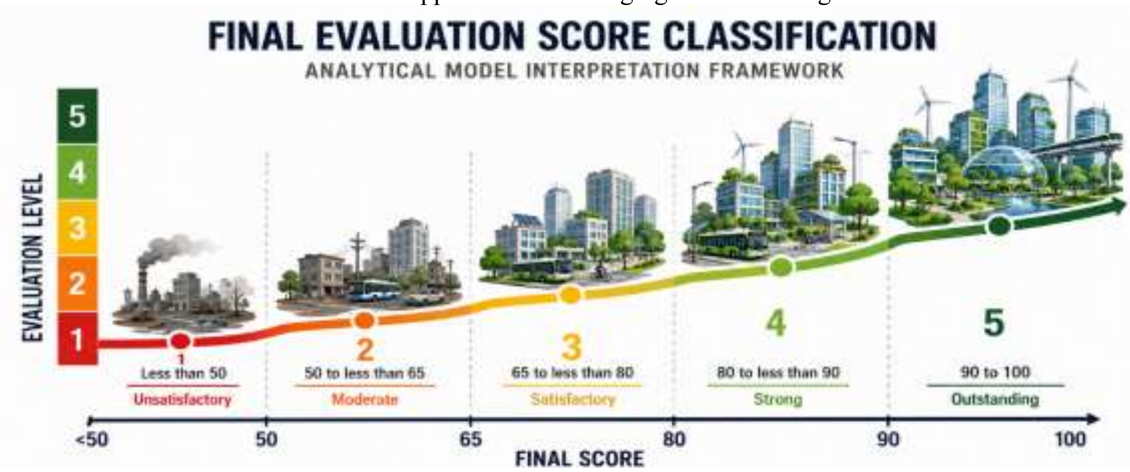

Figure . 6. Classification of the final evaluation score [Author].

5. The Electric Vehicles mobility and Infrastructures

Electric vehicle sharing enables users to access electric cars for short periods without owning them. These services may operate through station-based, free-floating, or peer-to-peer models and depend on digital platforms, parking facilities, fleet-management systems, and accessible charging infrastructure [46].

From a municipal perspective, EV sharing can reduce private-car ownership, support occasional travel, and complement public transport. Its effectiveness depends on fleet availability, pricing, service coverage, and whether shared vehicles replace private-car trips rather than walking, cycling, or public transport journeys [22], [47], [48].

The environmental benefits include lower operational emissions, reduced noise, and decreased dependence on fossil fuels. However, the total impact depends on the electricity mix, vehicle production, fleet utilization, and changes in travel behaviour. The greatest benefits occur when shared EVs reduce private ownership and support multimodal transport [49].

Smart charging and V2G can extend the role of shared EV fleets beyond transport. Smart systems can schedule charging according to electricity prices, renewable-energy availability, grid demand, and expected vehicle use. V2G can also allow parked vehicles to return electricity to the grid, supporting peak-load reduction and renewable-energy integration [50].

In Milan, EV sharing can therefore support sustainable mobility, reduce environmental impacts, and provide flexible energy-storage capacity. Its success requires coordinated planning of vehicles, charging stations, parking, digital platforms, public transport, and energy systems.

5.1. Charging Basics

Electric Vehicle Supply Equipment (EVSE) represents the principal interface between the electricity network and an electric vehicle. It supports the safe transfer of electrical energy while enabling monitoring, authentication, payment, communication and charging control. The effectiveness of EV charging infrastructure therefore depends not only on the charger itself, but also on its integration with the local electricity network, parking facilities, digital platforms and user services. Charging infrastructure should consequently be planned as a coordinated urban network rather than as isolated installations [51], [52].

EV charging is generally classified into AC Level 1, AC Level 2 and DC fast charging. Level 1 uses a conventional low-voltage residential outlet and is mainly suitable for long-duration home charging. Level 2 provides higher charging power and is commonly installed in homes, workplaces, residential buildings and public parking facilities. DC fast charging converts electricity within the charging unit and supplies direct current to the battery, making it more appropriate for highway corridors, transit facilities and locations where vehicles remain parked for short periods. Actual charging duration varies according to battery capacity, state of charge, charger power and the vehicle’s maximum charging rate [51], [53].

The spatial distribution and design of charging stations strongly influence their usability and contribution to electric-vehicle adoption. Site planning should consider proximity to the electricity supply, parking-space dimensions, pedestrian circulation, visibility, lighting, cable management, safety and accessibility for users with disabilities. Public charging networks are particularly important for residents without private parking, while fast-charging facilities can reduce waiting time and support longer journeys. Research also shows that users value charging speed, reliability and convenient access more than the simple numerical expansion of charging points [52], [54], [55].

Accordingly, effective EVSE deployment requires coordination among municipalities, electricity providers, property owners, transport authorities and charging operators. A balanced network should combine residential, workplace, public and rapid-charging facilities while maintaining technical compatibility, user accessibility and grid reliability. This integrated approach supports wider EV adoption and creates the infrastructure foundation required for smart charging and future Vehicle-to-Grid applications [51], [52].

5.2. Site Selection and Design of EV Charging Infrastructure

The selection of Electric Vehicle Supply Equipment locations requires a multi-criteria assessment that balances user demand, transport accessibility, electrical-grid capacity, installation cost and urban conditions. Suitable sites should be located near major traffic routes, residential and commercial areas, public transport facilities and destinations where vehicles remain parked for sufficient periods. Planning should also consider driver behaviour and range anxiety because technically feasible locations may remain ineffective when they do not correspond with users’ travel patterns and charging preferences [56], [57], [58].

Connection to the electricity network represents a central technical and economic factor. Sites located close to adequate power supplies generally require less cabling, trenching and electrical upgrading. The selected charging level must also correspond with grid capacity, expected parking duration and charging demand. Existing buildings and parking facilities may require dedicated circuits, upgraded panels or load-management systems, particularly when several vehicles charge simultaneously. Smart charging can reduce peak demand by distributing charging loads across time and available electrical capacity [51], [58].

Site design can be organized into three interconnected dimensions, such as Figure . 7: installation, access and operation. Installation factors include charger type, proximity to power, mounting method, parking-space dimensions, cable configuration, environmental conditions and physical hazards. Access factors include network connectivity, universal accessibility, proximity to building entrances and pedestrian routes, lighting, signage and visibility. Operational factors include metering, pricing, host–operator responsibilities, expected parking duration, maintenance and provision for future expansion. Addressing these dimensions together improves safety, usability and long-term system performance [56], [58].

An effective EV charging site should therefore provide more than an electrical connection. It should function as an accessible, visible and digitally connected component of the urban mobility system. Future-proof designs should allow additional chargers, higher power levels, renewable-energy integration and smart or bidirectional charging applications without requiring major reconstruction. This integrated approach supports user convenience, reduces infrastructure costs and strengthens the long-term adaptability of charging networks [51].

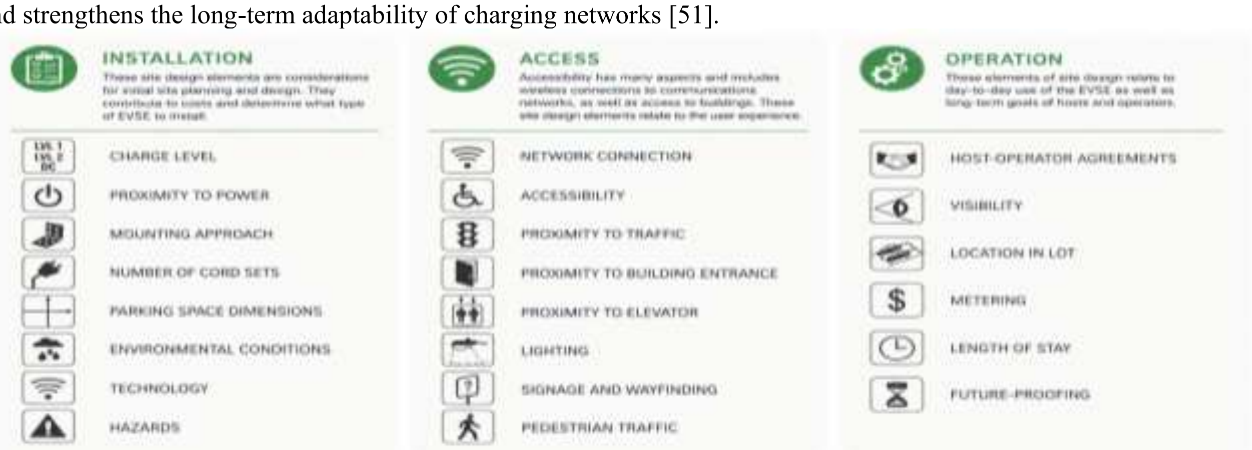

Figure . 7. Site design elements [author]

Effective EVSE planning depends on five interconnected interfaces that determine charger installation, operation, accessibility, and integration with urban and energy systems as shown Figure . 8.

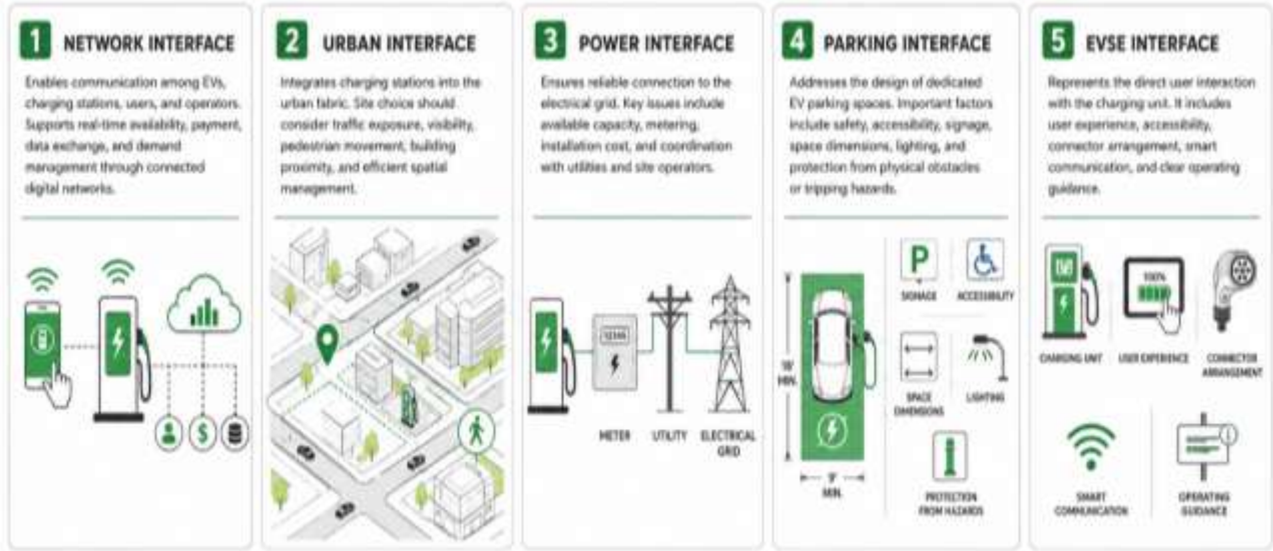

Figure . 8. Five Key Interfaces for EV Charging Infrastructure [Author]

a. Network Interface
Connects chargers with users, operators, payment systems and utilities. It supports metering, billing, monitoring, fault detection and smart charging [51].

b. Urban Interface
Integrates charging stations with land use, transport networks and public spaces. Site selection should reflect demand, accessibility and proximity to key destinations [56].

c.Power Interface
Links EVSE to the electricity grid. It must consider grid capacity, transformer loading, peak demand and renewable-energy integration [50].

d. Parking Interface
Addresses parking dimensions, circulation, accessibility, lighting, signage and cable safety. Effective design improves convenience and reduces operational risks [52].

e.EVSE Interface
Covers the direct interaction between the user, vehicle and charger, including connectors, payment, instructions, charging level and equipment reliability [51].

6. Case Study: Smart Charging for Shared Electric Mobility in Milan

6.1. Urban Mobility and Environmental Context

Milan represents a relevant case for examining the integration of shared electric mobility, charging infrastructure and intelligent energy management. The city experiences high travel demand, dense vehicle circulation and persistent air-quality pressures, which have encouraged the municipality to adopt measures aimed at reducing private-car use and supporting public, active and shared mobility. Milan's Sustainable Urban Mobility Plan links transport accessibility, environmental performance and digital innovation, while its smart-city strategy integrates mobility services with energy systems, urban data platforms and citizen participation [27], [59].

The city's transition toward electric mobility should therefore be understood as part of a wider urban transformation rather than as the replacement of conventional vehicles alone. Electric fleets, charging points, shared-mobility platforms and low-emission regulations operate as interconnected components of Milan's sustainability strategy. This integrated context makes the city suitable for evaluating whether smart charging can improve fleet availability, reduce charging-related grid pressure and increase the environmental value of shared electric vehicles.

6.2. Low-Emission Zones and Regulatory Support

Milan applies a two-level urban access-management system through Area B and Area C , Figure . 9. Area B restricts the circulation of the most polluting vehicles across a large part of the municipality, while Area C combines emission-based access regulation with congestion charging in the central urban area. These measures aim to reduce high-emission traffic, improve public-transport performance and encourage the transition toward cleaner vehicles and mobility services [59], [60].

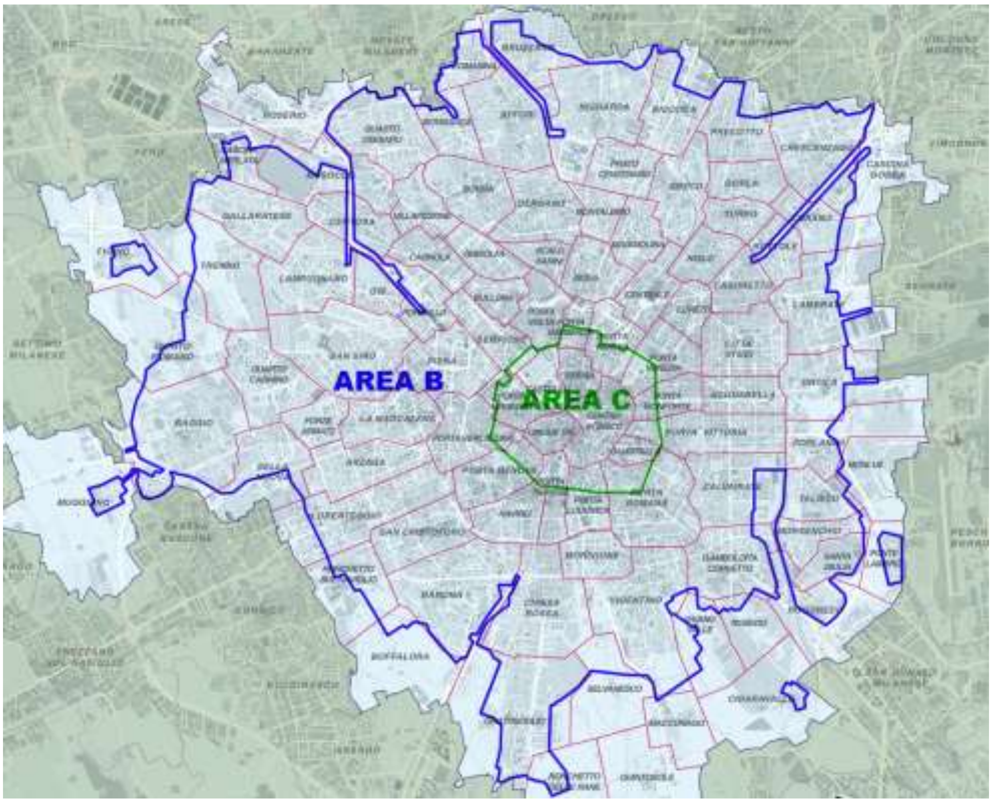

Figure . 9. Low-Emission Zones [61].

The two zones function as regulatory drivers for electric mobility. Restrictions on older internal-combustion vehicles operate as push measures, while access advantages and exemptions for electric vehicles act as pull incentives. This combination strengthens the attractiveness of electric and shared mobility, particularly for users who regularly travel to central and restricted areas. The continued reduction in entries to Area B and Area C also indicates that access regulation can influence vehicle use and encourage greater reliance on public transport, interchange facilities and sharing services [59].

6.3. Shared Electric Mobility and Digital Integration

Milan has developed several forms of shared mobility, including car sharing, bicycle sharing, scooter sharing and digitally integrated mobility services. The Sharing Cities programme provided an important experimental framework by combining electric car sharing, electric bicycles, charging infrastructure, smart parking, environmental monitoring and an Urban Sharing Platform. The programme followed a people–place–platform approach in which physical infrastructure, digital systems and stakeholder participation were developed together [27].

Earlier Milan-based studies also identified operational challenges associated with shared electric fleets. Bruglieri et al. (2014) showed that one-way electric car-sharing systems can develop spatial imbalances when vehicles accumulate in some locations and become unavailable in others. Battery state and charging requirements make this problem more complex because a vehicle may be physically present but unavailable for service due to insufficient charge. Smart charging should therefore be coordinated with fleet relocation, expected demand and vehicle availability rather than based only on electricity prices.[15]

The development of Mobility as a Service further strengthens the potential for integrated shared mobility in Milan. Silvestri et al. (2025) found that users placed high importance on public transport integration, real-time travel information, shared-vehicle availability, unified registration and electronic payment. These findings indicate that the effectiveness of shared electric mobility depends on digital integration and service reliability, both of which are also essential for AI-supported charging management [25].

6.4. Charging Infrastructure and Smart-Charging Requirements

The expansion of electric mobility requires a charging network that is spatially accessible, technically reliable and compatible with different vehicle and operator systems. In Milan, charging infrastructure has progressively expanded through municipal planning, private investment and smart-city projects. However, the effectiveness of the network depends not only on the number of chargers but also on their location, power level, availability, payment system and integration with fleet-management platforms, Figure . 10.

For shared electric fleets, uncontrolled charging can create operational and energy-system conflicts. Simultaneous charging during peak periods may increase local electricity demand, while poorly scheduled charging can reduce the number of vehicles available for users. Smart charging can address these problems by adjusting charging time and power according to battery state, expected trip demand, parking duration, grid conditions, electricity prices and renewable-energy availability. The required control process therefore links transport planning with energy management.

User experience also remains important. The source material identifies high charging prices, slow charging, insufficient territorial coverage, occupied or faulty chargers and complex digital payment procedures as barriers to public charging. These issues are consistent with international research showing that reliability, charging speed, accessibility and transparent payment systems strongly influence EV users' acceptance of public charging infrastructure [52], [54].

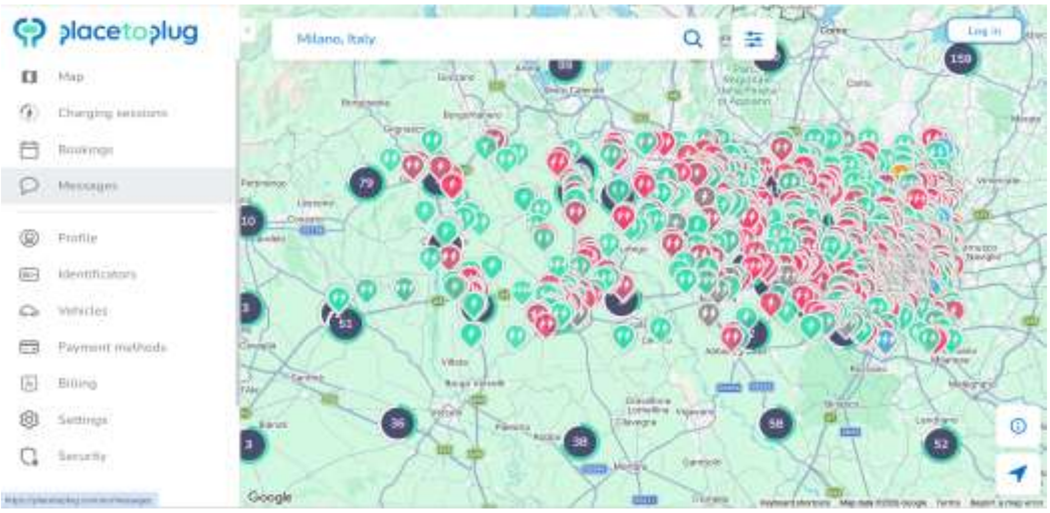

Figure . 10. Distribution of electric vehicle charging stations across Milan using the Placetoplug platform. [61].

6.5. Public-Transport Electrification and V2G Potential

Milan's public transport electrification programme provides the strongest applied basis for future smart charging and V2G integration Figure . 11. ATM has progressively replaced diesel buses with electric and hybrid vehicles as part of its Full Electric Plan. By the end of 2024, approximately 280 electric buses were operating on 23 urban routes, while the transition avoided around 5,000 tonnes of CO_2 during 2022–2024. ATM aims to electrify 50% of the city bus fleet by 2026 and continue toward full fleet electrification by 2030 [62].

Borghetti et al. (2023) assessed the V2G potential of electric buses located at the San Donato and Sarca depots. Their model prioritised passenger-service schedules and allowed buses to participate in V2G only when this would not delay their operating duties. The results indicated that the two depots could provide approximately 7–10 MW to the electricity grid, depending on the time and day, which corresponds to the electricity demand of about 2,300–3,300 households under the assumptions used in the study [39], [63].

This finding demonstrates that Milan's electric fleets can potentially operate as distributed energy resources as well as transport assets. Nevertheless, the results relate primarily to scheduled electric buses, whose operating and parking periods are predictable. Applying the same principle to shared electric cars would require more advanced forecasting because their locations, departure times and travel demand are less certain.

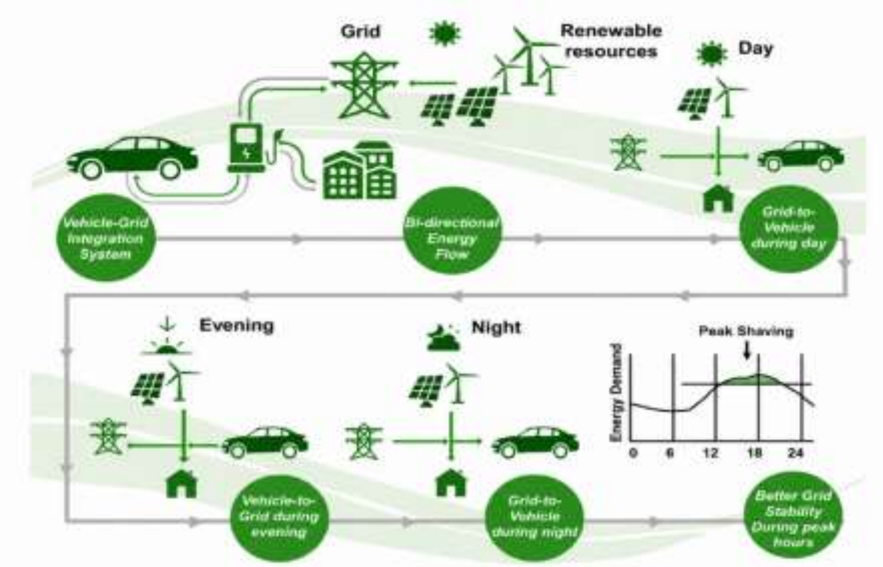

Figure . 11. Bidirectional energy flow in a vehicle-to-grid system across daytime, evening, night, and peak-demand periods.

7. Results and Discussion

The Milan case was evaluated over the period 2024–2025 using three principal indicators: transport-related emission reduction, improvement in urban-use efficiency, and intelligent data-processing capability. The indicators were assigned relative weights of 35, 35, and 30 points, respectively.

7.1. Evaluation of the Carbon-Emission Reduction Indicator

Directly comparable city-level CO_2 inventories were not available for Milan for both 2024 and 2025. Therefore, the annual mean nitrogen-dioxide concentration was adopted as an operational proxy for changes in traffic-related combustion emissions. NO_2 is strongly associated with road-transport activity in urban areas; however, it does not directly measure carbon dioxide. Consequently, the results represent changes in transport-related air-pollution performance rather than a verified reduction in total carbon emissions.

The *MobilitAria 2025* report recorded an annual mean NO_2 concentration of 34 µg/m³ in Milan during 2024. This value represented a 3% decrease in the citywide mean compared with 2023, while monitoring stations located near traffic corridors recorded a 5% reduction. These results indicate a gradual improvement in combustion-related air quality, although the concentration remained above stricter future European air-quality targets [65].

For 2025, the subsequent *MobilitAria* assessment recorded an annual mean NO_2 concentration of approximately 32 µg/m³. The citywide mean and traffic-station values decreased by approximately 6% compared with 2024. Traffic stations recorded about 33 µg/m³, while urban-background stations recorded approximately 29 µg/m³, confirming the continuation of the declining trend during the evaluation period [66].

The reduction rate was calculated as follows:

$$\text{Reduction Rate} = \frac{34 - 32}{34} \times 100 = 5.88\%$$

The calculated reduction of 5.88% falls within the evaluation category of more than 0% and less than 10%. Milan therefore receives one point out of four for this indicator as shown in Table 1.

$$\frac{1}{4} \times 35 = 8.75$$

Table 1. Evaluation of the Emission-Reduction Indicator in the Milan Case, 2024–2025

Evaluation item	Result
Indicator used	Annual mean NO_2 concentration
Indicator function	Operational proxy for traffic-related combustion emissions
Indicator value in 2024	34 µg/m³
Indicator value in 2025	32 µg/m³
Reduction-rate calculation	((34 − 32) ÷ 34) × 100 = 5.88%
Supporting traffic-station trend	Approximately 6% reduction
Evaluation criterion	Reduction greater than 0% and less than 10%
Score out of 4	1
Relative indicator weight	35 points
Weighted-score calculation	(1 ÷ 4) × 35 = 8.75
Weighted indicator score	8.75
Analytical interpretation	Limited but measurable improvement in traffic-related air pollution

The result demonstrates a modest improvement in Milan's traffic-related air quality. Nevertheless, it cannot be interpreted as an equivalent 5.88% reduction in CO_2 emissions. The environmental performance of electric mobility also depends on the electricity-generation mix, charging periods, vehicle utilisation, modal substitution, and the extent to which shared electric vehicles replace conventional private-car journeys.

Previous research has demonstrated that charging location and timing can significantly influence electricity demand and the emissions associated with electric-vehicle operation. Coordinating charging with grid conditions and renewable-energy availability is therefore essential for achieving greater environmental benefits [50].

7.2. Evaluation of the Urban-Use Efficiency Indicator

Urban-use efficiency was assessed using Milan's average Traffic Congestion Index. This indicator reflects the general level of pressure on the urban road network, with lower values representing improved traffic flow and more efficient use of transport infrastructure.

The Traffic Index annual data covering 2024 recorded an average congestion index of 27.68 for Milan. The maximum recorded value reached 92.97, and the city ranked nineteenth among the large cities included in the assessment [67].

For 2025, Milan recorded an average congestion index of 27.58. The maximum value increased to 109.45, while the city occupied the twenty-second position in the annual ranking. Although the average congestion level declined slightly, the increase in the maximum value indicates that severe short-term congestion events continued to occur [68].

Because congestion is a negative indicator, the improvement rate was calculated as follows:

$$\text{Improvement Rate} = \frac{27.68 - 27.58}{27.68} \times 100 = 0.36\%$$

As shown in Table 2, The reduction of approximately 0.36% represents a marginal improvement. Since the result falls within the range of more than 0% and less than 10%, the indicator receives one point out of four.

$$\frac{1}{4} \times 35 = 8.75$$

Table 2. Evaluation of Urban-Use Efficiency in the Milan Case, 2024–2025

Evaluation item	Result
Indicator used	Average Traffic Congestion Index
Indicator value in 2024	27.68
Indicator value in 2025	27.58
Improvement-rate calculation	((27.68 − 27.58) ÷ 27.68) × 100 = 0.36%
Maximum index in 2024	92.97
Maximum index in 2025	109.45
Annual rank in 2024	19th
Annual rank in 2025	22nd
Evaluation criterion	Improvement greater than 0% and less than 10%
Score out of 4	1
Relative indicator weight	35 points
Weighted-score calculation	(1 ÷ 4) × 35 = 8.75
Weighted indicator score	8.75
Analytical interpretation	Urban traffic efficiency remained broadly stable, with only marginal improvement

The result indicates that Milan did not experience a substantial improvement in citywide traffic efficiency during the evaluation period. The 0.36% reduction is too limited to demonstrate a significant transformation in road-network performance.

This finding does not prove that shared electric mobility or smart charging failed to improve individual services. Rather, it indicates that their effects were not sufficiently strong to produce a major measurable reduction in citywide congestion. Shared mobility may improve accessibility and vehicle utilisation without reducing total traffic when shared trips replace public transport, cycling, or walking instead of privately owned vehicles.

Research on Milan's one-way electric car-sharing system has shown that spatial imbalances can reduce service efficiency when vehicles accumulate in low-demand areas. Coordinating vehicle relocation with battery-charging requirements is therefore essential to maintain fleet availability and respond to changing demand patterns (Bruglieri et al., 2014).

Similarly, Milan-based research on Mobility as a Service has shown that users value public-transport integration, real-time information, vehicle availability, unified registration, route planning, and electronic payment. Shared mobility is therefore more likely to improve urban efficiency when it operates within an integrated multimodal system rather than as an isolated service [25].

7.3. Evaluation of the System's Intelligent Data-Processing Capability

Milan has established an advanced digital environment capable of supporting shared mobility, infrastructure monitoring, energy management, and future smart-charging applications. The Sharing Cities programme adopted a people–place–platform approach that connected electric mobility, smart parking, environmental monitoring, building-energy systems, and digitally managed urban services.

The Milan Urban Sharing Platform was designed to integrate information generated by different smart-city interventions and stakeholders. Its ecosystem-based structure supports technical and organisational interoperability through common standards, data-exchange mechanisms, and digital interfaces. This foundation allows municipal authorities, mobility operators, energy providers, and infrastructure managers to exchange and analyse urban information [27].

Milan's shared-mobility services also generate information concerning vehicle locations, booking patterns, parking behaviour, fleet distribution, and infrastructure availability. Research on MaaS in Milan confirms the importance of real-time traffic information, shared-vehicle availability, route optimisation, integrated accounts, and unified payments. These functions rely on continuous data collection and processing to improve service reliability and user experience [25].

A more direct example of intelligent energy processing is provided by Milan's electric-bus system. Borghetti et al. (2023) developed a quantitative V2G decision-support model for the city's public-transport operator. The model processes bus schedules, service requirements, vehicle availability, depot conditions, electricity demand, and the energy capacity available from parked electric buses.

The analysis of the San Donato and Sarca depots indicated that electric buses could potentially supply approximately 7–10 MW to the electricity grid, depending on the operating day and period. Under the assumptions adopted in the study, this capacity could serve approximately 2,300–3,300 households. The model therefore demonstrates how transport-operation data can be integrated with grid-support calculations without disrupting scheduled passenger services [39], [63].

Advanced artificial-intelligence techniques could extend these capabilities by processing battery state of charge, vehicle location, charger availability, electricity prices, expected departure times, traffic conditions, and charging demand. Multi-agent reinforcement-learning models can coordinate charging recommendations, reduce waiting times, minimise charging failures, and improve the distribution of vehicles across charging stations [40].

Moreover, uncontrolled charging may increase peak electricity demand, whereas coordinated charging and appropriately distributed infrastructure can reduce grid pressure and improve the environmental performance of electric mobility. Smart charging should therefore consider both the operational requirements of shared fleets and wider electricity-system conditions [50].

The available evidence indicates that Milan possesses:
- integrated digital platforms for smart-city applications;
- shared-mobility and MaaS data-processing capabilities;
- monitoring of vehicle distribution and service availability;
- interoperability between public and private operators;
- schedule-based analysis of electric fleets;
- V2G feasibility and energy-flow assessment;
- decision-support capability for mobility and energy management.

As summarized in Table 3, However, the available evidence does not confirm that Milan operated a fully autonomous citywide AI system during 2024–2025 that continuously controlled the charging and discharging of shared electric vehicles according to real-time mobility and electricity-grid conditions. The documented systems provide advanced monitoring, modelling, integration, and decision support, but complete closed-loop AI-V2G operation remains under development.

Milan therefore receives three points out of four for intelligent data-processing capability.

$$\frac{3}{4} \times 30 = 22.50$$

Table 3. Evaluation of Intelligent Data-Processing Capability in the Milan Case, 2024–2025

Evaluation item	Result
Documented data types	Mobility-service use, vehicle availability, traffic information, bus schedules, depot presence, infrastructure status, and electricity demand
Additional data required for full AI-V2G operation	Battery state, charger availability, electricity prices, renewable generation, expected departure time, and real-time grid conditions
Technologies used	Urban Sharing Platform, APIs, MaaS applications, digital fleet platforms, smart charging, and V2G decision-support models
Processing mechanism	Data integration, monitoring, timetable analysis, charging assessment, energy-flow calculation, and decision support
Analytical output	Improved mobility coordination, infrastructure management, charging planning, and assessment of grid-support potential
Processing level	Advanced integrated analysis and intelligent decision support
Main limitation	No verified citywide autonomous AI-controlled smart-charging and V2G system
Evaluation criterion	Intelligent analysis supporting decision-making without complete autonomous control
Score out of 4	3
Relative indicator weight	30 points
Weighted-score calculation	(3 ÷ 4) × 30 = 22.50
Weighted indicator score	22.50
Analytical interpretation	High digital and analytical readiness, but incomplete operational AI-V2G integration

7.4. Final Evaluation of the Milan Case, 2024–2025

The final score of 40.00 out of 100 indicates that Milan's smart charging and shared electric mobility experience achieved an unsatisfactory impact according to the proposed analytical model as shown in Table 4.

The case demonstrated a relatively advanced level of intelligent data-processing capability. However, the transport-related emission reduction and urban-use efficiency indicators achieved only limited improvement during the 2024–2025 assessment period, which reduced the overall evaluation score.

Table 4. Final Evaluation of the Milan Case, 2024–2025

Indicator	Score out of 4	Relative weight	Weighted indicator score
Transport-related emission reduction	1	35	8.75
Improvement in urban-use efficiency	1	35	8.75
Intelligent data-processing capability	3	30	22.50
Total	—	**100**	**40.00**

The emission-reduction indicator received a weighted score of 8.75 out of 35 points. Milan's annual mean NO_2 concentration declined from 34 µg/m³ in 2024 to approximately 32 µg/m³ in 2025, representing a reduction of 5.88%. Traffic-monitoring stations also recorded a decline of approximately 6%. This result indicates a limited but measurable improvement in traffic-related air pollution, rather than a directly verified reduction in CO_2 emissions (Kyoto Club and CNR-IIA, 2025; Tomassetti, 2026).

The urban-use efficiency indicator also received 8.75 out of 35 points. The average congestion index decreased from 27.68 in 2024 to 27.58 in 2025, producing an improvement of only 0.36%. This change indicates general stability rather

than a substantial improvement in road-network performance. The higher maximum congestion index in 2025 further shows that severe congestion episodes remained present (Traffic Index, 2025; Traffic Index, 2026).
The intelligent data-processing indicator received 22.50 out of 30 points. Milan possesses integrated smart-city platforms, MaaS services, shared-mobility data systems, and a documented V2G decision-support model for electric buses. These capabilities support data collection, operational analysis, charging assessment, infrastructure management, and grid-support calculations. Nevertheless, the citywide deployment of autonomous AI-controlled smart charging and operational bidirectional energy exchange was not conclusively documented during the evaluation period [25], [27], [39], [40], [63].
The final score of **40.00 out of 100** indicates an unsatisfactory overall impact according to the adopted evaluation scale. This classification does not imply that Milan lacks technological or institutional capacity. Instead, it reflects the limited environmental and traffic improvements recorded over the one-year assessment period and the difference between advanced digital readiness and the operation of a fully integrated AI-V2G system.
Milan's principal strength lies in its established shared-mobility services, interoperable digital platforms, multimodal integration, electric public-transport fleet, and V2G decision-support experience. Its main limitation is the lack of evidence showing that these components operate as a unified citywide system capable of continuously coordinating vehicle demand, battery availability, charging infrastructure, electricity prices, renewable-energy generation, and grid requirements.
Future assessments should incorporate comparable city-level CO_2 inventories, shared-fleet electricity consumption, vehicle kilometres travelled, charging-point utilisation, fleet availability, waiting times, modal-substitution rates, electricity returned to the grid, peak-load reduction, and renewable-energy participation. These indicators would provide a more direct assessment of the environmental, functional, and technical impacts of smart charging and V2G integration in Milan.

8. Conclusion

This study evaluated the potential contribution of AI-enabled smart charging and Vehicle-to-Grid integration to sustainable shared electric mobility in Milan during 2024–2025. The analytical model combined three dimensions: transport-related emission reduction, urban-use efficiency, and intelligent data-processing capability. The results reveal an uneven level of performance across these dimensions.
The environmental assessment showed that Milan's annual mean NO_2 concentration declined from 34 µg/m³ in 2024 to approximately 32 µg/m³ in 2025, representing a reduction of 5.88%. Although this indicates a measurable improvement in traffic-related air quality, it cannot be interpreted as an equivalent reduction in CO_2 emissions because NO_2 was used only as an operational proxy. More direct carbon-emission inventories are therefore required for future evaluation.
Urban-use efficiency improved only marginally. The average congestion index decreased from 27.68 to 27.58, producing an improvement rate of 0.36%. This result indicates relative stability rather than a substantial transformation in citywide traffic performance. Shared electric mobility may enhance accessibility, fleet utilisation, and multimodal connectivity, but its effect on overall congestion remains dependent on travel behaviour, modal substitution, fleet distribution, and integration with public transport.
Milan demonstrated its strongest performance in intelligent data processing. The city possesses integrated digital platforms, shared-mobility monitoring systems, MaaS applications, electric-fleet data, and V2G decision-support capabilities. These elements provide a strong foundation for coordinating mobility demand, charging schedules, vehicle availability, and grid interaction. However, full citywide autonomous AI-based charging and bidirectional energy exchange were not verified during the study period.
The final score of 40.00 out of 100 indicates limited overall performance according to the adopted evaluation scale. Nevertheless, Milan demonstrates substantial technological and institutional readiness. Future development should prioritise real-time AI optimisation, interoperable data exchange, renewable-energy integration, direct carbon monitoring, improved charger accessibility, and operational V2G deployment. These measures could transform Milan's existing digital capacity into measurable environmental, functional, and energy-system benefits.

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