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Public Policies for Electric Mobility and Renewable Energy: A Systematic Review of Opportunities, Challenges, and Perspectives

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Abstract: This systematic review examines the energy and mobility transition as a global imperative in the face of climate change, dependence on fossil fuels, and deteriorating urban air quality. Recognizing electric vehicles (EVs) and renewable energy sources (RES) as pillars for transport decarbonization, the study identifies persistent barriers: range anxiety, insufficient charging infrastructure, and high upfront costs for EVs; and intermittency and grid integration challenges for RES. Public policy plays a decisive role in overcoming these barriers by aligning incentives, infrastructure, and regulation. Key enabling technologies include Vehicle-to-Grid (V2G), which turns EVs into distributed storage assets, and second-life batteries for stationary storage, consistent with circular economy principles. The environmental advantage of EVs is tightly coupled to the electricity mix: when power generation is carbon intensive (e.g., coal), EV life-cycle emissions can be comparable to or higher than internal combustion engine vehicles (ICEVs). We synthesize evidence from 32 peer-reviewed studies (2020–2025) across multiple regions to identify effective initiatives, persistent obstacles, and emerging trends, providing actionable guidance for integrated, sustainable public policies.

Keywords: Vehicle-to-Grid; Battery Circular Economy; Charging infrastructure; Battery Swapping; Transport Decarbonization; Power Grid Mix; Business Models; Just Transition.

Abbreviations: EV, electric vehicle. RES, renewable energy source. V2G, vehicle-to-grid. GHG, greenhouse gas. ICEV, internal combustion engine vehicle.

1. Introduction

Global society is currently at a critical juncture, marked by the urgent need to address the consequences of climate change, the persistent dependence on fossil fuels, and the degradation of urban air quality (1–5). Fossil fuel-based mobility accounts for approximately 24% of global energy-related CO_2 emissions, with road transport being the main contributor (IEA, 2024). In this context, electric vehicles (EVs) and renewable energy sources (RESs), such as wind and solar, emerge as essential pillars for building a sustainable future (6,7).

In recent years, EV adoption has shown accelerated growth. In 2023, global sales surpassed 14 million units, representing 18% of total vehicle sales, with projections reaching 45% by 2030 if policies and incentives are expanded. However, large-scale adoption and effective integration with RESs still face significant challenges: range anxiety, limited charging infrastructure, high upfront costs, low public acceptance, intermittency of renewable generation, and constraints in storage capacity (3,8).

Studies indicate that well-structured policies can reduce the total cost of ownership of an EV by up to 30% and accelerate the expansion of charging infrastructure by more than 40% (Sang & Bekhet, 2015; Delgado et al., 2018; McKinsey, 2023). Moreover, integrated approaches between electric mobility and renewable generation, such as Vehicle-to-Grid (V2G) systems, can contribute to grid stability and optimize the use of clean energy (Simwaba & Qutieshat, 2025; Chapter 20 – Handbook of Power Electronics, 2024).

An analysis of international experiences reveals that countries with consistent incentive policies—such as direct purchase subsidies, tax benefits, infrastructure investments, and efficiency regulations—show EV adoption rates up to four times higher than the global average (Ayetor et al., 2022; Global Transport Scenarios 2050, 2023). Conversely, the absence of clear incentives or regulatory instability can create market uncertainty and delay private investments (Sang & Bekhet, 2015; 78101.pdf, 2024).

Given this scenario, this study aims to identify public policies and incentives that promote the adoption of electric vehicles and the development of associated infrastructure through a systematic literature review.

2.Theoretical Framework

Policies aimed at integrating renewable energy sources (RESs) and ensuring efficient grid management are essential for the advancement of electric mobility. Technologies such as Vehicle-to-Grid (V2G) enable electric vehicles (EVs) not only to consume energy but also to return it to the grid, enhancing system flexibility and stability (9–11). Additionally, the use of second-life batteries for stationary storage represents a promising solution to harness the residual capacity of traction batteries, reducing waste and mitigating environmental impacts (4,12)

Recent studies show that implementing V2G systems can reduce the need for grid expansion investments by up to 20% (3) and improve demand response capabilities, facilitating the integration of intermittent sources such as solar and wind (13). In the case of solar energy, for instance, integration with EVs allows for daytime charging with less impact on battery degradation, thereby extending battery lifespan (14).

Innovations in business models, such as peer-to-peer energy trading and vehicle aggregators, are fundamental to transforming existing sociotechnical systems (10). The application of circular economy principles to EV batteries,including reuse, repurposing, and recycling, can reduce the demand for primary raw materials and minimize environmental impacts (7,12). According to Blömeke et al. (2022), efficient recycling can recover up to 95% of metals such as nickel, cobalt, and lithium, alleviating issues related to scarcity and high costs.

Moreover, the deployment of second-life batteries in stationary storage systems could represent a multi-billion-dollar market by 2030, with the potential to reduce RES intermittency and optimize the use of clean energy.

Therefore, effective public policies must act in a coordinated manner: encouraging EV adoption while simultaneously directing investments toward the expansion of renewable generation. Projections indicate that if the growth of the electric fleet is not accompanied by a cleaner energy matrix, up to 40% of the potential emission reductions could be lost.

Given this scenario, it is necessary to understand not only the technologies and business models involved but also the role of public policies in enabling the integration between electric mobility and renewable energy sources. Accordingly, this research adopts a systematic literature review approach, aiming to (i) identify public policies and incentives that promote EV adoption and infrastructure; (ii) map the main challenges to scaling EV/RES integration; (iii) discuss technological trends (e.g., V2G, battery circularity, battery swapping) and business model innovation; (iv) analyze how the power generation mix conditions EV environmental performance; and (v) synthesize research gaps and convergences to inform future strategies.

3. Methodology

This study was developed using a systematic literature review methodology, following the recommendations of Gonçalves (2019) regarding the steps of topic definition, source collection, and organization. Initially, scientific articles published in indexed journals were identified and selected, prioritizing those with methodological rigor and relevance to the themes of electric mobility, renewable energy integration, and storage technologies. The search was conducted in databases such as Scopus, Web of Science, and Google Scholar, using combined descriptors and Boolean operators, which enabled the identification of high-impact and up-to-date publications. The method consist of:

- *Protocol development:* Clearly and explicitly define the scope of the review, search strategies, and study selection and analysis criteria, ensuring reproducibility and minimizing bias in the research. Defining database and search strategy (table 1).

Table 1. Data base and Key Words.

Data Base	Key Words
Science direct	"Electric Mobility" AND "Renewable Energy" AND "Automotive OR Vehicle" AND "government programs" AND "government initiatives" AND "public policies"
Web of Science	"Electric Mobility" AND "Renewable Energy" AND "Automotive" AND "government programs"
Google acadêmico	"Electric Mobility" AND "Renewable Energy" AND "Automotive OR Vehicle" AND "government programs" AND "government initiatives" AND "public policies"

- *Select the works:* Apply the inclusion and exclusion criteria (tabel 2)

Table 2. Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
1. Articles on technologies related to electric mobility and renewable energy;	1. Retracted Articles (explicitly check if the #RETRACTED status is present);
2. 2. Focus on sustainable mobility, economic decarbonization, or alternative fuels/energy storage (including batteries and charging/fueling infrastructure	2. Studies clearly unrelated to the transition to sustainability in the automotive transportation sector;
	3. Works that are not scientific articles;
3. Cites public policies.	4. Duplicate works;
	5. Works not from the last 5 years

- *Data extraction:* Systematically collect key data from each selected study and extract summary data from the studies

- *Synthesis and Analysis of Results:* Process and interpret the extracted data to identify patterns, trends, gaps and contradictions, and significant conclusions.

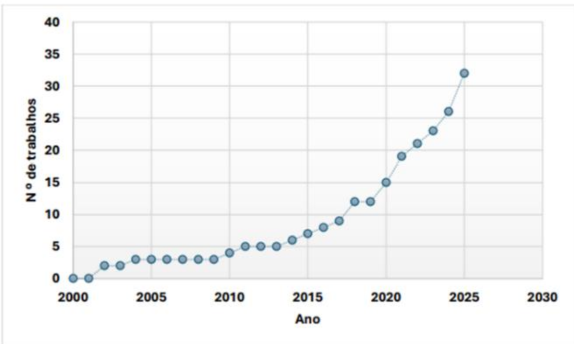
The analysis of the selected articles was conducted qualitatively, through full-text reading and critical interpretation of the content. Each study was examined to identify key public policies, incentives, barriers, and proposals for the integration of electric vehicles (EVs) with renewable energy sources (RESs). The information was organized in a comparative manner, allowing for the recognition of convergences, differences, and relevant examples across various countries and regions. This process enabled the construction of a structured synthesis, which served as the foundation for the discussion of results and the formulation of the recommendations presented in this study.

5. Results and Discussion

From 32 initial studies mined, 17 were excluded and 15 met the criteria, considered included. Trends include increased global EV adoption linked to political support, innovative business models for V2G and battery reuse, and region-specific challenges (e.g., infrastructure gaps in Africa, policy-driven success in China).

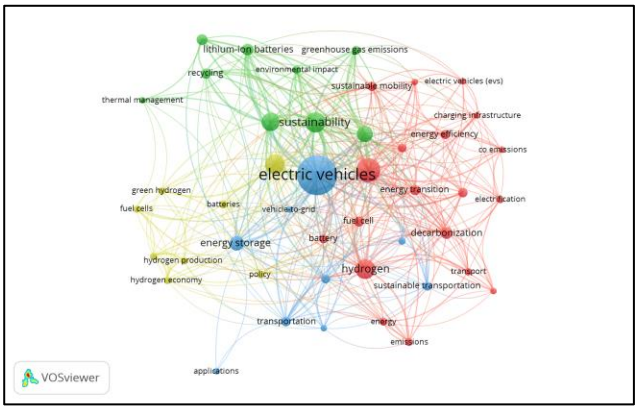
An interesting observation is the number of published works in relation to time (figure 1), showing that the decision to use 5 years is compatible with the selective criterion of papers.

Figure 1. Papers published per year



Another approach that should be explored is the semantic network of the systematic review tool, with neural behavior that behaves like a visual tool of the interaction between the chosen keywords (Figure 2).

Figure 2. Semantic network of key words



5.1 Adoption and infrastructure policies: what works and why

Comparative evidence shows that integrated policy packages—combining economic incentives with infrastructure investment, standardization, and regulatory governance—deliver more persistent effects than vehicle purchase subsidies alone. In China, national and subnational policies gradually shifted from direct subsidies to the stimulation of charging and battery-swapping infrastructure, tax instruments, and technical standards, which underpin global leadership in EVs and associated services. In Mexico, the 2024 DACG (CRE) established regulatory foundations for interoperability, safety, and a national digital platform, while the country expanded charging corridors via public–private partnerships; nonetheless, infrastructure remains unevenly distributed, with rural 'charging deserts'. In Ghana, total cost of ownership (TCO) analysis indicates that plug-in EVs are at least 30% cheaper than ICEVs under favorable fuel–electricity price differentials and tax reliefs; in South Africa, high taxation, load-shedding, scarce infrastructure, and a carbon-intensive grid depress adoption, calling for tax exemptions, local manufacturing, and accelerated renewable penetration.

Policy implication: programs should integrate (a) temporary, declining economic incentives; (b) a reliable fast/semi-fast charging network prioritizing corridors and equity zones; (c) connector/metering standards; and (d) regulatory oversight for interoperability and open data.

5.2 Structural barriers: range, upfront costs, and grid constraints

Three barriers recur across studies: range anxiety, high upfront costs, and insufficient infrastructure. The absence of stations and real-time information reinforces the perception that EVs are unsuitable for long-distance travel. In systems with intermittent or congested grids, rapid charging can exacerbate peak demand unless paired with active demand management. Industrial constraints—battery costs and critical materials—motivate policies for local content, recycling, repurposing (second life), and targeted R&D.

Policy implication: beyond purchase subsidies, lower the cost of use (off-peak tariffs; demand response), reduce infrastructure CAPEX (credit lines; streamlined permitting), and address supply chains via recycling, second life, and innovation funding.

5.3 Technologies and business models: V2G, circularity, and battery swapping

Vehicle-to-Grid (V2G) emerges as a systemic lever to absorb renewable surpluses, provide ancillary services (frequency regulation, reserves), and monetize flexibility. Actor mapping reveals new roles (aggregators, DSOs/TSOs, OEMs, utilities) and five business model categories (equipment, grid services, aggregation, integrated solutions, and secondary markets). Circular economy strategies for traction batteries—reuse, second life, and recycling—reduce raw material pressure, costs, and environmental impacts; evidence points to economic and environmental advantages for mechanical recycling routes (graphite and lithium recovery). Battery swapping, enabled by standardization and policy support in China, offers competitive refueling times, dilutes battery CAPEX, and is attractive for fleets (taxis, last-mile)—with strong potential in developing countries, provided safety standards, interface norms, and renewable integration are in place.

Policy implication: (i) regulate and value V2G/G2V (bidirectional metering, dynamic tariffs, market access to ancillary services); (ii) set circularity targets (minimum collection, recycled content) and incentives for recycling/second life; (iii) deploy battery-swapping pilots with technical standardization and concessional models focused on fleets.

5.4 Environmental advantage hinges on the electricity mix

Multiple studies converge that EV life-cycle emissions are highly sensitive to the carbon intensity of electricity. In coal-heavy systems, EVs can lose their advantage or even exceed ICEVs in life-cycle emissions; conversely, higher renewable shares yield immediate and larger gains. Techno-environmental assessments suggest that e-fuels produced from 100% renewable sources can complement decarbonization and leverage the legacy fleet and infrastructure, albeit with higher energy use than EV scenarios. Grid studies (e.g., Portugal) highlight the importance of managed charging to avoid local overloads.

Policy implication: transport electrification must proceed in lockstep with power sector decarbonization (renewable auctions, distribution grid modernization, smart tariffs), or climate benefits will erode.

3.5 Equity, just transition, and social acceptance

Policies must balance environmental goals with socio-economic viability, especially where informal public transport is prevalent. The Philippines' jeepney modernization shows that replacement without accessible finance, retrofit pathways, and public infrastructure can exclude small operators; a just transition requires concessional credit, cooperative arrangements, and phased roll-outs. In South Africa, beyond fiscal reform, trust-building (battery safety), workforce training, and grid reliability are needed. Digital transformation (MaaS, data, connectivity) reconfigures roles and demands adaptive regulation and data protection.

Policy implication: embed equity criteria (priority zones, social tariffs, retrofit options) and inclusive financing; align local governments and operators for progressive adoption.

5.6 Alignment with the study objectives

- Policies and incentives: evidence from China, Mexico, Ghana, and South Africa shows that policy 'combos' (incentives + infrastructure + regulation + standards) outperform isolated subsidies.
- Barriers: range, upfront costs, grid constraints, critical materials, and governance are the main obstacles.
- Technological trends: V2G, battery circularity, and battery swapping enable system efficiency and new markets.
- Electricity mix: environmental gains scale with power sector decarbonization; renewable e-fuels can complement.
- Gaps and convergence: need for valuation of flexibility services, circularity targets, interoperable data, ex-post policy evaluation, and equity mainstreaming.

6. Conclusion

Advancing electric mobility and renewable integration depends on a coordinated policy ecosystem. Across geographies, strategic public support—combining time-bound incentives, robust charging infrastructure, and enabling regulations—drives sustained EV adoption. The climate benefit of transport electrification is inseparable from power sector decarbonization. System-level enablers such as V2G and battery circularity (reuse, second life, recycling) can optimize grid operation, absorb renewable surplus, and mitigate environmental impacts. Future work should deepen business model innovation, digital transformation, and long-term policy impact evaluation, including consumer behavior and smart-charging integration with renewables.

Policy recommendations include:

- Decarbonizing national electricity grids;
- Encouraging smart charging technologies;
- Fostering circular economy models for battery reuse and recycling;
- Ensuring equity in the energy transition;
- Standardizing and regionalizing public incentives.

For future research, it is recommended to:

- Broaden the scope of investigation;
- Diversify data sources;
- Deepen regional analyses;
- Conduct comprehensive national policy evaluations;
- Explore comparative studies across countries with varying levels of maturity in EV adoption and renewable integration.

These directions will contribute to the development of more effective, adaptable, and context-sensitive strategies, accelerating the energy transition and supporting climate change mitigation efforts.

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