A Review of the Computer Science Literature on Electric Car Charging Solutions and Emission Monitoring

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Oct 1, 2024, version 0.1

Abstract

As the significance of sustainable energy solutions increases, the need to develop innovative digital applications for electric vehicle (EV) charging is escalating. This study focuses on solutions to issues encountered by reviewing the literature in computer science and other related areas. Throughout the process, conferences and journals are examined regarding contributions to infrastructure, sustainability, usability, security, and user experience in digital services. The primary goal of this study is to offer automized, budget-friendly, and sustainable solutions for providing efficient and user-oriented electric vehicle charging experience in the growing market for electric vehicles.

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1. Introduction

The global shift is towards promoting sustainable energy solutions and reducing carbon emissions, reinforcing the usage of electric vehicles (EVs) due to the limited natural resources. As the adoption of EVs is increasing, user-friendly and efficient charging solutions become paramount since traditional fueling infrastructures can not directly fit in with EV requirements, which creates new challenges in the context of technical issues and user experience.

This study examines the integration of cutting-edge AI-based solutions, such as real-time station availability monitoring, carbon emission measurement, and tailored route optimization, to address typical issues related to EV charging. Furthermore, to provide a seamless charging experience, this study aims to provide a personalized experience by optimizing time, cost, and environmental friendliness based on the user's priorities.

Technical developments and various research in the EV ecosystem are inspected to set the groundwork for this project. That process started with a market investigation to see current infrastructures, the underlying technical and architectural basis used, and the features provided. This investigation highlights crucial points specific to EV charging, such as crowded or invaded stations, incorrect route directions, and non-available but available stations.

In light of these processes and findings, solutions produced from that study aim to close gaps in the market by utilizing artificial intelligence to provide cost-effective, eco-friendly, and personalized solutions to each individual's needs, contributing to a more user-friendly and environmentally friendly EV charging experience. As the team carries out this study, we aim to give a thorough overview of the breakthroughs and solutions that drive ChargeMind's development.

2. Market Analysis

2.1 Plugshare

PlugShare is a free EV driver app for mobile (Android and iOS) and web that allows users to find charging stations, leave reviews, and connect with other plug-in car owners. As of August 2023, it is available in 29 languages [1]. It has a worldwide public charging map with stations from every major network in North America, Europe, and most of the world.

PlugShare uses the user's location or provided address to list charging stations for electric cars and show their locations on the map. The app also has certain filtering features. The user can filter by the charging station they want to go to, the station's rating, services near the station (food, shopping, parking, accommodation, grocery stores, etc.), the number of electric vehicle charging stations in a given area, stations currently in use but coming soon, charging stations provided by companies or brands that offer a specific charging service (e.g., Supercharger, Blink, Fastned), and the type of socket. PlugShare also allows users to add stations to share their home chargers with other users. Users can register to provide information about their electric vehicles at theapp's startp. Registered users can also submit new stations, update information on existing stations, and add notes and photos for other processes. Electric vehicle charging stations are usually displayed in different colors on the map according to their access status and charging power levels. This color coding makes it easier for users to quickly find suitable stations.

The "Pay with PlugShare" feature in PlugShare allows users to pay for certain charging stations directly from the app. This feature does not require a membership, balance, or recurring payment plan and allows you to pay only for what you use. At supported stations, the "Pay with PlugShare" option is displayed in the station details. By clicking on this option, users can view charging fees, complete payment with a credit card or other payment method, and start charging sessions. When the charging process is completed, the payment summary and receipt are provided through the application.[2]

Although PlugShare offers good options for filtering to users, the travel planner feature is visible in the application, but this feature does not meet the expectations of the users. The user cannot see the chargers along the route they will travel, but only sees a road map. At the same time, the user interface is criticized for being complicated and difficult to understand. This may cause problems for users or those who do not have technical knowledge.

2.2 Lixhium

Lixhium is a national charging station application that combines the electric vehicle charging ecosystem on a single platform, brings together licensed charging station operators and electric vehicle users, and displays all stations on the same map. It is a 'neutral' marketplace with various features like smart route planning, commenting, calculating the appropriate charging amount and fee for the vehicle, illustrating the availability of stations, paying using a virtual card with wallet integration, and getting points [3].

Even though we cannot publicly access their technological infrastructure, we can say that they use big data analytics and may include machine learning algorithms [4].

However, through the feedback evaluations received from users; It is also inadequate due to problems such as slow updates, delays in adding newly opened stations, misleading station suggestions, screen freezes during route creation, and inability to produce alternative routes [5].

2.3 Open Charge Map

Open Charge Map is a free and open-source application launched in 2011 that helps electric vehicle (EV) owners find the best charging stations. It allows users to easily find charging stations near them or anywhere they want on a map. It also provides users access to station details (working hours, charging connection types, pricing information, etc.) and also has a rating system that is supported by user reviews. The main aim of this application is to make that process easier for electric vehicle owners when they plan their travel routes and provide the most suitable charging options.

This program offers filtering options that help users determine the speed and type of connection they want. Users can get a more customized experience with features such as visualization on the map, live occupancy status, directions, and user reviews. It also allowed users to update station information and add new charging points constantly.[6]

In addition to having many useful features, OpenChargeMap has some drawbacks. Because the platform is based on data that is observed through user support, some station information may be incorrect or out of date. These directions given incorrectly can be dangerous enough to affect users' roadmaps for travel, especially due to information on fullness status or speed of charging. Users report that the fullness information of stations, especially those that are full during peak hours, is not updated in a timely manner, which can be a significant problem for EV drivers traveling long distances. However, issues such as lack of information or lack of data about charging stations in certain areas shown on the map reduce the reliability of the application.

2.4 Voltla

Voltla is an application for electric vehicle owners to find all charging stations, learn vehicle charging prices from a single point, create routes to charging stations and start charging & payment. It is a platform that supports sustainable transportation and contributes to Turkey's EV infrastructure. It can be used on iOS and Android devices.

Volta offers charging stations in the vicinity to users based on location information. As in other EV applications, Voltla also has certain filtering options. This filtering can be done according to the charging type, AC (Alternating Current) or DC (Direct Current), socket power, socket kWh price range, and brand (Turkey and non-Turkey brands). At the same time, the user is also offered the opportunity to save their filters in order to prevent the user from re-entering the filtering options they frequently use. Electric vehicle charging stations are shown in different colors on the map according to the charging type. The user can send a request to the company and save their car and address to the system. The most striking feature of the application is that it provides information about the unit prices of electric vehicle charging companies according to the socket type and the amount of energy charged (Kwh).

Voltla offers its users three different methods to start the charging process. The first of these is to select the socket you want to start charging from the menu that opens when you click on the pins where you can start charging and receive payment via Voltla with an icon symbol on the map. Another method is to start the charging process by scanning the QR code on the screen of the devices at the stations where the charging process can be started or by scanning it with the help of the camera. The third method is to start charging by clicking on the start charging button with the socket code on the QR code reading screen. Before starting the charging process, Volta checks whether the socket is placed correctly, its distance to the charging station, whether the user has any previous debts, and starts the charging process if everything is appropriate. The payment is automatically withdrawn from the selected credit card with the card information entered by the user.

One of the negative aspects of the Volta application is that it only allows Turkish phone numbers to be registered during registration. This situation restricts access for users outside of Türkiye. With the widespread use of electric vehicles, accessibility to international users is an important criterion for a charging infrastructure application.[7]

2.5 ChargePrice

ChargePrice is one of the largest platforms for independent price comparison for electric vehicle (EV) charging. Apart from this feature, it has various data sets, such as the real-time status of charging stations, availability, charging rates, and vehicle features. It helps operators optimize their tariffs and improve their charging infrastructure. It also allows users to select their favorite charging stations and share them with other users. ChargePrice ensures the quality of this data by constantly checking it with cross-queries[8]. ChargePrice also provides the opportunity to create and manage a portfolio of personalized recharge cards, such as "My Best Charging Card," to users.

Additionally, the capacity to deliver real-time data and continuous communication between users and charging stations is improved by combining API and OCPI (Open et al.) connections with various operators. As a result, consumers may access the most recent data regarding charging station performance, availability, and cost straight from the platform. To develop its platform and fix any operational problems, user feedback is also a key component of its service improvement process through reviews and ratings. Frequent quality checks are carried out based on user experiences and invoice accuracy to guarantee further the platform's reliability and correctness of the information. Price alerts are another feature of ChargePrice that helps consumers minimize and avoid unforeseen expenses by providing proactive and automatic notifications if charging rates change. Lastly, ChargePrice encourages direct engagement with operators, enabling consumers to easily submit input to enhance the charging infrastructure, ask for help, or address issues.

Despite the advantages, realince of the real time data one of the struggles due to the possible challenges such as delayed or inaccurate data caused by connectivity problems or discrepancies between operators and charging stations.

3. EVRP

EVRP, or Electric Vehicle Routing Problem, is a variation of Vehicle Routing Problem that studies the concept of finding an optimal set of routes for an electric vehicle such that it conforms to various constraints, including but not limited to the battery percentage of the electric vehicle and traffic density. While the adoption of electric vehicles has seen a significant increase over the past decade, electric vehicles still need recharging and consequently necessitate elaborate route planning. Due to this situation, studies about EVRP have started to emerge at an exponential rate in recent years [9].

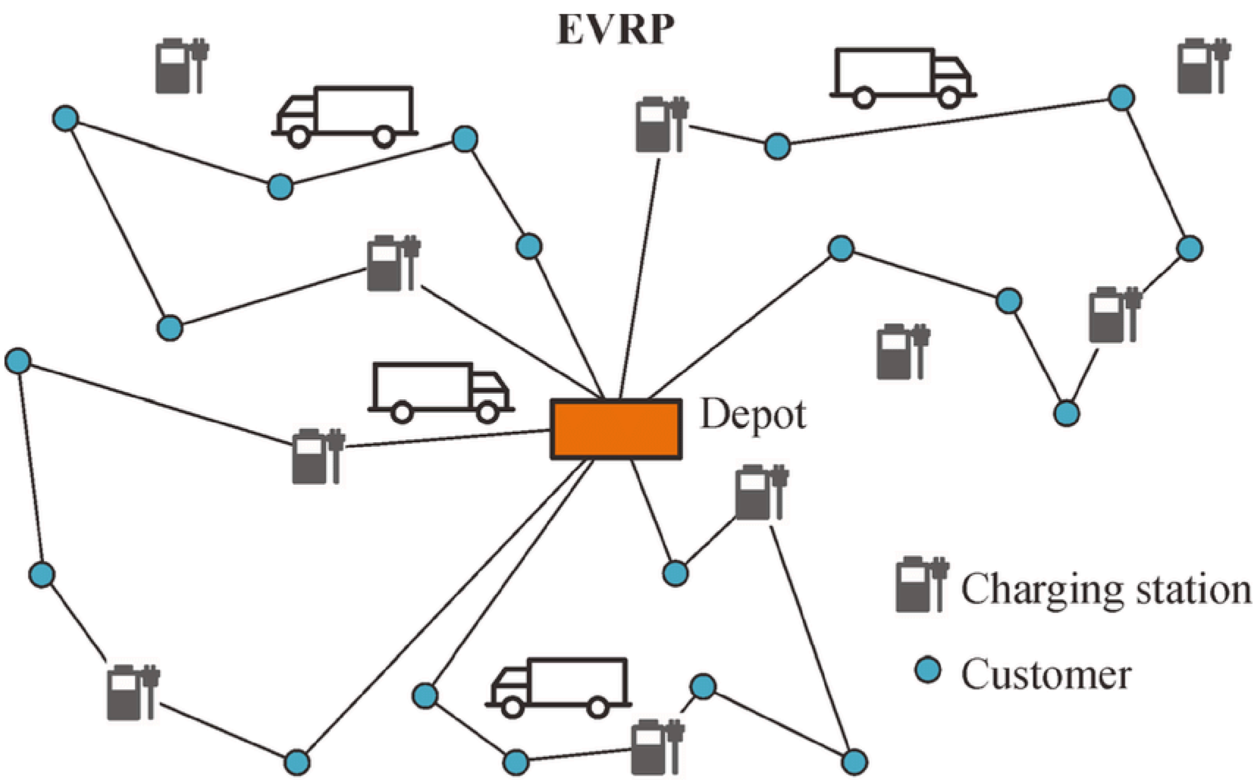

Figure 1 - EVRP Graph
[Source: https://www.researchgate.net/figure/An-example-solution-for-EVRP_fig2_351700506]

While EVRP focuses on fleets of vehicles, it can also be used for end-user electric vehicles. In our project, we aim to facilitate electric vehicle usage via not only using machine learning, but also EVRP methodologies to ease the electric vehicle driver experience, eliminating long-range anxiety and the adoption of the heavy load vehicles.

4. Machine Learning

With numerous parameters, comes the great challenge to predict what comes next in real-world scenarios. This includes foreseeing whether a charge station will be available when the driver arrives at the location. To avoid such situations, we aim to leverage the power of machine learning to find the paths that will ultimately optimize the paths that will be taken by electric car drivers.

For the possible case, features that will be selected will include both discrete and continuous data, such as hours being numerical and weather being either rainy or sunny. Handling both values of both types at the same time requires a sophisticated machine learning model, which in turn has driven us to compare existing machine learning models.

4.1 Linear Regression

It is the statistical methodology that models the relationship between a dependent and an independent variable. It makes the assumption that the variables have a linear correspondence and places a line through the available data. It is easily understandable and easy to implement, computationally efficient in small datasets, and each feature coefficient is easily interpretable; however, it is inefficient for complex data and prone to outliers. Foreseeing the availability of charging stations necessitates a non-linear understanding of features. Linear regression cannot address this situation, being a not accurate choice. On the other hand, using this model effectively still benefits our project.

4.2 Decision Trees

A decision tree splits at the decision points repeatedly based on feature values. Accuracy improves at each decision split. It is suited for non-linear relationships, easily representable visually, and allows both continuous and discrete data to be used, but it can result in completely different trees even when a small change occurs in data, it may yield poor performance on complex datasets, and they have a tendency to overfit which in turn makes them perform poorly in scenarios where there is unseen data, making it harder to predict charging station availability accurately.

4.3 Random Forest

The Random Forest method combines multiple decision trees. A random subset is used to train each decision tree for random features and random data. Ultimately, predictions are averaged to reduce overfitting and increase accuracy. This method has some pros, such as that it can handle both interactions and non-linear relationships, and it is less prone to overfitting compared to single decision trees. However, they can be computationally expensive for large datasets. Due to the ensemble nature, they can become less interpretable. They may also face challenges in making fine-grained predictions in highly dynamic environments. While Random Forests can handle tabular data considerably well, they art fine-tuneless compared to Gradient Boosting Machines(GBM). It may also require a significant amount of computational resources even without being much more efficient than GBM. This model can still be preferred for our project.

4.4 Gradient Boosting Machines

The gradient Boosting Machines (GBM) method gathers simple models together to form a better, more powerful single model. It can handle non-linear and linear relationships, and it is exceptionally superior on structured tabular data; on the other hand, it can be computationally expensive for very large datasets, necessitates careful setup of hyperplanes, and is less interpretable than Linear Regression or single Decision Trees. While GBM offers high performance on tabular data, there may be training and scaling problems because of high computational needs. Still, creating a preferable choice for the project.

5. Real-Time Operations

Obtaining instant data using Google Maps has a great advantage for real-time operations. Google Maps anonymously collects the location and speed information of millions of users worldwide and instantly analyzes this data to provide up-to-date information about traffic conditions. This information obtained is of great importance for the logistics sector, etc., which is sensitive in operational terms. For example, if someone who wants to travel using electric vehicles uses traffic data to plan a route, delivery times are optimized, and fuel costs are reduced. At the same time, alternative routes are suggested in the event of an unexpected traffic jam, thus minimizing time loss.

Thanks to this integration in applications optimized for electric vehicles, it is important to plan charging stops and breaks efficiently, especially on long-distance journeys. An EV application equipped with instant traffic data suggests suitable charging stations that the driver can reach in the shortest time, helping him avoid routes with traffic congestion. In addition, it can estimate possible waiting times at charging stations by taking into account traffic data during rush hour and adjusting the driver's route accordingly.

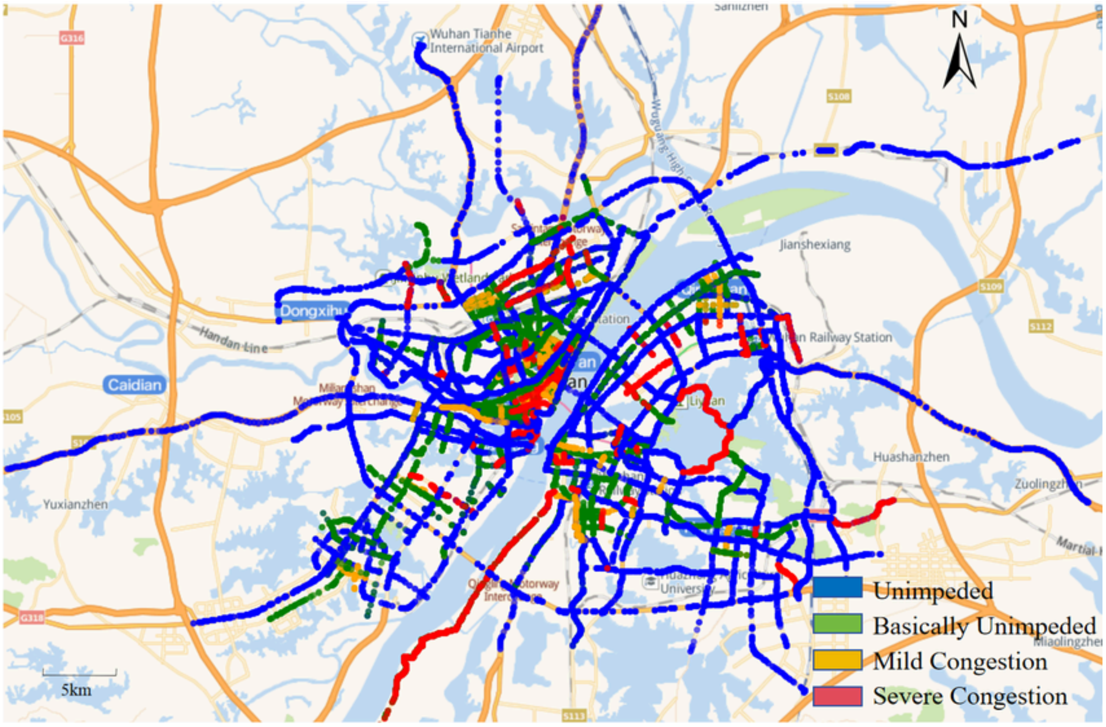

Figure 2 - Traffic Density Map
[Source: https://www.researchgate.net/figure/Real-time-traffic-data-collection-area_fig1_382702699]

The fullness data that comes from charging stations allows users to see in real-time whether the charging points at the stations are full or empty. This allows EV drivers to see if there is a suitable charging point before arriving at a station and evaluate alternative stations if necessary. Using full information provides a great advantage for users, especially during busy times or in areas with limited stations. This data from charging stations plays a major role in estimating how busy a station is, average waiting times, and which charging connections are available. This data also helps to minimize both waiting times and unnecessary routes.

6. Carbon Emission

The transportation sector is one of the largest sources of greenhouse gas emissions in the European Union, and despite efforts such as increasing the deployment of electric vehicles (EVs), emissions have shown little reduction since 2005. Estimates for 2023 show only a slight drop of 0.8% compared to 2022, with projections indicating that domestic transport emissions will not fall below their 1990 levels until 2032 [10]. By transitioning to electric vehicles (EVs), carbon emissions can be reduced globally, with EVs offering a cleaner alternative to traditional combustion engines. Charged EVs, however, have a larger carbon footprint due to the electricity used to charge them. In order to fully understand EV adoption's environmental impact, it is crucial to monitor carbon emissions from charging stations. It is traditional to use sensors to detect air quality and greenhouse gas emissions, but it is also possible to estimate these emissions without using sensors. An example is the use of energy consumption data, grid emissions factors, and other indirect methods.

The design of an energy big data and carbon emission monitoring system can benefit from machine learning models like the perceptron model, especially when targeting carbon neutrality and carbon peaking. By integrating real-time data from energy consumption and emissions sources, these systems can track carbon footprints effectively. For example, the perceptron model can classify and predict emissions based on inputs such as energy consumption and regional grid factors, providing more accurate emissions data for real-time decision-making [11].To fully understand EV adoption's environmental impact, it is crucial to monitor carbon emissions from charging stations. While it is traditional to use sensors to detect air quality and greenhouse gas emissions, it is also possible to estimate these emissions without using sensors. An example is the use of energy consumption data, grid emissions factors, and other indirect methods.

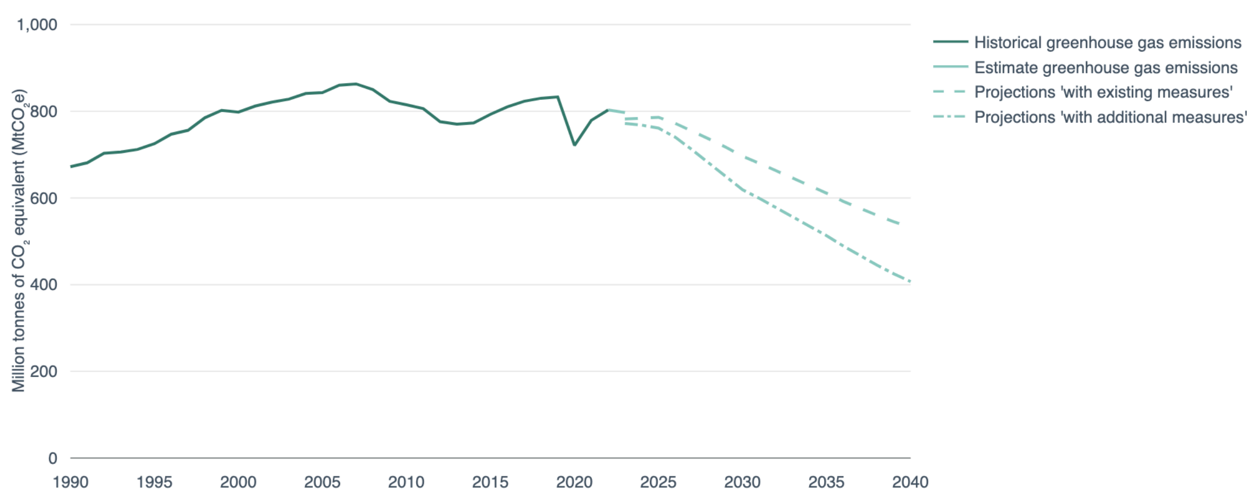

Figure 3 - Greenhouse gas emissions from transport in Europe [Source: European Environment Agency,2023,https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport].

The energy consumption per charging session is a standard method of estimating carbon emissions at EV charging stations. It is possible to measure the carbon dioxide emissions related to electricity consumption during the charging process by monitoring the energy used (in kWh) and applying a region-specific emissions factor (kg CO_2 per kWh). As an example, in the case of an EV that consumes 10 kWh and the local grid's emissions factor is 0.5 kg CO_2/kWh, then the total carbon emissions would be 5 kg of CO_2. Besides, an alternative approach is to utilize real-time carbon intensity data provided by public APIs from regional or national grid operators. Emitted CO_2 per kWh of generated electricity can be provided by these APIs at any given moment. As a result, it is possible to estimate carbon emissions without the need for physical sensors by linking the duration of each charging session with the grid's carbon intensity.

Furthermore, carbon footprint can be provided from third-party services's APIs, which estimate the based on energy consumption, vehicle type, and regional factors. By the usage of these services, the accuracy of emission stigmatizations may be improved, and sensor-based monitoring systems may be placed with alternative solutions.

Additionally, installation and maintenance of the physical sensors can be cumbersome and quickly scaled to multiple charging stations. Therefore, the primary benefits of these alternative methods are cost-effectiveness, scalability, and simplicity. However, estimation accuracy depends on the quality and granularity of the emissions factors used, whereas the variability of the electricity grid's carbon intensity must also be taken into account. Besides, certain local factors, such as traffic or weather, may indirectly influence carbon emissions and are more challenging to account for without physical sensors.

In the implementation phase of these alternative solutions, which include a carbon emission monitoring feature, energy consumption-related data from charging sessions should be gathered. Then, this data must be combined with real-time grid carbon intensity data from public APIs so that emissions calculation can be based on the consumed energy and the carbon intensity at that time. The formula for emissions calculation would be:

Carbon Emission = Energy Consumed (kWh) × Grid Carbon Intensity (kg CO_2/kWh)

In conclusion, users will have the privilege of monitoring the carbon footprint of each charging session in real-time via this method. Moreover, daily, weekly, or monthly emissions trends can be displayed on the application, which would offer insights and help users make more environmentally friendly decisions.

7. Conclusion

This literature review gives an overview to the modern day problems of electric vehicles, current status of the market, and possible solutions to address problems with various methods ranging from EVRP and machine learning models. We aim to provide customized experience to electric vehicle drivers via utilizing aforementioned machine learning models where it is possible to apply.

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