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# Wireless Dynamic Charging for Urban and Residential Roads: A Review of Vehicle Dynamics, Drive Cycles, and Energy Gain Feasibility

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***ABSTRACT***
*Dynamic wireless power transfer (DWPT) allows an electric vehicle (EV) to recharge its battery while in motion, by embedding transmitter coils beneath the road surface that couple inductively with a receiver coil mounted on the vehicle underbody. Most DWPT research to date, and nearly all operating pilot deployments, have been built around highway or fixed-route transit corridors, where vehicles travel at sustained speed over long, uninterrupted stretches. Urban and residential roads present a fundamentally different operating envelope: short charging segments, frequent stop-start motion at intersections and driveways, low and variable speed, and tight capital budgets relative to national highway programmes. This review consolidates the literature on dynamic and quasi-dynamic wireless charging with a specific focus on vehicle dynamics, standard drive-cycle characteristics, and energy-gain feasibility under these urban and residential operating conditions. It surveys system architectures, coil and segment-activation strategies, vehicle-detection methods, eco-driving and speed-control approaches proposed for signalized intersections, and the cost and standardization landscape, including the SAE J2954 family of standards and real-world pilots such as eRoadArlanda, Elonroad, and Electreon. The review identifies a clear gap: existing energy-gain and feasibility models are largely calibrated to highway-speed, long-segment conditions and do not adequately capture the short dwell-time, low-speed, high-stop-frequency character of residential and urban streets. Technical, infrastructural, grid, regulatory, and vehicle-compatibility challenges specific to this environment are discussed, and future research directions are proposed, including low-speed misalignment-tolerant coil design, intersection-level activation control, and techno-economic models suited to neighbourhood-scale deployment.*

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## I. Introduction

Electric vehicle (EV) adoption is constrained less by vehicle technology than by the convenience, cost, and footprint of charging infrastructure. Static wireless power transfer (WPT), in which a vehicle parks over a buried transmitter pad and charges without cables, has matured to the point of formal standardization and early commercial deployment. Dynamic wireless power transfer (DWPT) extends the same inductive-coupling principle to a vehicle in motion: transmitter coils are embedded in short segments beneath the road surface and are energized in sequence as a vehicle passes overhead, transferring energy to an onboard receiver coil without the vehicle stopping. The appeal of DWPT is considerable it can reduce the onboard battery capacity required for a given range, shrink vehicle mass and cost, and remove the queuing and dwell-time penalties associated with plug-in or even static wireless charging.

The great majority of DWPT research, pilot programmes, and commercial roll-outs have targeted highway corridors and dedicated transit routes. Sweden's eRoadArlanda, Elonroad, and Electreon deployments, Germany's eHighway trials, and the recent Detroit and UCLA inductive-road pilots in the United States all share a common feature: vehicles travel at sustained, relatively high speed over continuous stretches of road ranging from a few hundred metres to several kilometres. Urban and residential streets differ from this picture in almost every relevant respect. Speeds are low (typically under 50 km/h) and highly variable due to intersections, stop signs, pedestrian crossings, and traffic calming measures; vehicles frequently come to a complete stop; trip segments are short; and the capital available for a single residential street or neighbourhood is a small fraction of a national highway electrification budget. These differences change which technical problems matter most coil-to-vehicle coupling under frequent starts and stops, activation latency, and grid loading from many short, clustered, intermittent charging events and they change which economic questions are relevant, since a street-level or intersection-level deployment cannot be justified by the same amortization logic as a cross-country corridor.

### *1.1 Significance of this work*

Despite an expanding body of DWPT literature, reviews and system studies have concentrated overwhelmingly on highway-speed operation, and where urban contexts are considered, the emphasis is usually on traffic-signal-linked "quasi-dynamic" charging at a single intersection rather than on the vehicle-dynamics and drive-cycle characteristics of an entire urban or residential trip. This creates a gap between the operating assumptions embedded in most energy-gain and feasibility models and the actual conditions a residential or city street would present. The present review is intended to close part of that gap by drawing together vehicle-dynamics, drive-cycle, and DWPT-specific literature into a single assessment focused specifically on the low-speed, stop-start, short-segment character of urban and residential deployment.

### *1.2 Paper layout*

The remainder of this review is organized as follows. Section 2 surveys related work and positions the present review against existing DWPT literature, identifying the specific research gap it addresses. Section 3 describes the technological framework of DWPT systems and reviews real-world pilot deployments and their reported costs. Section 4 examines vehicle dynamics and standard drive-cycle characteristics relevant to urban and residential driving. Section 5 reviews energy-gain feasibility modelling approaches and how they would need to be adapted for low-speed conditions. Section 6 discusses system architecture and enabling components, including standardization efforts. Section 7 offers a critical assessment and discussion. Section 8 sets out challenges and limitations specific to urban and residential deployment. Section 9 concludes, and Section 10 outlines future research directions.

## II. Related Work

Prior surveys of wireless EV charging tend to fall into three groups. The first group reviews inductive WPT broadly, covering static and dynamic modes together, coil topologies, compensation networks, and standardization, without singling out the urban or residential operating envelope [2,9]. The second group focuses specifically on dynamic and quasi-dynamic charging but is organized around highway or dedicated-lane deployment, vehicle platooning, and inter-city corridor economics [1,3,4,5,6]. The third and smallest group addresses charging behaviour at signalized intersections or within city road networks, typically from a traffic-engineering or eco-driving optimization perspective rather than a vehicle-dynamics or drive-cycle perspective [1,8,21,22,23,24,25,26]. A review synthesizing these three strands specifically for residential and urban streets, with attention to standard drive cycles and vehicle-level energy accounting, has not previously been assembled.

Liu et al. investigated the deployment of DWPT at urban intersections for connected and autonomous vehicles, showing that eco-driving behaviour combined with a well-designed charging-segment layout could meaningfully reduce network-wide energy consumption and increase the energy transferred and stored per vehicle, while noting that most prior DWPT studies had focused on highway driving and electric buses rather than ordinary passenger cars in city traffic [1]. Complementing this, several studies have examined "quasi-dynamic" wireless charging, in which EVs recharge during short, naturally occurring stops such as red lights or queues, arguing that this approach makes more efficient use of otherwise idle dwell time than either fully static or fully dynamic charging, while raising questions about equipment layout, coverage, and the trade-off between transmission efficiency and charging speed [14].

A body of eco-driving and speed-control literature has grown around wireless charging lanes, motivated by the observation that driving speed strongly affects both charging efficiency and the duration of effective charging on a DWPT segment. Zhang et al. proposed an eco-driving control strategy for connected and automated vehicles approaching signalized intersections equipped with wireless charging lanes, coordinating speed to both save energy and make better use of the charging opportunity [23]. More recent work has extended this to multi-objective optimization balancing travel time, energy consumption, and load balancing on the charging lane [22], to reinforcement-learning-based eco-driving control for partial wireless-charging-lane coverage at intersections [24], and to lane-reversal strategies that dynamically allocate a wireless charging lane to whichever traffic direction has greater demand [25].

On the infrastructure side, dynamic wireless charging has moved from laboratory demonstration into a number of real, publicly documented pilots. Sweden's eRoadArlanda uses an embedded conductive rail rather than induction and has operated since 2018 [17]; Elonroad has deployed a similar ground-level conductive system in Lund [18]; and Electreon has built inductive DWPT test tracks in Sweden, Germany, Italy, Israel, and the United States, including a quarter-mile inductive road in Detroit and an expanding project with UCLA's campus bus fleet ahead of the 2028 Olympic Games [19,20]. These projects, together with Sweden's own national assessment, have generated the first large-scale, real-world cost and performance data for DWPT, discussed further in Section 3.3.

On vehicle-side detection and control, recent work has applied machine-learning methods to vehicle position detection during dynamic charging, aiming to improve coil-activation accuracy without relying solely on fixed-position inductive sensing [10], while load-demand modelling work such as the modified Toeplitz convolution (mCONV) approach has sought to make grid-impact analysis of DWPT deployments computationally tractable at scales ranging from a handful of transmitter pads to many kilometres of road [12]. Standardization has also progressed: the SAE J2954 family of standards defines interoperability, alignment, and electromagnetic-compatibility requirements for light-duty wireless charging, and its Differential Inductive Positioning System (DIPS) tested to a claimed efficiency of up to 93% at up to 11 kW is explicitly intended to extend to dynamic charging in a forthcoming SAE J2954/3 standard [27,28,29].

***Table 1. Summary of Related Literature***

| Ref. | Focus / Context | Methodology | Key Finding | Gap Relevant to Urban/Residential DWPT |
|---|---|---|---|---|
| [1] | DWPT at urban intersections, CAVs | Simulation + experiment, urban network layout | Eco-driving with optimized segment layout cuts energy consumption up to ~62% for CAV-dominant traffic | Focused on intersections within a signal-controlled network, not full residential trip drive cycles |
| [4] | On-road WPT for e-mobility, general | Literature synthesis | Coil, converter, compensator, and controller design jointly determine power transfer rate | Highway/general on-road framing; residential-scale segment sizing not addressed |
| [9] | Comparative review of WPT technologies | Literature synthesis | Quasi-dynamic charging at intersections makes efficient use of fragmented dwell time | Notes intersection use case but does not model drive-cycle-level energy gain |
| [23] | Eco-driving at signalized intersections with WCL | Optimization model | Coordinated speed control improves both energy savings and charging-lane utilization | Single-intersection scope; not extended to multi-intersection residential routes |
| [22] | Speed control on dynamic wireless charging lanes | Multi-objective mathematical programming | Comprehensive control strategy improves energy efficiency and load balancing with minor travel-time cost | Calibrated to highway/arterial lane speeds rather than residential-street speed limits |
| [24] | Partial wireless-charging-lane coverage at intersections | Deep reinforcement learning (TD3 agent) | DRL control smooths intersection passage while using partial WCL coverage efficiently | Single/paired intersection case studies; network-level residential feasibility untested |
| [10] | Vehicle detection/positioning for DWPT | Machine learning position estimation | ML-based detection improves activation accuracy over simple fixed sensing | Evaluated for track-style DWPT, not validated for low-speed stop-start conditions |
| [12] | Grid-load modelling for DWPT networks | Modified Toeplitz convolution | Enables tractable load-demand modelling from a few transmitter pads to many km of road | Demonstrated at highway/network scale; residential feeder-level clustering not modelled |
| [17,18,19,20] | Real-world electric road deployments | Field pilots, government assessment | Capital costs of US$1–7 million per lane-km reported; efficiencies of 64–95% depending on system | All pilots are highway, bus-route, or test-track based; no residential-street pilot yet reported |
| [27,28,29] | Standardization, alignment methodology | Industry consensus standard, lab + field testing | Defines interoperability and alignment for up to 11 kW at up to 93% efficiency; dynamic extension (J2954/3) in progress | Current standard addresses stationary charging; dynamic/urban alignment tolerance not yet standardized |

**Table 1. Summary of literature relevant to dynamic wireless charging for urban and residential roads.**

### *2.1 Research gap*

Reviewing this literature alongside standard drive-cycle and vehicle-dynamics references reveals several unaddressed gaps specific to urban and residential DWPT. First, energy-gain and feasibility estimates in the DWPT literature are drawn predominantly from highway-speed or dedicated bus-route conditions; there is very little quantitative treatment of energy gain under the low-speed, frequent-stop conditions typical of residential streets and urban arterials away from dedicated charging lanes. Second, eco-driving and speed-control studies for wireless charging lanes are almost all framed around a single signalized intersection or a short arterial stretch, rather than a full residential trip drive cycle with multiple stop events. Third, coil-activation and vehicle-detection research has been validated primarily on track-style or highway-style DWPT testbeds; low-speed, stop-and-go misalignment behaviour, and the effect of frequent full stops directly over an energized segment, remain underexamined. Fourth, grid-impact and load-demand modelling has been developed and demonstrated chiefly for highway-scale or corridor-scale deployments; the clustering effect of many short, closely spaced residential-street segments on a local distribution feeder is not yet well characterized. Fifth, essentially all reported real-world capital-cost data come from highway, test-track, or transit pilots; no public techno-economic study specifically addresses the capital cost, per-household benefit, and payback period of DWPT segments sized for a residential street or driveway approach.

***2.2 Key contributions***
The contributions of this review are as follows:

- A focused synthesis of DWPT literature specifically through the lens of urban and residential vehicle dynamics and drive cycles, rather than highway or dedicated-corridor operation.
- A structured comparison of standard drive-cycle characteristics (urban vs. highway components) against the operating assumptions used in existing DWPT energy-gain models.
- A consolidated, sourced comparison of real-world electric road / DWPT pilot capital costs, presented on a common per-lane-km basis.
- Identification of specific, testable research gaps in low-speed coil activation, intersection-to-intersection eco-driving, and residential-feeder grid impact.
- A set of future research directions aimed at making urban and residential DWPT feasibility assessment as rigorous as the highway-corridor literature already is.

## III. Technological Framework

***3.1 Research design***

This review followed a structured literature-identification and screening process. Searches were conducted across Scopus-indexed venues, ScienceDirect, IEEE Xplore, Frontiers, MDPI journals, arXiv preprints, SAE technical standards, and Google Scholar, using keyword combinations including "dynamic wireless power transfer," "wireless charging lane," "electric road system," "urban intersection charging," "drive cycle," and "vehicle dynamics wireless charging." Records were screened for direct relevance to dynamic or quasi-dynamic wireless charging, urban or residential driving contexts, vehicle-level energy accounting, or standardization; results addressing only static/parked wireless charging were retained solely where needed for comparative context (as in the manuscript this review extends). Screened literature was grouped thematically into: (i) DWPT system architecture and components, (ii) vehicle dynamics and drive-cycle characteristics, (iii) energy-gain and feasibility modelling, (iv) eco-driving and control strategies, (v) real-world pilots and cost data, and (vi) standardization and safety.

***3.2 Static, quasi-dynamic, and dynamic wireless charging***
Three modes of wireless EV charging are commonly distinguished in the literature. Static wireless charging occurs while the vehicle is parked over a transmitter pad, as in a driveway or parking bay, and is the mode addressed by the SAE J2954 standard in its current published form [27]. Quasi-dynamic (or "opportunity") charging occurs during short, naturally occurring stops at a red light, a stop sign, or a queue and has attracted particular interest for urban intersections because it uses otherwise idle dwell time without requiring continuous road electrification [14]. Dynamic wireless charging, the primary subject of this review, transfers energy continuously while the vehicle is in motion, typically through a series of short transmitter segments embedded along a lane that energize only when a vehicle is detected overhead [3,4]. Urban and residential deployment realistically spans all three modes within a single trip: a vehicle may charge dynamically along a short stretch of arterial road, quasi-dynamically at the intersection queue that follows, and statically once parked at a destination or at home.

***3.3 Real-world pilot deployments and capital costs***

Although most DWPT literature remains simulation-based, a growing number of physical pilots provide grounded cost and performance data. Sweden's eRoadArlanda, opened in 2018 near Stockholm, uses an embedded conductive rail rather than induction, connects to the vehicle through a retractable arm, and was reported at the time to cost roughly US$1.2 million per kilometre, a small fraction of the cost of an equivalent urban tram line [17]. Elonroad has deployed a similar ground-level conductive system in Lund, also at a reported cost of roughly €1 million per kilometre, and is exploring both passenger-car and heavy-vehicle applications [18]. Electreon's inductive technology, tested in Sweden, Germany, Italy, Israel, and the United States, has been costed very differently across sites: an early Swedish assessment for a planned E20 motorway stretch priced offers at roughly SEK 24–29 million per two lane-kilometres before the tender was cancelled as too expensive, while a UK feasibility study (the Coventry DynaCoV project) found a 200-metre inductive installation, including vehicle-integration costs, at roughly £1.475 million an order of magnitude more expensive per kilometre than the conductive systems, and a finding that led the study's authors to conclude that dynamic wireless charging was, at that scale, three to ten times more expensive than conductive charging and not yet financially viable in that context [13,19]. More recent Electreon deployments in the United States, including the Detroit inductive road and the expanding UCLA campus-bus project, along with a company-quoted future target of roughly US$1.2 million per mile as the technology scales, suggest costs may fall as deployment matures, though a genuinely low-cost residential-scale figure has not yet been reported anywhere in the literature [19,20].

Figure 1 summarizes these reported capital costs on a common basis. The comparison should be read cautiously: costs are not perfectly like-for-like, since they combine conductive and inductive systems, differ in whether vehicle-side integration is included, and were reported at different project maturities. Nonetheless, the spread roughly US$1 million to US$7 million per lane-kilometre illustrates why every documented DWPT pilot to date has been justified either as a national or corridor-level program (Sweden), a fleet-specific transit investment (UCLA's bus fleet), or a government-funded research trial (Coventry, Detroit), rather than as an economically self-contained residential-street investment.

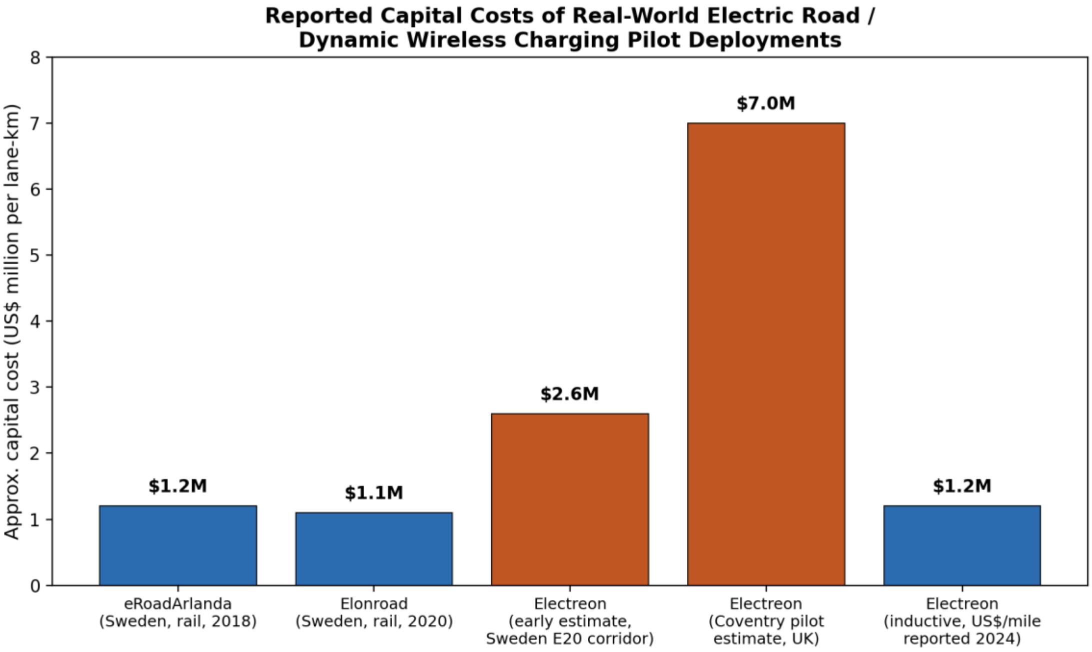


**Fig. 1. Reported capital costs of real-world electric road / dynamic wireless charging pilot deployments, converted to an approximate common basis of US$ million per lane-km. Sources: [13,17,18,19,20]. Figures are order-of-magnitude comparisons drawn from heterogeneous public reporting and should not be treated as directly comparable engineering estimates.**

Sweden's own national programme illustrates the scale of investment such systems require even where the underlying technology is judged mature: after receiving construction offers exceeding budget for a planned electric motorway between Hallsberg and Örebro, and after a multi-year national assessment, the Swedish Transport Administration's final 2024 report recommended against building a national electric-road network at that time on cost-effectiveness grounds, pausing the programme [13,14]. This outcome, from the country with the longest continuous experience of electric-road piloting, underscores why a residential-scale business case necessarily far smaller than a national corridor and without the amortization benefit of continuous heavy-vehicle traffic needs its own dedicated techno-economic treatment rather than a simple down-scaling of highway figures.

## IV. Vehicle Dynamics and Drive Cycle Considerations

### *4.1 Standard drive cycles: urban vs. highway components*

Standard drive cycles such as the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), the US EPA's FTP-75, the New European Driving Cycle (NEDC), and various national urban drive cycles are built from distinct low-speed urban, medium-speed suburban/extra-urban, and high-speed motorway phases. The urban phases of these cycles are characterized by low average speeds (commonly in the range of 15–30 km/h), frequent full stops, short acceleration and deceleration events, and a high proportion of time spent at zero or near-zero speed at intersections. The highway/motorway phases, by contrast, are characterized by sustained speeds well above 80 km/h with comparatively few speed transitions. Because nearly all published DWPT energy-gain studies model vehicle motion using highway-phase or dedicated-lane assumptions constant or near-constant speed over a segment of defined length they implicitly adopt a drive-cycle profile that is close to the motorway phase of a standard cycle and very different from its urban phase. Vehicle dynamics in a residential setting are therefore better represented by the urban phase of WLTP/FTP-75-style cycles than by any highway-oriented DWPT study published to date.

***4.2 Speed–acceleration–deceleration profiles on residential and urban streets***

Residential streets add further departures from even the general urban drive-cycle phase: posted speed limits are frequently below the 30–50 km/h range assumed in city-cycle testing, traffic-calming measures (speed bumps, chicanes, narrow lane widths) impose additional deceleration events, and driveway or curb-side parking manoeuvres introduce very low-speed, high-curvature motion not represented in standard drive cycles at all. Studies of DWPT at signalized intersections capture part of this picture Liu et al. modelled eco-driving behaviour of connected and autonomous vehicles approaching a four-arm, fixed-time signalized intersection and found that coordinating vehicle speed with the DWPT segment layout could substantially reduce network-wide energy consumption while increasing the energy transferred and stored per vehicle [1] but this captures a single intersection rather than the sequence of stops, turns, and speed changes typical of an entire residential trip.

***4.3 Effect of low and variable speed on coupling and dwell time***

Coupling efficiency and energy transfer window in a DWPT segment both depend on vehicle speed, though in partially opposing ways. A slower vehicle spends more time over an energized segment (a longer dwell time), which can allow more total energy to be transferred per segment if the segment can sustain continuous activation; however, driving speed on wireless charging lanes has also been shown to significantly affect both charging efficiency and effective charging time, since very low or highly variable speed changes how activation, hand-off between adjacent segments, and coil-to-coil alignment behave over the course of a pass [21]. A full stop directly over an energized segment which is common at residential intersections and driveway approaches but essentially absent from highway DWPT operation represents an edge case closer to static or quasi-dynamic charging than to true dynamic charging, and the literature on activation control, segment hand-off, and thermal/electromagnetic behaviour under this condition is comparatively thin. Eco-driving control strategies developed for wireless charging lanes at signalized intersections address exactly this transition zone, coordinating vehicle speed so that the vehicle either passes smoothly through the intersection while charging or is brought to a controlled stop in a way that still makes efficient use of the charging lane, and multi-objective formulations have shown that a comprehensive control strategy can substantially improve energy efficiency and charging-lane load balancing at only a minor cost in travel time [22,23,24].

***4.4 Vehicle mass, rolling resistance, and regenerative braking interaction***

Two further vehicle-dynamics factors are specific to the stop-start character of residential driving. First, the frequent acceleration events following each stop increase tractive energy demand relative to sustained-speed highway driving for a given distance travelled, meaning that a residential-street DWPT segment must in principle recover more energy per unit distance simply to offset the additional consumption caused by repeated acceleration, before it can also contribute to net range extension. Second, regenerative braking recovers a portion of kinetic energy during the deceleration events that dominate urban and residential driving, which is largely absent from highway operation; any energy-gain accounting for residential DWPT should therefore net the energy delivered by charging segments against both the additional consumption from repeated acceleration and the energy already recovered through regenerative braking, rather than treating charging segments as a simple addition to a highway-style baseline. None of the DWPT energy-gain literature reviewed here performs this full accounting for a residential or general urban drive cycle, which is identified in Section 2.1 as a specific research gap.

## V. Energy Gain Feasibility

***5.1 Review of energy-gain estimation approaches***

Existing energy-gain estimates for dynamic wireless charging come predominantly from highway or grid-impact studies rather than vehicle-level urban studies. Fuller modelled dynamic wireless charging in California and argued that, without requiring larger or more costly batteries, it could offer an affordable way to extend usable EV range, estimating that the state would need to invest on the order of US$2.5 billion to install a 40 kW dynamic charging system and that roughly 240 miles of electrified road would be needed to let EVs charge at 100 kW while driving, a cost that could nonetheless be lower than a year of gasoline refuelling at the prices assumed in the study [30]. Turk et al. compared in-transit and home charging strategies for the Texas power grid using publicly available vehicle-miles-travelled data and a production cost model, finding that dynamic wireless charging could improve load matching with renewable generation and, in areas of high renewable penetration, meaningfully reduce consumer vehicle costs [31]. Majhi et al. framed dynamic wireless charging facility placement as a mixed-integer optimization problem balancing individual driver cost against total infrastructure investment across a road network [32]. All three of these widely cited studies are framed at the scale of a state, a grid region, or a road network, and none isolates the energy gain achievable on a single residential street or a single urban trip under realistic low-speed, stop-start conditions.

### *5.2 Adapting these models to urban/residential conditions*

Adapting network- or grid-scale energy-gain models to a residential-street or single-trip scale requires at least three changes. First, the constant-speed or free-flow-speed assumption typically used to estimate energy transferred per unit length of energized segment needs to be replaced with a full urban/residential drive-cycle speed trace, so that dwell time and coupling efficiency are evaluated at the actual, highly variable speeds a vehicle experiences rather than at a single representative highway speed. Second, segment activation and hand-off logic triggered in the reviewed vehicle-position-detection literature by fixed inductive sensing, ultrasonic/infrared proximity sensing of the type used in static residential wireless charging pads, or more recent machine-learning-based position estimation needs to be evaluated specifically under repeated low-speed approach-and-stop behaviour rather than continuous-speed pass-through [10]. Third, because urban/residential DWPT segments are short and numerous rather than long and few, load-demand models built for continuous highway corridors, such as the modified Toeplitz convolution approach developed to keep grid-load computation tractable from a few transmitter pads up to many kilometres of highway, would need to be re-parameterized for many short, closely spaced, intermittently activated segments clustered on a single low-voltage residential feeder rather than distributed along a long, lightly branching highway feeder [12].

### *5.3 Comparative synthesis of system parameters, operating conditions, and control logic*

Table 2 synthesizes the operating conditions and control logic reported across the DWPT literature reviewed here, positioned against the urban/residential focus of the present review.

| Refs. | Major Focus | System Parameters | Operating Conditions | Control Logic |
|---|---|---|---|---|
| [1] | DWPT at urban signalized intersections | Segment layout, CAV penetration rate | Fixed-time signal control, mixed CAV/human-driven traffic | Eco-driving speed coordination, segment layout optimization |
| [21,22,23] | Wireless charging lanes with eco-driving | Lane length, speed range, energy demand | Highway/arterial lane speeds, variable driving speed | Multi-objective speed control (travel time, energy, load balancing) |
| [24] | Partial WCL coverage at intersections | Coverage fraction, reward weighting | Signalized intersection approach and departure | Deep reinforcement learning (TD3) acceleration control |
| [25] | Lane-reversal for bidirectional demand | Lane allocation, directional flow | Highway with asymmetric directional demand | Mixed-integer lane-reversal optimization |
| [10] | Vehicle position detection | Sensor type, detection accuracy | Track-style DWPT pass-through | Machine-learning position estimation |
| [12] | Grid load-demand modelling | Pad count, road length, traffic volume | Highway to network-scale deployment | Modified Toeplitz convolution (mCONV) load modelling |
| [13,17,18,19,20] | Real-world pilot deployment | Segment/rail length, receiver power rating | Continuous highway, bus route, or test-track operation | Fixed or scheduled activation; billing by energy consumed |
| [27,28,29] | Standardization and alignment | Power class (up to 11 kW), coil topology | Primarily stationary; dynamic extension in development | Differential Inductive Positioning System (DIPS) |
| Present review | Urban/residential DWPT feasibility | Short segment length, low/variable speed, stop frequency | Stop-start urban and residential drive cycles, driveway approach | Proposed: intersection-to-driveway eco-driving + low-speed activation control (future work) |

**Table 2. Comparative analysis of DWPT studies by system parameters, operating conditions, and control logic, positioned against the urban/residential focus of the present review.**

### *5.4 Battery downsizing versus infrastructure investment trade-off*

A central premise of the DWPT literature is that continuous or frequent en-route charging allows a smaller onboard battery to deliver a given effective range, reducing vehicle mass, cost, and material demand; EVolution Road's cost analysis, for example, illustrates the trade-off at national scale, estimating that a passenger car relying primarily on fast-charging stations may need on the order of 50–100 kWh of battery capacity, versus roughly 20 kWh if electric-road charging is available, with a correspondingly lower total depreciation cost across the vehicle-plus-infrastructure system [15]. Whether an analogous trade-off holds at residential-street scale is unresolved: the battery-downsizing benefit of a residential DWPT segment accrues only to vehicles that regularly use that specific street, so the fixed capital cost of the segment (Section 3.3) is amortized over a much smaller and less predictable set of charging events than a highway corridor used by continuous through-traffic. This asymmetry between concentrated capital cost and diffuse, trip-dependent benefit is a central open question for residential DWPT feasibility.

## VI. System Architecture and Enabling Components

### *6.1 Segment design and activation control*

A DWPT installation is built from a sequence of short transmitter segments, each energized only while a vehicle is detected overhead, so that the road is not left continuously live between passes. In a residential or urban setting, this segment length must be reconciled with two competing pressures: shorter segments reduce the fraction of road left permanently energized and simplify hand-off logic, but require more frequent activation switching and more closely spaced power electronics and grid connection points, raising both cost and control complexity relative to the long, sparsely divided segments used on highway pilots [3,4]. The stop-start character of residential driving compounds this: a vehicle that stops directly over or just short of an activated segment behaves differently from one passing through at speed, and control logic developed for continuous-speed highway pass-through does not automatically transfer to this case.

### *6.2 Vehicle detection and activation sensing*

Detection of vehicle presence and position is required both to activate the correct segment and to avoid needlessly energizing unoccupied road. Approaches reported in the literature include fixed inductive sensing (used in most highway DWPT pilots), ultrasonic and infrared proximity sensing of the kind already used for alignment in residential static wireless charging pads, and, more recently, machine-learning-based position estimation intended to improve activation accuracy beyond simple threshold-based sensing [10]. None of these has been validated specifically for the low-speed, stop-and-reverse manoeuvres (parking, three-point turns, driveway approach) that a residential deployment would need to handle reliably, which is identified as an open technical question in Section 8.

### *6.3 Coil topology and low-speed misalignment tolerance*

The coil topologies surveyed in the broader wireless-EV-charging literature bipolar pads (BPP), Double-D pads (DDP), Double-D quadrature pads (DDQP), circular pads (CP), and circular-rectangular pads (CRP) trade off coupling strength, tolerance to lateral and angular misalignment, and footprint. For continuous highway-speed DWPT, misalignment tolerance mainly needs to accommodate lane-keeping variation; for residential and urban DWPT, it additionally needs to accommodate driveway-approach angles, parking manoeuvres, and the tighter turning radii typical of residential streets, none of which has received dedicated comparative testing in the literature reviewed here.

### *6.4 Standardization: SAE J2954 and the Differential Inductive Positioning System*

The SAE J2954 family of standards defines interoperability, alignment, electromagnetic compatibility, and safety criteria for light-duty wireless EV charging, currently covering up to 11 kW at efficiencies reported up to 93% [27,28]. Its Differential Inductive Positioning System (DIPS) leaves the otherwise idle ground-assembly coil powered at a very low signal level so that the vehicle-side coil can triangulate its position for alignment guidance, and the standard explicitly anticipates a forthcoming dynamic-charging extension, SAE J2954/3, which is still under development [29]. Because the current standard is framed around stationary charging, urban and residential DWPT deployments today would need to rely on manufacturer-specific or pilot-specific control and alignment schemes until a dynamic-charging standard is finalized a further reason that no residential-scale DWPT product exists yet.

***6.5 Vehicle-to-infrastructure communication***

Effective segment activation, billing, and safety interlocking depend on some form of vehicle-to-infrastructure (V2I) communication layer, whether through dedicated short-range communication, cellular V2X, or the low-intensity magnetic signalling used for DIPS-style alignment. Eco-driving and speed-control studies for wireless charging lanes generally assume connected and, in some cases, autonomous vehicles capable of coordinating speed with signal timing and charging-lane occupancy in real time [1,23,24]; a residential or general urban deployment serving a mixed fleet of connected, partially connected, and conventionally driven vehicles would need a communication and control architecture robust to this heterogeneity, which the literature reviewed here has not yet addressed in a residential-specific way.

## VII. Critical Assessment and Discussion

***7.1 Synthesis***

Read together, the literature surveyed in Sections 2–6 supports three broad conclusions. First, the technical building blocks needed for urban and residential DWPT already exist in some form coil topologies, activation sensing, eco-driving speed control, and standardization frameworks have all been demonstrated but every one of them has been developed and validated primarily for highway-speed or dedicated-lane conditions, not for the stop-start, low-speed, mixed-manoeuvre conditions of an ordinary residential street. Second, real-world pilot cost data, while limited, consistently show capital costs (roughly US$1–7 million per lane-km, Section 3.3 and Fig. 1) that are justified today only by corridor-scale or fleet-scale amortization; no publicly documented pilot has yet tested whether a much smaller, street-scale segment can be justified on its own economic terms. Third, energy-gain modelling has matured considerably at grid and network scale but has not yet been extended down to the level of a single urban or residential drive cycle with a full accounting of stop-start acceleration losses, regenerative braking recovery, and short-segment dwell time, leaving the central feasibility question does a residential DWPT segment deliver a net range or cost benefit once realistic drive-cycle losses are subtracted empirically open.

***7.2 Feasibility discussion***

The technology acceptance model (TAM) and the theory of diffusion of innovation (DOI), both used to interpret adoption patterns in the wider wireless-EV-charging literature, are informative here. TAM suggests that perceived ease of use and usefulness drive adoption; a residential DWPT segment that reliably tops up a vehicle's battery during the ordinary course of a daily commute would score well on perceived usefulness, but only if activation, alignment, and billing are fully automatic and require no behaviour change from the driver a bar that current sensing and standardization maturity (Section 6) does not yet clearly meet for stop-start conditions. DOI likewise predicts that a technology with lower complexity and higher compatibility with existing infrastructure diffuses faster; residential DWPT currently scores poorly on both counts relative to static home wireless charging, since it requires road excavation, utility coordination, and a still-incomplete dynamic-charging standard, whereas static charging can be installed within a single driveway using an already-standardized system (SAE J2954, current edition).

***7.3 Practical implications***

For urban planners, the pilot cost data reviewed in Section 3.3 suggest that residential DWPT is unlikely to be justifiable as a stand-alone street-level investment in the near term, and that nearer-term deployment is more likely at the scale of a shared arterial corridor, a bus route, or a small number of high-traffic intersections using quasi-dynamic charging, consistent with how essentially every documented pilot to date has actually been funded. For automotive OEMs, the misalignment-tolerance and low-speed-detection gaps identified in Sections 6.2–6.3 point toward vehicle-side investment (robust low-speed position sensing, misalignment-tolerant receiver coils) as a parallel track to infrastructure development, so that vehicles are ready to exploit urban DWPT segments as and when SAE J2954/3 and comparable dynamic-charging standards mature.

## VIII. Challenges and Limitations

***8.1 Technical challenges***

Coil misalignment tolerance under stop-start, low-speed, and driveway-approach manoeuvres remains inadequately characterized; segment activation latency and hand-off logic have been validated chiefly for continuous-speed pass-through rather than for vehicles that slow, stop, or reverse over a segment; and thermal and electromagnetic behaviour when a vehicle stops directly over an energized segment for an extended period plausible at a residential stop sign or driveway has not been systematically studied.

***8.2 Infrastructural and economic challenges***

Reported capital costs (Section 3.3, Fig. 1) are an order of magnitude higher, per lane-km, for inductive systems than for the conductive rail systems piloted in Sweden, and even the lower conductive-system costs have been judged not cost-effective for a national rollout by Sweden's own 2024 assessment [13,14]. A residential street or small neighbourhood, lacking the continuous through-traffic that justifies highway or transit-corridor investment, faces a correspondingly harder economic case, and no dedicated residential-scale techno-economic study yet exists to quantify it.

***8.3 Grid impact***

Grid-load modelling approaches such as mCONV have made highway- and network-scale DWPT load analysis computationally tractable [12], but the clustering of many short, closely spaced, intermittently activated segments on a single residential low-voltage feeder plausible if a neighbourhood installed DWPT along several streets has not been specifically modelled, and the coincidence of many households charging dynamically during the same evening commute window could plausibly produce sharper, more localized load peaks than the same number of vehicles charging statically overnight.

***8.4 Regulatory and safety considerations***

Electromagnetic field (EMF) exposure is a well-studied concern for static wireless charging, with international guidelines from ICNIRP and IEEE C95.1 setting frequency-dependent limits on induced electric field and specific absorption rate, and SAE J2954 itself incorporating EMF criteria consistent with ICNIRP limits, including a magnetic flux density limit around 27 µT in areas accessible to the general public [27,35,36]. Existing exposure assessments have modelled adults and children in standing, sitting, and lying postures near static or parked wireless charging systems, generally finding exposure within ICNIRP limits except in specific worst-case postures such as a person lying directly beneath the vehicle [34,36,37]. Dynamic and quasi-dynamic charging in a residential or urban setting introduces exposure scenarios not covered by this static-charging literature: pedestrians and cyclists crossing an energized segment, children playing on or near a residential street with embedded coils, and the cumulative exposure from multiple closely spaced energized segments along a single block. Dedicated EMF exposure assessment for these scenarios is presently absent from the literature.

***8.5 Vehicle-side compatibility***

Ground clearance, chassis material, and receiver-coil placement vary significantly across vehicle classes (two-wheelers, hatchbacks, sedans, SUVs), a variation the standard highway-oriented DWPT literature generally does not address in comparative terms. Residential streets, unlike a purpose-built highway DWPT lane, are shared by the full diversity of a country's vehicle fleet, making cross-class coil compatibility a more pressing concern for urban/residential deployment than for a dedicated transit or freight corridor.

## IX. Conclusions

Dynamic wireless power transfer has progressed from laboratory demonstration to a number of real, publicly documented highway, transit-corridor, and test-track pilots, supported by an expanding literature on system architecture, eco-driving control, vehicle position detection, and standardization. This review has shown that this literature, taken as a whole, is built almost entirely around highway-speed or dedicated-lane operating assumptions, and that the low-speed, stop-start, short-segment, tightly budgeted character of urban and residential roads has been addressed only partially, chiefly through studies of quasi-dynamic charging and eco-driving at individual signalized intersections. Standard drive-cycle characteristics for urban driving diverge substantially from the near-constant-speed assumptions used in most published DWPT energy-gain models, real-world pilot capital costs (US$1–7 million per lane-km) are justified today only at corridor or fleet scale, and grid-load, EMF-exposure, and vehicle-compatibility considerations specific to a residential setting remain largely unexamined. The original contribution of this review lies in assembling these strands vehicle dynamics, drive cycles, real-world cost data, and DWPT system literature into a single assessment focused specifically on residential and urban feasibility, and in identifying the concrete research gaps (Section 2.1) that would need to be closed before a residential-scale DWPT deployment could be evaluated with the same rigor as an existing highway pilot.

**What's Next**

Closing the gaps identified in this review will likely require, at minimum: (i) drive-cycle-based energy-gain models that use full urban/residential speed traces rather than constant-speed assumptions, netting stop-start acceleration losses and regenerative-braking recovery against segment energy delivered; (ii) coil and activation-control designs specifically tested for driveway-approach angles, parking manoeuvres, and extended full stops over an energized segment; (iii) extension of grid-load modelling approaches such as mCONV to the clustered, low-voltage-feeder case of a residential neighbourhood; (iv) dedicated EMF exposure assessment for pedestrians, cyclists, and children in residential DWPT scenarios, building on the existing static-charging exposure literature; and (v) a techno-economic model that treats a residential street or small neighbourhood, rather than a highway corridor or transit fleet, as the unit of investment, so that the amortization logic already established for highway DWPT (Section 3.3) can be properly adapted or shown not to transfer to the residential case. Progress on standardization, particularly the pending SAE J2954/3 dynamic-charging standard, will also be a prerequisite for any of these research directions to translate into a deployable residential DWPT system.

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