

# Wireless Power Transfer and IoT-Enabled Electric Vehicle Charging in the Context of 100% Renewable Energy Systems: A Review

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**Abstract** - The way we charge electric vehicles (EVs) is changing from using plug-in chargers to more advanced systems that use wireless power transfer, include sensors, and connect to networks. At the same time, energy research is shifting towards power systems that rely completely on renewable sources. This review brings these two areas together by looking at nine studies from 2022 to 2026. These studies cover wireless power transfer (WPT), charging management using the Internet of Things (IoT), planning for charging infrastructure, robotic charging, and the history and modeling of 100% renewable energy systems. The review compares different wireless charging methods like inductive, resonant, and capacitive, and also mentions magnetic gears as another related contactless technology. It covers cloud-based management and security systems, as well as robots that use vision guidance for charging. These topics are then connected to renewable energy research, where solar and wind power are key, and transport electrification is a major way to link energy and transportation. Studies on employment, system resilience, and national decarbonization explain why this shift is important beyond just technology. The review finds that most charging studies are tested only through simulations, and issues like interoperability, cost, and electromagnetic safety are still not fully solved. Also, among the nine studies, very few model the renewable energy supply that the charging systems rely on. This is because the studies were selected rather than found through a systematic search, so the finding is just an indication. The review suggests a layered approach to integration and lists research gaps for students and researchers working at the intersection of EV charging and renewable energy.

**Key Words:** Electric vehicle, Wireless power transfer, Internet of Things, Dynamic wireless charging, 100% renewable energy, Sector coupling, Charging infrastructure, Cybersecurity.

## 1. INTRODUCTION

### 1.1 Motivation

Electric vehicles (EVs) are promoted as a way to cut exhaust emissions and urban air pollution, but their benefit depends on two things: how conveniently and safely they can be charged, and how clean the electricity is. These questions are usually studied by separate communities. One community works on charging

hardware and communication, such as wireless power transfer (WPT) and Internet of Things (IoT) based charging systems [1]. The other works on energy systems that run entirely on renewable sources, a field that began in the 1970s and has grown quickly since the mid-2000s [2].

Charging stations are also a grid problem. Large numbers of chargers raise issues of power quality, limited grid capacity and uncertain demand [3], and they create new cyber-security risks when stations are networked and managed from the cloud [4]. Automation is arriving as well, with robots that detect the charging port and plug in without a driver [5]. At the same time, renewable energy research uses detailed models to show how solar, wind, storage and transport can be combined [6], and it asks what the transition means for jobs [7], for national decarbonisation [8] and for the resilience of countries [9].

### 1.2 Scope and Method of This Review

This review is based on nine papers provided for the study. Four of these papers focus on EV charging: a review of wireless power transfer and IoT in EV charging [1], a review of charging station infrastructure [3], a cloud-based charging management and security framework [4], and a vision-guided charging robot [5]. One paper is a historical review of 100% renewable energy research [2], which also considers EV charging as a flexibility option. The remaining four papers deal with the renewable energy transition: modelling frameworks [6], global employment [7], transport decarbonization in Denmark [8], and country resilience [9]. All the papers were read in full, grouped by theme, and compared based on their methods, results, and limitations. No new experiments were conducted. The nine papers were selected rather than found through a systematic search, so this is a selective and illustrative synthesis, not a systematic review.

Three of the nine papers are themselves reviews ([1]-[3]), four are energy-system modelling, scenario, or index studies ([6]-[9]), and only two ([4], [5]) directly report on charging systems; Sections 4 and 5.1 largely rely on [1]. Therefore, conclusions about the broader literature, especially the apparent lack of renewable supply modelling in charging studies, need to be verified through a systematic search. All numerical values mentioned here are taken from the cited authors' reports, and statements

marked as interpretation reflect the opinion of this review, not the cited papers.

### 1.3 Organization

Section 2 provides an overview of renewable energy. Section 3 discusses the charging infrastructure. Section 4 focuses on wireless power transfer. Section 5 covers IoT, management, security, and automation. Section 6 combines the two main topics. Sections 7 to 10 present a comparison, identify research gaps, explore future possibilities, and conclude the review.

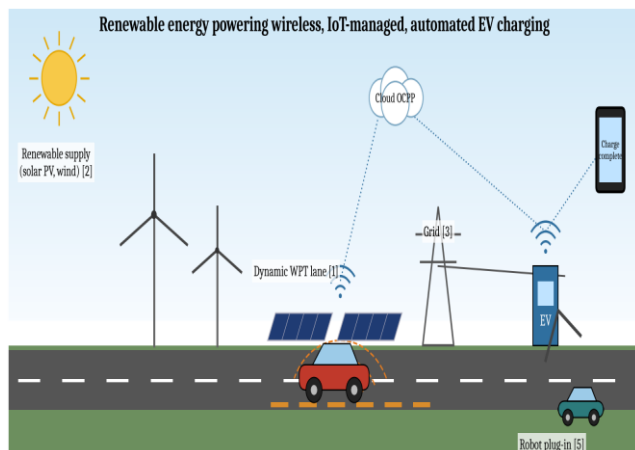


**Fig -1: Graphical abstract - renewable energy powering wireless, IoT-managed and automated EV charging (illustration drawn for this review)**

## 2. RENEWABLE ENERGY SYSTEMS RESEARCH

### 2.1 History and Growth of the Field

Breyer et al.[2] point out that research on 100% renewable energy systems started in the mid-1970s, mainly because high oil prices led to the first studies on the topic. However, the field only gained a lot of attention in the mid-2000s, and by July 2021, there had been 550 articles published. Around 74% of these studies look at national or regional systems, with the United States, Denmark, Germany, and Australia being the most studied countries. Most of the research concludes that it is possible to have a fully renewable energy system around the world at a low cost. Solar photovoltaics (PV) and wind power are the main energy sources in these systems. Cost optimization usually favors more solar PV, while the desire for a more diverse energy mix usually leads to more wind power. Recent studies focus on issues like grid congestion, energy storage, connecting different energy sectors, electrifying transport and industry, power-to-X technologies, and carbon dioxide removal [2]. These are the main findings from the studies reviewed in [2]. There is also debate in the broader literature about the feasibility of 100% renewable systems, but this review does not examine that debate. The same paper also lists some open problems. These include

proving that a system with 100% inverter-based, non-synchronous generation can operate stably, understanding how these systems affect the availability of critical materials, addressing the imbalance in research between the Global North and the Global South, and including solutions for off-grid areas. It also mentions that organizations like the IEA and IPCC have been slow to incorporate these findings. [2].

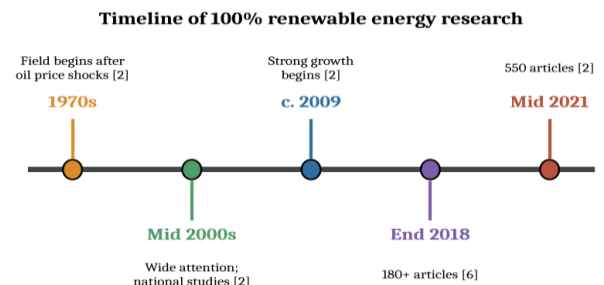


**Fig -2: Timeline of 100% renewable energy research**

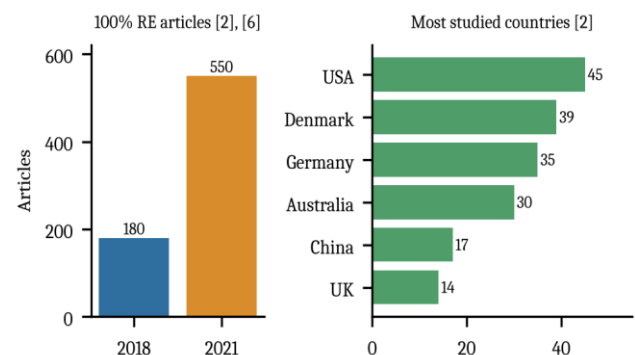


**Fig -3: Growth and country coverage of 100% renewable energy research**

### 2.2 Energy System Modelling

Lopez et al. [6] compare two widely used tools under identical assumptions: the LUT Energy System Transition model, which is an optimisation model, and EnergyPLAN, which is a simulation tool. Using Bolivia as a case study, both give a solar PV dominated system. However, EnergyPLAN has limits in sector coupling, which raised annualised costs by about 30% compared with the single-node LUT result. Overnight scenarios, which ignore the existing energy system, undershoot costs by 20 to 30% compared with transition scenarios. Higher spatial resolution can lower system cost where the best solar resources are concentrated in a few regions, and aligning heating value conventions changes cost by 2 to 4% [6].

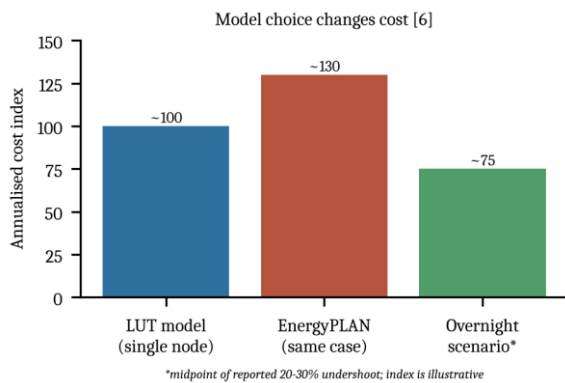


Fig -4: Effect of model choice on annualised cost

## 2.3 Socioeconomic and Sustainability Context

Ram et al. [7] estimate that direct energy jobs in the power, heat, transport and desalination sectors grow from about 57 million in 2020 to nearly 134 million by 2050 in a 100% renewable scenario, while fuel production jobs fall from about 18 million to about 4 million. About 10 million storage jobs appear by 2050, mainly in batteries. The authors state that the batteries needed for battery electric vehicles are not counted, so automotive and charging jobs would add to this figure [7].

Bolson et al. [9] build an eight-indicator resilience index for 160 countries over 20 years. Socioeconomic indicators improved, but natural resources were depleted and environmental impacts worsened. They conclude that the material footprint must fall by a factor of 1.5 and average CO2 emissions per person by an order of magnitude [9]. Technology alone is therefore not enough, and a charging system that needs large amounts of material should be judged against this limit (interpretation).

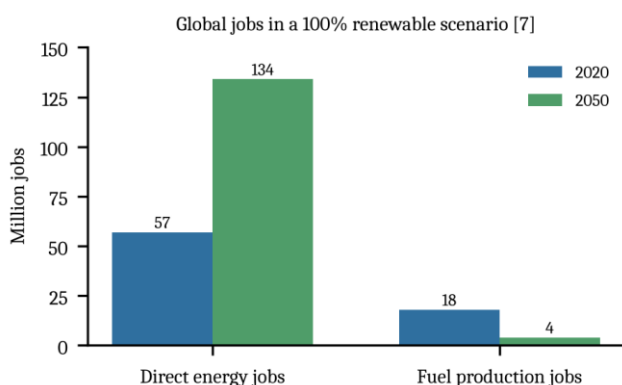


Fig -5: Global energy jobs, 2020 and 2050

## 2.4 Transport Decarbonisation

Kany et al. [8] model the Danish transport sector, which caused 44% of national CO2 emissions in 2019. Their pathway gives a 41% cut in greenhouse gas emissions by

2030 and full decarbonisation by 2045, without a significant rise in socio-economic cost. Road transport is largely electrified and demand is shifted to rail and cycling, while electrofuels cover aviation, shipping and heavy transport. Expanding the charging network is estimated at 0.4 billion euro by 2030 and a further 0.7 billion euro from 2030 to 2045 [8].

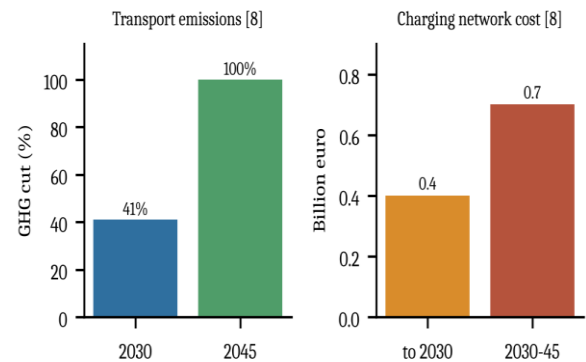


Fig -6: Danish transport decarbonisation and charging network cost (data from [8])

## 3. EV CHARGING INFRASTRUCTURE

### 3.1 Charger Types and Station Challenges

Yousuf and others [3] discuss various types of charging equipment, such as conductive AC chargers (which are Level 1 and Level 2), DC fast chargers that use the Combined Charging System, CHAdeMO, or Tesla connectors, and inductive or wireless charging methods. They also mention other alternatives like battery swapping, mobile charging, and robotic charging stations. The challenges they point out include the diversity of electric vehicles and battery technologies, high costs for installation, limited grid capacity, uncertain future demand, and problems related to power quality, security, and stability. Issues with power quality involve voltage fluctuations, unexpected power spikes, frequency instability, and harmonic distortion [3].

The paper also notes that parked electric vehicles can act as storage for demand response programs and for vehicle-to-grid (V2G) applications.

It states there are 131 V2G projects in 27 countries, using more than 6800 chargers. The V2G market is projected to grow from USD 11.3 million in 2023 to USD 59.2 million by 2030. However, this projection hasn't been independently confirmed, and only the starting and ending values are given, so any intermediate growth shown in Figure 7 is estimated [3].

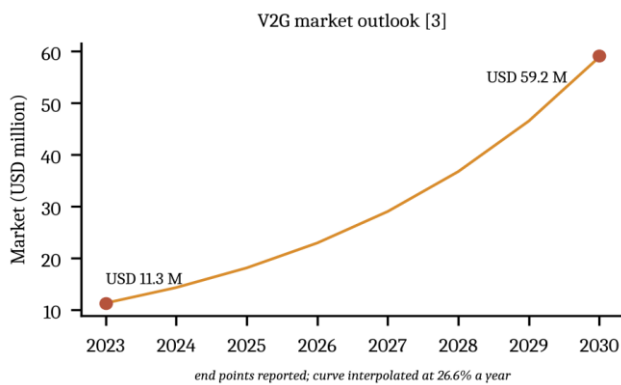


**Fig -7: V2G market outlook to 2030**

### 3.2 Optimisation Strategies

The review groups optimisation into location planning, network integration, charging time scheduling and price planning, solved with single-stage or multistage methods such as mixed-integer linear programming [3]. Single-stage models give an integrated solution but can be hard to scale to large networks, whereas multistage models split the problem into smaller parts [3].

## 4. WIRELESS POWER TRANSFER FOR EVS

### 4.1 Operating Principle

Karim et al. [1] explain that a transmitter coil in the road or pad carries alternating current and creates a time-varying magnetic field. By Faraday's law this induces a voltage in a receiver coil under the vehicle, and a rectifier converts it to direct current for the battery. Efficiency depends on mutual inductance, coupling coefficient, frequency, air gap and resonance. Compensation networks, namely series-series, series-parallel and LCC, are used for reactive power control and voltage regulation, and ferrite cores and coil shapes such as circular, rectangular and double-D shape the magnetic flux [1].

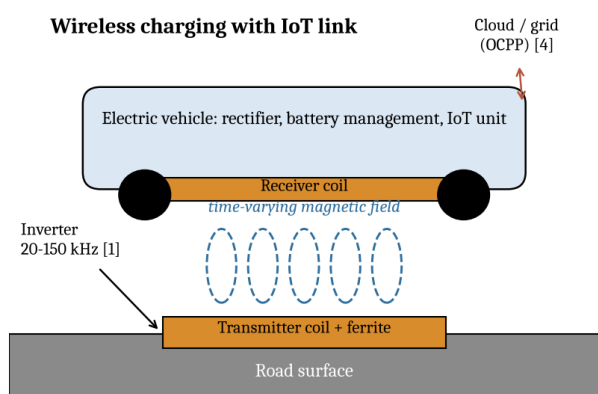


**Fig -8: Principle of wireless EV charging with an IoT link (schematic drawn for this review)**

### 4.2 WPT Techniques

Table 1 summarizes the four wireless power transfer methods discussed in [1]. Inductive power transfer is the most developed and is used for both stationary and moving charging. Resonant inductive coupling can handle bigger gaps and misalignment but requires precise adjustment. Capacitive power transfer is lightweight and produces less electromagnetic interference but transfers less power. Magnetic gear transmission moves torque, not electricity, and is mentioned in [1] as a related contactless method. In real use, most electric vehicle inductive systems already use resonant compensation, so the first two methods are somewhat similar

**Table -1: Comparison of WPT techniques (from [1])**

| Technique          | Strengths                                             | Limitations                                    |
|--------------------|-------------------------------------------------------|------------------------------------------------|
| Inductive (IPT)    | Most mature; safe; static and dynamic use             | Sensitive to misalignment; limited range; EMI  |
| Resonant inductive | Better range and misalignment tolerance; lower losses | Tuning complexity under changing load          |
| Capacitive (CPT)   | Light hardware; low EMI; small eddy losses            | Low power; sensitive to gap and plate position |
| Magnetic gear      | Quiet; no wear; overload protection                   | Mechanical torque only; costly magnets         |

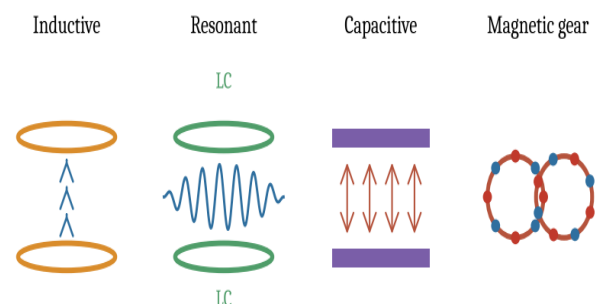


**Fig -9: Sketches of the four WPT techniques**

### 4.3 Dynamic Wireless Charging

Dynamic wireless charging (DWC) powers the vehicle while it moves and could reduce battery size. Studies on highways, motorways and urban roads show that road type, speed and charging lane length strongly affect energy transfer; urban roads suit lower speeds, while highways face intermittent coupling and high infrastructure cost [1]. Regional studies using the ERCOT transmission model and Canadian highway networks suggest that in-transit charging can cut operating cost and better match EV demand to renewable generation [1]. Many DWC results

rely on simulation with constant speed and perfect alignment, so the paper judges DWC to be better suited at present to controlled settings such as bus lanes and logistics corridors [1].

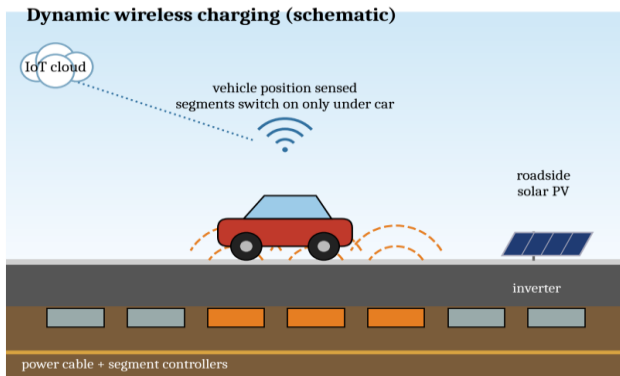


**Fig -10: Dynamic wireless charging lane with segment switching**

#### 4.4 Technical Progress, Challenges and Safety

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## 5. IoT, MANAGEMENT, SECURITY AND AUTOMATION

### 5.1 IoT Layers in Wireless Charging

Karim et al. [1] describe three interdependent layers: the physical WPT layer (coils, compensation, power electronics), the IoT communication and control layer (sensing, adaptive power and frequency control, fault diagnosis), and the application and service layer (user interaction, grid coordination, scheduling, billing and security). IoT supports coil position detection, segmented coil activation in dynamic lanes and decisions that consider traffic and grid conditions [1]. The same paper notes that ISO 15118 and Plug-and-Charge studies reveal weaknesses in key management and authentication, and that most security studies treat communication layers on their own without the WPT hardware [1].

### 5.2 Cloud-Based Management and Security

Hamdard and their team introduced the Hybrid EV Charging Management and Security (H-EVCMS) framework. This system combines both centralized and decentralized control approaches to manage multiple charging stations. It uses the Open Charge Point Protocol (OCPP) 1.6 and has an improved session management process to make the system more secure. Each charging station is given a weight based on two things: the number of bookings (which counts for 60%) and the power it uses (which counts for 40%). The station with the lowest weight is chosen to spread out the demand more evenly and lower the overall cost of charging. When tested with simulated data, this framework performed better in using resources than the earlier EVCMS framework. The authors also pointed out possible future work, which involves dealing with cybersecurity risks that could impact the connection between the charging station and the server.

**H-EVCMS selection flow [4]**

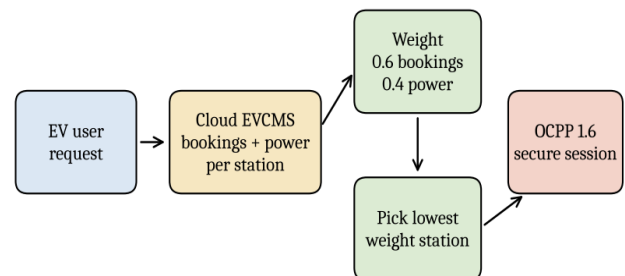


**Fig -11: Station selection flow in H-EVCMS**

### 5.3 Vision-Guided Robotic Charging

Mahadevan et al. [5] present AViTRoN for automatic charging robots. A YOLOv8 model, a 3D depth sensor and an infrared sensor running in the Robot Operating System detect the port type, and a GSM/GPRS module alerts the user when charging ends. The model recognizes seven port types (CCS1, CCS2, GB/T, Type 1, Type 2, CHAdeMO and Tesla), and the arm kinematics were tested in Gazebo simulation. Real-world integration with automated guided vehicles remains future work [5].

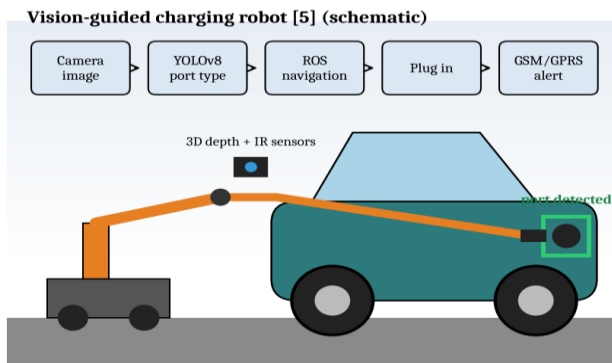


Fig -12: Vision-guided robotic charging pipeline

Table -2: YOLOv8 detection results per port type

| Port type   | Precision | Recall | mAP50 |
|-------------|-----------|--------|-------|
| Type 1      | 0.988     | 1.000  | 0.995 |
| CCS1        | 0.990     | 0.875  | 0.971 |
| GB/T        | 0.990     | 0.933  | 0.925 |
| Type 2      | 0.861     | 0.842  | 0.917 |
| Tesla       | 0.838     | 0.882  | 0.879 |
| CHAdemo     | 0.905     | 0.750  | 0.830 |
| All classes | 0.927     | 0.947  | 0.930 |

The paper also reports 7.8 ms inference time per image and 11,128,680 model parameters [5]. CCS2 is one of the seven classes but its separate figures are not given in the text of [5], so it is omitted from

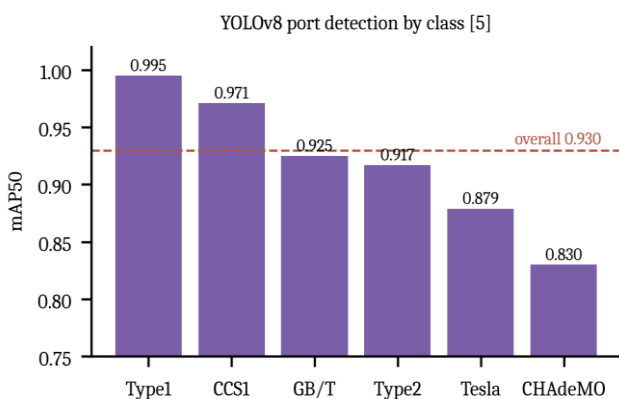


Fig -13: Detection mAP50 by charging port type (CCS2 omitted; data from [5])

## 6. MERGING THE TWO TOPICS

### 6.1 A Layered View

The papers come together at one point: EV charging serves as both a sector coupling load and a flexibility resource within a renewable energy system. The historical review [2] outlines a priority order for final energy use, beginning with direct electricity applications like heat pumps and

battery electric vehicles, and identifies smart EV charging and vehicle-to-grid (V2G) as underutilized flexibility options. Figure 14 positions the topics related to charging within this energy framework as five distinct layers. This structure represents the interpretation of the review and is not based on a model from any single paper not based on a model from any single paper.

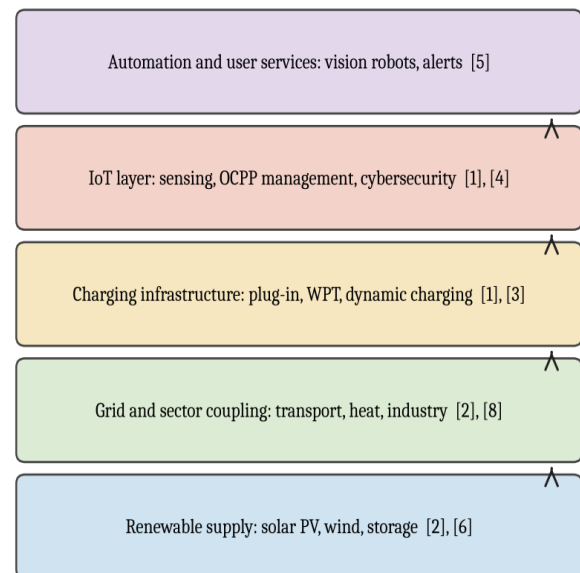


Fig -14: Layered view linking renewable supply to charging, IoT and automation

### 6.2 Where the Studies Connect

**Supply and demand.** Renewable models rely on storage, demand response and sector coupling [2], [6]. Charging reviews show that EVs can act as storage and that V2G is growing [3], and that DWC can match EV demand to renewable generation [1]. Solar PV powered roadside wireless charging is reported to reduce grid dependence and emissions [1], which fits the finding that solar PV dominates many cost-optimal systems [2], [6].

**Infrastructure cost.** The Danish pathway puts charging expansion [8], while DWC road works are described as expensive [1].

**Control and security.** A system with high shares of variable renewables needs charging that responds to price and grid signals. OCPP-based management [4] and IoT control layers [1] provide the communication needed, but they also widen the attack surface, a risk that both papers flag [1], [4].

**Materials and jobs.** The history review calls for more study of critical materials [2], and the resilience study asks for a lower material footprint [9]. WPT coils depend on ferrite cores and magnetic gears on rare-earth magnets [1],

so material use should be added to WPT assessments (interpretation). The job study [7] excludes EV batteries, so charging infrastructure employment remains unquantified.

**Automation.** Robotic charging [5] removes the user from plugging in and could suit shared or autonomous fleets, but the paper itself is limited to detection and simulation, so its link to renewable operation is only prospective.

### 6.3 Proposed Concept: Renewable-Aware Charging

Building on the station weight of [4], which uses only bookings and power consumption, supplied by a renewable forecast and a grid signal. The scheduler would then choose between plug-in or robot charging [5], a static WPT pad [1] and dynamic or V2G modes [1], [3], and report back through OCPP and IoT monitoring. Fig -15 shows the idea. This is a concept proposed by the authors of this review. It is not from the cited papers and has not been simulated or tested, and the weights a, b and c would have to be chosen and validated in future work.

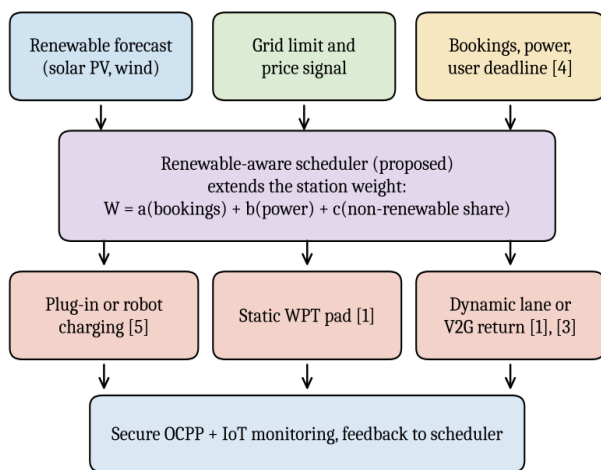


**Fig -15: Proposed renewable-aware charging scheduler (concept)**

**Table -3: Evidence base reported for each technology**

| Technology            | Evidence reported                                 | Ref. |
|-----------------------|---------------------------------------------------|------|
| Inductive WPT         | Most mature; used for static and dynamic charging | [1]  |
| Dynamic charging      | Mostly simulation; suited to controlled corridors | [1]  |
| OCPP-based management | Tested with generated data                        | [4]  |
| Vision-based robot    | Trained model and Gazebo simulation               | [5]  |
| V2G                   | 131 projects in 27 countries                      | [3]  |
| 100% RE systems       | 550 studies by mid-2021                           | [2]  |

## 7. COMPARATIVE SUMMARY OF REVIEWED PAPERS

**Table 4. Summary of the nine reviewed papers**

| Re f. | Type        | Focus                            | Main finding / limitation                                                                   |
|-------|-------------|----------------------------------|---------------------------------------------------------------------------------------------|
| [1]   | Review      | WPT and IoT in EV charging       | Compares four WPT methods; IoT as system layer; mostly simulation-based evidence            |
| [2]   | Review      | History of 100% RE research      | 550 articles by 2021; solar PV and wind central; materials and 100% inverter operation open |
| [3]   | Review      | EVCS infrastructure              | Challenges, charger types, optimisation; V2G growing; large-network scalability is hard     |
| [4]   | Framework   | H-EVCMS management and security  | OCPP 1.6 plus weighting gives better station use; cyber-threat analysis pending             |
| [5]   | System      | Vision-based charging robot      | YOLOv8 mAP50 0.930, seven port types; simulation only                                       |
| [6]   | Modelling   | LUT model vs EnergyPLAN, Bolivia | Solar PV dominant; about 30% cost gap; overnight scenarios undershoot cost 20-30%           |
| [7]   | Modelling   | Global energy jobs to 2050       | 57 to 134 million jobs; EV batteries not counted                                            |
| [8]   | Scenario    | Danish transport to 2045         | 41% cut by 2030, full decarbonisation 2045; charging cost 0.4 + 0.7 billion euro            |
| [9]   | Index study | Resilience of 160 countries      | Material footprint to fall 1.5-fold; CO2 per person by an order of magnitude                |

## 8. CHALLENGES AND RESEARCH GAPS

- **Simulation-only evidence.** Most charging proposals, including DWC and robotic charging, are validated by simulation, so field data and long-term trials are scarce [1], [5].
- **Isolated treatment of layers.** Power transfer, communication, security and control are usually studied separately [1].

- **Grid impact.** Peak load, power quality and large-scale DWC effects need more study [1], [3].
- **Standards and interoperability.** WPT, IoT and charger standards are not harmonised across makers and countries [1].
- **Health and safety.** Evidence on long-term field exposure is mixed, and foreign object detection must be reliable [1].
- **Cost and materials.** Roadway installation is costly [1], and material demand is not assessed against material footprint targets [2], [9].
- **Security.** Weak authentication in Plug-and-Charge and exposed charge point links need stronger protection [1], [4].
- **Regional balance.** Renewable studies cover the Global North far more than the Global South [2], so charging solutions for developing regions are poorly understood.

## 9. FUTURE SCOPE

Future work should (i) build joint models in which a renewable energy system model includes EV charging demand, V2G and WPT corridors, (ii) test DWC and robotic charging in field pilots, (iii) improve alignment tolerance, efficiency at speed and cost of dynamic charging [1], (iv) strengthen OCPP and Plug-and-Charge security [1], [4], (v) add life-cycle and material assessments of charging hardware [2], [9], and (vi) study operation with 100% inverter-based generation including bidirectional EV chargers [2].

## 10. CONCLUSIONS

This review merged two research areas: wireless and IoT-enabled EV charging, and 100% renewable energy systems. WPT offers convenient contactless charging, with inductive and resonant methods the most practical, while IoT, OCPP management and vision-based robots add intelligence and automation. Renewable energy research shows that solar PV, wind, storage and sector coupling can supply the whole energy system, with transport electrification as a major element. charging papers rarely model the renewable supply, and renewable models rarely model charging technology. The layered view and the gaps listed here can help students and researchers join the two, with attention to field validation, standards, security, cost and materials.

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