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Dynamometer Testing of Electric Vehicles: Methods, Standards, and Emerging Trends

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Abstract: Dynamometer testing (dynotest) is essential for evaluating electric vehicle (EV) performance under controlled laboratory conditions, enabling repeatable measurement of power, torque, efficiency, and energy consumption while emulating real-world driving cycles. This review surveys recent developments in EV dynotesting, highlighting IEEE and international test standards, key performance parameters, and evolving methodologies. We compare chassis and hub dyno architectures, including new "vehicle-in-the-loop" and modular test benches, and discuss integration of hardware-in-the-loop (HIL) simulation for real-time controller validation. Standardized drive cycles (e.g. WLTP, EPA/UDDS, JC08) are widely used on dynos to benchmark EV energy use. We summarize representative studies that apply dynotests to EV powertrains, including single-motor and dual-/multi-motor drivetrains. Emerging challenges are reviewed: bidirectional (regen) energy flow, thermal management under high load, synchronization of multiple drive units and batteries, and specialized needs for all-wheel-drive (AWD) and multi-motor EV testing. The review concludes that comprehensive dynotest methods, combined with rigorous standards, HIL integration, and advanced data analysis, are critical for validating next-generation EV drivetrains and enabling accurate energy-consumption benchmarking. Future work should address remaining gaps in multi-axis dyno platforms, long-term durability tests, and AI-driven real-time analysis during dyno runs.

Keywords: Electric Vehicle; Chassis Dynamometer; Drive Cycle; Hardware-In-The-Loop, Regenerative Braking; All-Wheel-Drive

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1. Introduction

The shift to electrified mobility has driven demand for precise EV performance evaluation. Unlike internal combustion engines, EV drivetrains offer high efficiency but introduce new testing requirements such as energy recovery and rapid thermal dynamics. Dynamometer test benches (dynotests) enable simulation of road-load conditions in a repeatable way[1, 2]. A chassis dynamometer ("roller dyno") uses motorized rollers to impose road-load torque on the vehicle's wheels, while a hub dynamometer tests individual motors or e-axles directly on torque-rated shafts. IEEE 1515-2000 (Electronic Power Subsystems) provides foundational test definitions for powertrain subsystems, and related standards (e.g. IEEE 112-2017 for motors) specify measurement procedures[3]. Regulatory cycles (EPA urban/FTP, WLTP, JC08, etc.) have been codified as dynamometer driving schedules for EV certification and comparison[1, 4].

Dynamometer testing is crucial throughout EV development. For example, Alhanouti and Gauterin (2023) used an IEEE-compliant chassis dyno to examine measurement repeatability and accurately estimate EV energy use, validating dyno-based benchmarking methods[1, 5-7]. Zainuri et al. (2022) evaluated a converted electric vehicle on a hub dyno, measuring torque, RPM and power to assess motor controller performance under dynamic load[8]. Experimental studies on standardized drive cycles (e.g. WLTC, EPA UDDS) have quantified EV energy consumption per km and illustrated the influence of load patterns [1,9-11]. These efforts demonstrate that dynotests are pivotal for drivetrain validation, efficiency mapping, and ensuring compliance with EV performance targets[12].

This review synthesizes recent literature (2019–2025) on EV dynamometer testing. We first outline common dyno architectures and test parameters, and then examine IEEE and industry standards that guide EV dynotest setups[13]. Next, we review drive-cycle and HIL-based methodologies used for EV testing. Key challenges—bidirectional energy flow, multi-motor synchronization, thermal effects, etc.—are discussed with supporting references[14]. We summarize representative studies (Table 1) illustrating various test configurations and research focuses. Throughout, we highlight gaps and recommend directions for future high-fidelity EV dynotest research.

2. Review Methodology

2.1 Literature Search Strategy

A structured literature search was conducted using IEEE Xplore, Google Scholar, and ScienceDirect from January to July 2026. The primary review period was limited to publications from 2019 to 2025. The search combined terms related to electric vehicles, dynamometer testing, and performance evaluation, with supplementary searches addressing drive cycles, hardware-in-the-loop (HIL), regenerative braking, thermal behavior, and multi-motor/all-wheel-drive (AWD) systems.

Core search string: ("electric vehicle" OR EV) AND ("dynamometer" OR "chassis dynamometer" OR "hub dynamometer" OR "motor dynamometer") AND (testing OR "performance testing" OR evaluation). Selected publications before 2019 were retained separately as foundational references when they provided essential historical, methodological, or technical context. The search and reporting structure was informed by PRISMA 2020 principles for transparent reporting of identification, selection, appraisal, and synthesis [1].

5.2 Inclusion and Exclusion Criteria

Tabel 1

Criterion	Inclusion	Exclusion
Publication period	2019–2025 for primary corpus	Outside the primary period, unless retained as foundational reference
Topic	EV dynamometer or closely related EV test-bench studies	Unrelated to EV testing or dynamometer evaluation
Testing focus	Power, torque, efficiency, energy, drive cycle, HIL, regeneration, thermal, multi-motor/AWD	Outside defined review scope
Publication type	Peer-reviewed journals, relevant conference papers, and technical papers with sufficient technical information	Duplicate, non-scientific, or insufficiently documented sources
Language	English	Non-English sources for the primary corpus

Publications meeting the inclusion criteria proceeded to screening and full-text assessment. Duplicate records and studies outside the defined scope were excluded from the primary evidence synthesis.

2.3 Study Selection

The study-selection process consisted of record identification, duplicate removal, title and abstract screening, and full-text assessment. A total of 185 records were identified from IEEE Xplore (n = 48), Google Scholar (n = 79), and ScienceDirect (n = 58). After duplicate removal, 100 unique records remained for screening. Title and abstract screening excluded 50 records that did not satisfy the predefined relevance criteria. The remaining 50 records underwent full-text assessment, and 30 records were retained in the primary evidence set.

Tabel 2

c	Records
IEEE Xplore	48
Google Scholar	79
ScienceDirect	58
Total identified	185
Duplicates removed	85
Records screened	100
Excluded after title/abstract screening	50
Full-text assessed	50
Full-text excluded	20
Included in primary evidence set	30

The selection flow is summarized in Table 1. The 30-source primary evidence set was used for the structured synthesis; selected standards and pre-2019 foundational publications were treated separately as methodological or historical references.

2.4 Data Extraction and Synthesis

Data were extracted using a structured framework covering publication year, dynamometer type, vehicle or powertrain configuration, drive cycle or test condition, measured parameters, HIL integration, main research focus, key findings, and identified limitations or research gaps. The extracted information was synthesized across five dimensions: (1) dynamometer architecture, (2) testing objective, (3) testing methodology, (4) vehicle or powertrain configuration, and (5) emerging testing capability.

This classification was used to compare the literature rather than to reproduce each study as an isolated narrative summary. The resulting evidence map links test architecture and test objective to the methods and vehicle configurations used in recent EV dynamometer research. Representative studies are presented in Table 2.

2.5 Quality Assessment

Included sources were considered according to publication type, methodological clarity, relevance to the review scope, and the availability of sufficient technical or experimental information. Peer-reviewed journal articles with clearly described methods and direct relevance to EV dynamometer testing were treated as higher-strength evidence. Relevant conference and SAE technical papers were treated as supporting evidence when methods and findings were sufficiently documented. Foundational references and other supporting sources were used primarily for historical or methodological context and were not used to establish the principal evidence base.

2.6 Review Scope and Limitations

The primary evidence synthesis was limited to literature published from 2019 to 2025 and retrieved from IEEE Xplore, Google Scholar, and ScienceDirect. Relevant studies indexed exclusively in other databases may therefore have been missed. In addition, heterogeneity in dynamometer architecture, vehicle configuration, drive cycles, test conditions, and reported parameters limits direct quantitative comparison across all studies. Pre-2019 publications were retained selectively as foundational references rather than as part of the primary evidence set.

3. EV Dynotest Architectures and Standards

3.1 EV Dynotest Architectures and Standards

Dynamometer test systems for EVs range from simple single-axle rigs to advanced multi-axis platforms. The most common setup is a chassis dynamometer with two rollers for one axle; it spins the wheels while measuring torque and speed[15]. A more modular approach is a hub dynamometer, where individual wheels or e-motor shafts are connected directly to torque sensors, isolating drivetrain losses such as tire slip[16-18]. For example, Alhanouti et al. (2023) describe a vehicle-in-the-loop chassis dyno at KIT that uses wheel-hub dynos to remove tire uncertainty, enabling precise drivetrain power and efficiency measurements[1, 19]. In general, chassis dynos include tire effects and inertia but allow testing of the full vehicle (including auxiliaries), whereas hub dynos provide more controlled motor-only tests.

Key performance parameters measured on an EV dyno include:

1. Power and Torque: Real-time wheel torque and speed are used to compute motor output; measurement uncertainty depends on sensor accuracy and dynamometer calibration [2, 16].
2. Efficiency: Comparison of input electrical power (from battery) to mechanical output yields motor-inverter efficiency. Mapping efficiency over torque–speed space requires multiple dyno sweeps.
3. Energy Consumption: Simulating standard drive cycles allows calculation of Wh/km (or miles/kWh) for the whole vehicle [16].
4. Regenerative Braking: Bidirectional power flow must be handled; dyno braking modules (dyno-in-the-loop) absorb or return energy to the battery during deceleration tests. Accurately emulating regenerative torque is challenging and requires careful control algorithms.
5. Thermal Response: Long-duration tests track motor/inverter temperatures under sustained load, which is critical for thermal management evaluation. Few studies explicitly focus on thermal behavior, but it is recognized as a limiting factor in continuous dyno testing.
6. Dynamic Response: High-speed data acquisition is used during step inputs (acceleration, deceleration) to capture transient behavior and any control system latency [20, 21].

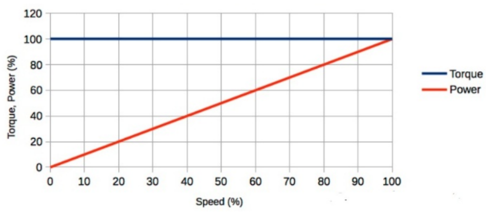


Figure 1. Torque vs Motor Speed.
http://engineeringtoolbox.com/electrical-motors-hp-torque-rpm-d_1503.html

Standards play a guiding role in dyno testing. IEEE Std. 1515-2000 (Recommended Practice for Electronic Power Subsystems) provides parameter definitions and test conditions for EV powertrains. IEEE 112-2017 defines induction motor test procedures that are applicable to EV traction motors. More recent guidelines, like IEEE Std. 1679.1-2017, address battery characterization (though for stationary use) and suggest approaches for battery testing in vehicle setups[3]. In practice, dynotest facilities often adapt automotive regulations (UNECE, SAE J1634, etc.) for EV energy and efficiency testing, embedding standard drive cycles into the dyno control software. For example, WLTP and US EPA driving schedules are routinely programmed into chassis dynos to ensure consistency with certification procedures.

3.2 Drive Cycles and Test Protocols

A primary function of EV dynotests is to reproduce standardized drive cycles under laboratory conditions. These include urban and highway cycles specified by regulatory bodies (e.g. EPA's UDDS and HWFET, WLTP low/mid/high classes, Japan's JC08). On a chassis dyno, the vehicle's wheels are driven to follow a target speed profile; accompanying rollers generate the requisite road-load torque via a polynomial "road load" curve derived from coast-down tests. Tests may be done by a human driver or by steering/throttle robots for repeatability. The resulting energy use per cycle is used to compute consumption (Wh/km) and range estimates under that drive pattern.

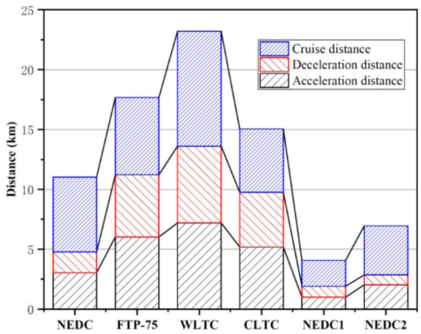


Figure 2. Energy Consumption per Drive Cycle
https://www.evengineeringonline.com/how-is-the-energy-consumption-and-range-of-evs-measured/

Dynotest studies have leveraged these cycles to compare EV performance. For example, Lairenlakpam et al. (2019) ran a converted EV through WLTC and Indian driving cycles on a chassis dyno and reported speed, torque, and energy-consumption metrics[9]. These data helped assess the prototype powertrain's city/highway efficiency. Similarly, Alhanouti and Gauterin (2023) tested an EV on both NEDC and WLTP cycles, identifying discrepancies between expected and measured energy due to tire-roller interactions. Their work underlines that even with standardized profiles, physical dyno conditions (roller inertia, tire slip) can affect results[1]. They ultimately developed a tire-roller friction model (LuGre model) to reconcile dyno measurements with vehicle simulations. This finding shows the importance of accounting for dynamometer system dynamics when interpreting drive-cycle tests[22, 23].

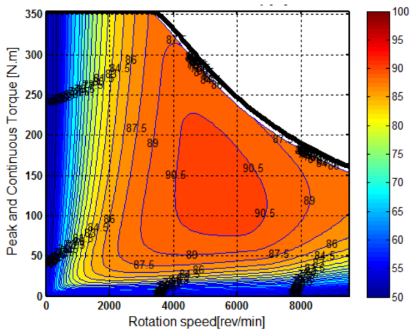


Figure 3. Motor Efficiency Map
https://www.researchgate.net/figure/Efficiency-map-of-the-electric-motor-and-inverter_fig4_323522307

In summary, drive-cycle dynotesting provides a consistent basis for energy consumption benchmarking. By using harmonized procedures, researchers can compare EV models and validate simulations. The literature repeatedly emphasizes that strict adherence to standard cycles (and proper dyno calibration) is needed to yield meaningful efficiency and power metrics.

3.3 Drives Cycles and Protocols

Integrating hardware-in-the-loop (HIL) simulation with dynotesting enables advanced control validation. In an HIL setup, part of the vehicle (often the control unit) is real hardware, while the plant (motor, vehicle dynamics, etc.) is emulated by a real-time simulator. For EVs, HIL platforms have been developed to accelerate drivetrain and controller testing. Poon et al. (2012) pioneered an EV HIL rig where a small-scale EV drive controller was tested against real-time models of vehicle dynamics and road-load; they demonstrated successful use of the EPA UDDS drive cycle in closed-loop tests[24]. More recently, Badardin and Abu Bakar (2023) described a modular EV dyno platform with an HIL subsystem that simulated driving cycles and validated control logic under dynamic loads[25].

Crucially, Düzgün et al. (2025) have demonstrated that a well-designed HIL testbench can emulate a full PHEV drivetrain with high fidelity. In their study, the HIL system ran a series-parallel hybrid control unit through WLTC driving profiles; the chassis simulation matched target speeds ($R^2 \approx 0.9993$) and battery state-of-charge (SoC) stayed within ±50 Wh of the real cycle. Overall energy errors were under 1%, and fuel/CO_2 deviations under 3%[5]. This shows HIL can closely reproduce vehicle-level efficiency and energy flow. However, such complex HIL-dyno rigs remain mostly in research labs due to high cost and integration effort.

Hardware-in-the-loop dynotesting allows real-time controller calibration and fault injection (e.g. grid disturbances, battery faults) without risking a full vehicle[26, 27]. While substantial HIL work on EVs exists (Poon et al., 2012; Düzgün et al., 2025), published studies of HIL with actual dyno benches are still emerging. In practice, some labs use “dyno-in-the-loop” by connecting a dyno with real-time simulation of battery and loads[24]. For example, an autonomous vehicle test at WMich described a CAN-bus-enabled drive kit on a chassis dyno to replay EPA cycles, demonstrating that dyno controllers can mirror real EV behavior under software control[28, 29]. In this way, HIL and dyno testing converge to create “virtual vehicles” on the bench[5].

3.4 Representative Dynotest Studies

The literature was synthesized by comparing architecture, testing objective, methodology, and vehicle configuration rather than repeating each study as an independent narrative. Table 2 provides a representative extraction of studies that directly illustrate the dominant approaches identified in the review.

Study	Dyno / Testbench	Vehicle / System	Test / Method	HIL	Main measurements	Main focus
Alhanouti & Gauterin (2023) [6]	Roller chassis	EV	NEDC / WLTP-class 2	No	Energy, torque, power	Repeatability and energy estimation
Noval et al. (2025) [7]	Chassis dyno	Light EV	Controlled dynamometer tests	No	RPM, torque	Dynamometer accuracy
Lairenlakpam et al. (2019) [8]	Chassis dyno	Converted EV	IDC, MIDC, WLTC	No	Speed, torque, energy	Drive-cycle performance and energy
Zainuri et al. (2022) [9]	Hub dyno	Converted EV	Dynamic loading	No	Torque, RPM, power	Retrofitted EV powertrain
Düzgün et al. (2025) [10]	HIL testbench	PHEV	WLTC / closed loop	Yes	Speed, energy, SoC	Controller validation
Gong et al. (2023) [11]	HIL / simulation	EV powertrain	Real-time HIL	Yes	Control variables	Controller-HIL methods
Reick et al. (2021) [12]	Chassis dynamometer	EV/HEV	Power measurement	Optional	Wheel power, motor power	EV power-test procedure
Rautenberg et al. (2023) [13]	VIL chassis / hub dyno	BEV	WLTP	No	Power, efficiency	Reproducible drivetrain testing
Badardin & Abu Bakar (2023) [14]	HIL system	EV test platform	Driving-cycle simulation	Yes	Torque, cycle response	HIL drive-cycle validation
Goberville et al. (2025) [15]	Modular dynamometer	Vehicle + virtual scenario	Automated-driving scenarios	Yes	Energy, propulsion response	Interoperable VIL/ADS testing

The representative studies reveal a progression from conventional chassis-dynamometer measurements toward increasingly modular and simulation-integrated test environments. Chassis systems remain important for vehicle-level energy and performance measurements, while hub and powertrain configurations are useful when component-level isolation is required. HIL and VIL methods are increasingly used for controller validation and automated-driving scenarios, but their additional model and synchronization requirements limit their use to more specialized laboratories [6,10–15].

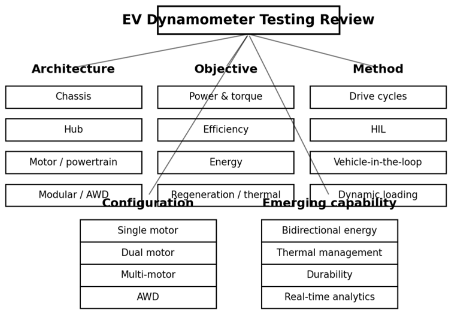
The synthesis also indicates that energy consumption, power, and torque are better represented in the literature than long-duration durability or comprehensive thermal characterization. Multi-motor and AWD testing is emerging, particularly where torque-vectoring and automated-driving scenarios require independent control of multiple axles. These patterns motivate the taxonomy shown in Figure 3.

3.5 Challenges and Emerging Trends

EV dynotesting presents several unique challenges beyond those of conventional ICE vehicles:

1. Bidirectional Energy Flow: Regenerative braking means the dyno must absorb returned energy or feed it back to the battery. Emulating precise regen torque profiles requires fast-response dyno brakes and control loops. Studies note that test setups must handle both motoring and generating modes seamlessly. In practice, many dynos dissipate regen energy in resistors or recirculate it, but sophisticated rigs can return it to the grid or battery. This "bidirectional" operation can introduce stability issues if control is not tightly synchronized with vehicle feedback loops[35, 36].

2. Thermal Effects: EV motors and inverters heat up quickly under test conditions. Continuous high-load dyno runs (e.g. sustained full power) can lead to thermal saturation, altering performance. Only a few studies have addressed this, but it is widely recognized as a limitation on test duration. Proper cooling (liquid jackets, fans) and thermal monitoring are essential to maintain steady-state test conditions and to characterize component limits[37-39].



3. System Synchronization: Accurate dyno results require tight synchronization among vehicle subsystems. Motor controllers, inverters, and the battery management system (BMS) must be coordinated with the dyno's control. Any latency or misalignment (e.g. time lags in control signals) can skew the power or torque readings. Lairenlakpam et al. note that mismatches in controller response can affect energy-consumption measurements under drive cycles. Similarly, when multiple motors (AWD) are tested, synchronizing torque and speed across axles is complex[9, 40, 41].
4. HIL Complexity: While HIL offers richer testing, it adds cost and complexity. Building a stable real-time simulation that includes battery dynamics, power electronics, and mechanical loads is nontrivial. The benefit is accelerated calibration (as Düzgün et al. showed), but setting up vehicle-in-the-loop "dyna-sims" requires extensive model validation. Moreover, PHIL (power hardware-in-loop) to include actual battery or motor hardware with simulated loads is an emerging area but not yet mainstream in EV dyno labs[25, 42].
5. Multi-Axle and AWD EV Testing: Many current dynos are single-axle. Testing AWD or multiple motor EVs (common in high-performance and commercial vehicles) necessitates multi-belt or multi-roller setups. Statically linking two rollers can test a 4WD vehicle, but dynamic torque-vectoring scenarios require independent control of each wheel's load. Few published studies have reported full multi-axis EV dynos; Goberville et al. (2025) is a rare example of a planned modular AWD testbed. The literature calls for more research on dyno methods that can impose uneven loads for torque vectoring and differential braking – conditions that single-axle tests cannot simulate[18, 43, 44].
6. Environmental Factors: Standard dynos typically simulate level, uniform road conditions. Real-world factors like inclines, crosswinds, or rough pavement are usually omitted. Some advanced rigs now incorporate adjustable road-load profiles or climate chambers, but these remain specialized. Future high-fidelity dynos may need to emulate these variables to fully predict EV performance in varied conditions[30, 45-48].
7. Long-Term Durability Testing: Current studies focus on short-cycle performance. The community has identified a gap in accumulated mileage or endurance tests on dynos to

simulate aging of batteries, motors, and power electronics. Extended stress testing (e.g. thousands of hours) on a dyno could reveal reliability issues, but standardized protocols for such tests are not yet established[22, 49-53].

8. Addressing these challenges requires harmonized protocols and new instrumentation. One underexplored area is real-time data analytics during dyno tests. Integrating machine learning or AI for anomaly detection could improve calibration (e.g. identifying friction changes) on the fly. Additionally, mobile testbeds and vehicle-in-loop approaches hint at a future where dyno labs can incorporate live or recorded traffic data for even more realistic driving simulations[24, 29, 54, 55].

4. Conclusions

Dynamometer testing is foundational for EV development, offering controlled, repeatable evaluation of powertrain performance. The literature shows that chassis and hub dynos—when coupled with standardized drive cycles—provide critical data on power, torque, efficiency, and energy use. IEEE and automotive test standards ensure that measurements are comparable across studies. Emerging trends include modular multi-motor dynos and integration of hardware-in-the-loop simulation for real-time controller validation.

To meet the needs of modern EVs, test benches must handle bidirectional energy flow (regeneration) and multiple motors, and they must accommodate advanced features like torque vectoring. High-impact studies in recent years (see Table 1) have begun to explore these aspects, but significant gaps remain. Notably, there is a need for standardized protocols on durability cycling, for multi-axis AWD testing, and for leveraging real-time analytics in dyno environments.

In sum, rigorous dynamometer methods—grounded in established standards and enhanced with modern simulation technologies—are essential for validating next-generation EV technologies. Future work should pursue unified test protocols for EV-specific phenomena, incorporate HIL and AI tools for smarter testing, and expand testing frameworks to cover the full range of multi-motor and real-world driving scenarios. These developments will ensure that dynotest remains a vital part of the EV design and certification process, helping to accelerate the transition to cleaner transportation.

Table 1 Sources: Study details are drawn from the cited literature, including Alhanouti & Gauterin (2023), Zainuri et al. (2022), Lairenlakpam et al. (2019), Badardin & Abu Bakar (2023), Rautenberg et al. (2022), and Goberville et al. (2025), among others.

This review provides a structured synthesis of EV dynamometer testing across test architecture, testing objective, methodology, vehicle configuration, and emerging capability. The literature indicates that chassis dynamometers remain central to vehicle-level power, torque, efficiency, and energy-consumption evaluation, while hub and powertrain dynamometers provide greater isolation of drivetrain components. Standardized procedures such as SAE J1634, SAE J2263, UN GTR No. 15, and UN Regulation No. 85 provide complementary foundations for energy consumption, road-load determination, drive-cycle testing, and electric-drive power measurement [2–5].

HIL and VIL approaches expand the capability of dynamometer laboratories by enabling closed-loop controller validation and integration with simulated driving environments. At the same time, they introduce additional requirements for model accuracy, synchronization, and instrumentation. The evidence synthesis indicates that conventional power and energy measurements are more mature than thermal characterization, long-term durability, and multi-axis AWD testing.

The principal research gaps are therefore methodological and infrastructural: harmonized EV-specific dynamometer procedures, robust bidirectional energy-flow control, standardized multi-axis AWD testing, longer-duration thermal and durability protocols, and validated real-time data analytics. These gaps provide a clearer basis for future research than broad calls for “advanced testing” alone. The review should be interpreted within its scope and database limitations; nevertheless, the proposed evidence map provides a practical framework for organizing future EV dynamometer studies.

Declarations

Data Availability: The review is based on published literature and the structured search and screening procedure described in Section 2.
Conflict of Interest: The authors declare that they have no financial, personal, professional, or other relationships that could influence the objectivity or interpretation of this work.

Conflic of Interest

This sentence explicitly states that the author of the article or scientific report has no financial, personal, professional, or other affiliations that could be considered a potential conflict that could affect the objectivity, integrity, or transparency of the scientific work. This statement is made to maintain reader confidence in the neutrality of the research

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