Electric Vehicle Charging: It is not as simple as charging a smartphone (Vision Paper)

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ABSTRACT

While the electric vehicle (EV) industry is facing some challenges concerning its refueling, its rapid growth in popularity is increasing these difficulties. In this paper, we demonstrate the gravity of the problems that EVs may experience for charging, both now and in the near future, and show how establishing new charging stations can be challenging. We also present the challenges in optimizing the use of charging stations by EV users. Then, we envisage opportunities for the rise of alternative charging options, such as distributed generation, crowdsourced, wireless and mobile charging stations. Additionally, we explain directions on how route and charging stations' location planning can cater to optimizing the charging infrastructure.

CCS CONCEPTS

• **Applied computing** → **Transportation**; • **Information systems** → **Geographic information systems**.

KEYWORDS

Electric Vehicles, Facility Location Problem, Route Planning

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1 INTRODUCTION

In recent years, the number of EVs has increased significantly, accounting for 17% of total European sales in 2021. Currently, the share of EVs in the new car market in Norway is the highest at 72%, whereas market shares for EVs in Germany, the United Kingdom, the United States, and Australia are 25%, 15%, 4.5% and 1.58%, respectively [7]. The number of EVs is expected to sharply increase in the near future due to the recent reduction in prices, government support, and the significant progress in the mileage range of EVs. The UK government aims to end the sale of new conventional petrol and diesel cars by 2040 [11]. EVs are exempt from all federal taxes based on fuel consumption in the United States, and in Norway, EVs are not subject to import taxes [10]. Despite the popularity and several initiatives to transition to zero-emission vehicles, the long charging time, the lack of an extensive charging network, and difficulty in optimally crafting routes with charging requirements remain major impediments to the uptake of EVs. Such challenges will be further amplified disproportionately with a sharp growth of the number of EVs in the next few years.

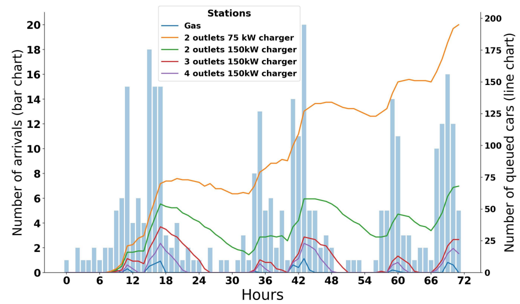

Figure 1: Arrivals and the number of cars in queue of a simulation for 72 hours. The system is modeled as an M/M/c where c defines number of outlets and the Poisson process with λ of 1, 3, 12, 3, 12, 3 describes the arrival per hour in 0-7, 7-10, 10-12, 12-16, 16-20, and 20-24, respectively.

Consider the challenge of a longer EV charging time compared to traditional gas stations. Any queuing in the charging stations can rapidly accumulate to a much higher wait time. Figure 1 illustrates the impact of long charging times on the charging process of around 350 cars arriving at a station over 72 hours. This is a reasonable assumption of the number of cars in a locality that will require charging on the road when a large portion of the cars are EVs [4]. We assume that each EV takes 60 and 30 mins to charge on average at 75 (since chargers generally provide less output in practice, this is considered as a feasible charging rate for a 150 kW charger) and 150 kW chargers , respectively, and we have considered that the arrival rate during a day fluctuates to show the real usage pattern [4]; so there is a peak and underutilized time for each station. Figure 1 shows the formed queue length and car arrivals at a station with 2 – 4 ports and compares against a traditional gas station. The average service time to get refueled in the gas station is assumed to be 3 – 6 minutes. This simulation indicates that the maximum

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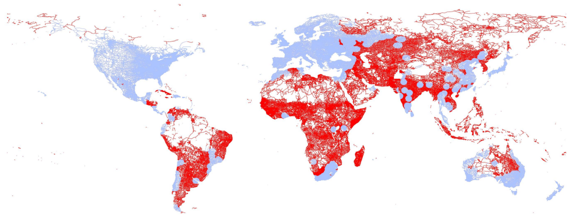

Figure 2: Accessibility map for a 400 km (round-trip) EV using commercial chargers. After fully charging at any existing station, if there are no other charging stations within the car's max range, those roads are considered unreachable and colored red—otherwise colored blue.

number of cars in a queue using a gas station is nine, as opposed to 37 and 24 when the charging stations have 3 and 4 outlets, and unbounded when they have 2 outlets. EV owners must tolerate higher waiting times compared to conventional car owners, even when the charging station has four fast chargers.

Analyzing the current road coverage and coverage gaps can help give insight into the current situation of EV charging stations. Figure 2 shows the main roads and their current accessibility status using an EV with a range of 400 km (round-trip). As is shown, most parts of Africa, South America, and Asia, as well as around 50% of Alaska, 30% of Australia, and 8% of Canada, can not be accessed using an EV due to the lack of sufficient charging stations at this time. In this paper, we identify the key research challenges that EVs may experience for charging and define those from a Spatio-temporal optimization lens. Specifically, we present the challenges in optimal route planning and location planning for charging stations and how the problems can differ for different geographical regions, both now and in the future. Then, we present several alternate methods and directions for charging EVs that can help address these challenges.

2 CHALLENGES

2.1 Station utilization for sharp growth of EV population

According to [18], BloombergNEF's Economic Transition Scenario projects EV sales to increase sharply from 3 million in 2020 to 66 million per year globally in 2040. Within that year, EVs will account for more than two-thirds of passenger vehicle sales worldwide. The number of required fast and regular charging stations per 1,000 EVs is estimated at 3.4 and 40, respectively [15]. The number of EVs in the US could reach 35 million by 2030; therefore, 2 million charging stations will be required [5]. This equates to establishing 380 EV charging ports per day over the next nine years, while it was about 30 ports a day between 2010 and 2020 [23]. The situation in Europe is even more concerning. According to [6] in Europe alone, up to 6.8m public charging points will be required by 2030. Considering the statistics above, it is quickly apparent that current charging infrastructure development rates are insufficient to meet the sharply increasing demand.

Although establishing new charging stations are important to increase charging options, simply increasing the number of stations and outlets will not linearly meet the demand. As demonstrated in Figure 1, the number of cars in a queue can increase rapidly at peak hours with a high number of cars, and the peak hour queues remain considerably high even with adding new charging outlets.

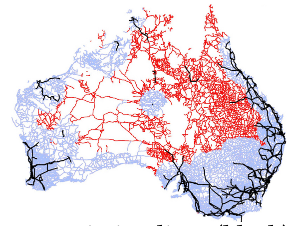

Figure 3: Power transmission lines (black), shown together with not accessible (red), and accessible (blue) routes of Australia by a 400 km ranged EV using existed charging stations. The coloring method is described in the caption of Figure 2.

Hence, it's crucial to optimally utilize the existing stations, and new ways of charging, e.g., route selection, charging time planning, and alternative charging options should be investigated.

Additional challenges for route planning. While web sites such as `abetterrouteplanner.com` and `openchargemap.org` provide an interactive map of charging stations between user-specified locations, crafting routes with the most appropriate charging option is a challenging task. As shown in Figure 1, queues can form even at fast-charging stations with four outlets compared to the gas station since charging an EV is much slower than refueling a traditional vehicle. Hence, with the EV numbers growing, it's even more crucial to optimally plan the routes to reduce queuing. Planning routes considering the EVs' refueling constraints and stations' properties (e.g., number of outlets, charging time) with minimizing wait time and detour is computationally expensive. However, it is more challenging when other factors are considered, such as the nearby points of interest, vehicle energy consumption, station availability and failures, the real-time traffic flow, and the road network topology. It can be even more complex for rural areas and regional road trips because if stations are sparse or some are overloaded, drivers' routes need to be altered to pass a suitable station.

2.2 Spatial-temporal challenges

The physical environment imposes major constraints on the location of charging stations. Charging stations need to be connected to power, so they are typically located close to densely populated areas, interstate highways, and major hubs where electricity is readily available. The geographical distribution of the population can cause to have many long stretches of roads without any major town, which makes it challenging to establish charging stations at regular intervals. As an example, most Australians live in the five largest cities, all located on coasts, and the population density outside these cities is less than two people per square kilometer. As a result, many parts of the country are not connected to the power grid. Australia's power transmission lines and road accessibility status are shown in Figure 3. Almost all charging stations have been established in areas which have access to the power transmission. Due to the lack of a power grid in many parts of the country, charging stations have not been established all over Australia, which has seriously reduced the accessibility of the roads by EVs. This problem is also observed in other areas with low population density, such as Canada and Alaska. The lack of access to electricity grid makes it impossible to install charging stations in some regions without providing alternate means of supplying power.

Finding the best place for establishing charging stations. A challenge with charging, especially in remote areas, is that people will want something to do during the multi-hour charging process. Charging stations must be placed at an existing point of interest (POI), or a POI such as a roadhouse must be created along with the charging station. Determining such a location can be even more challenging for rural areas and regional travel, as a long stretch of road may have no locality; hence establishing a charging infrastructure for a low demand may not be economically viable. Another influential factor to consider is the climate which directly affects charging stations. Maintaining a comfortable temperature for passengers in cold or warm weather is energy-intensive; Consequently, EVs in cold and warm climates have a significantly shorter range than usual, resulting in higher charging station demand.

Challenges in finding suitable areas for establishing new stations include identifying hotspots in areas lacking charging facilities while considering the potential availability of those points. Charging stations' spatial location, nearby POI for the EV occupants while charging, important landmarks (e.g., offices), climate and temperature, and seasonal travel changes affect their current and future demand and utilization. Additionally, power grid accessibility and status, renewable energy uncertainty, and traffic patterns are among the factors that must be considered when establishing new stations.

3 VISIONS TO ADDRESS THE CHALLENGES

We envisage several charging options, such as distributed generation, crowdsourcing, and mobile stations, which will be adopted to create an extensive charging network. Optimizing the usage of charging facilities (both traditional and alternatives) and planning routes accordingly will also be critical to addressing the increasing demand for charging. We describe these visions below.

3.1 Smart and optimal route planning

Optimizing route planning of EVs has recently been studied in [2, 3, 8, 19, 20, 24]. The combined problem of route planning and recharging was studied as far back as 2010 by Artmeier et al. [1] by integrating battery constraints into the Dijkstra algorithm, yielding a worst case complexity of $O(n^3)$. Later, the problem was modelled as a multi-criterion shortest path problem considering driving time and energy consumption which respond in some seconds and are not affordable for a large number of cars [9, 19]. However, [19] considers the energy savings of driving below the speed limit and strikes a balance between the fastest and most economical routes.

The studies above only consider providing individual user-level local optimization and plan a route for each EV through the charging stations. Such uncoordinated optimization may cause excessive waiting times in some locations and underutilized stations in others. This problem is related to the well-known congestion-aware route assignment problems[12–14], but it differs from them in that we are concerned with stops rather than routes. An open challenge is to devise algorithms for socially optimal real-time routing with a reasonable response time for a large number of vehicles. Providing a system-wide global optimization is important because if a long queue forms at a fast-charging station, the charging process may take longer than at a less crowded, slower charging station. Efficient real time multi-criteria optimization formulations and accurate prediction on station usage will also be an important research goals. The selfishness of users must also be considered; even if the social optimum involves an EV going to a slow charger, the driver may choose to go to a fast charger despite increasing others' delay. This raises interesting mechanism design issues.

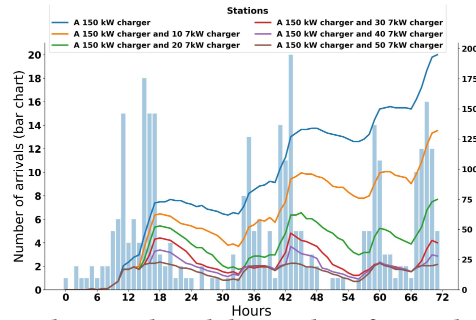

Figure 4: The arrivals and the number of queued cars when there is 0, 10, 20, 30, 40, or 50 crowdsourced 7kW home charging stations. Other parameters are the same as for Figure 1.

3.2 Crowdsourcing the home charging stations

EV owners prefer to charge in the most convenient way [16]. Therefore, drivers will choose to charge at home or workplaces as much as possible and use on-road charging stations when necessary. Home chargers may be in use around 50% of the time if EVs are plugged in overnight. However, this leaves 50% of the time that they can be made available to the public, for a suitable fee, in a "crowdsourcing" model. This will allow owners to earn money while increasing the charging opportunities for EV drivers. In urban areas, any idle chargers will be available for sharing. In contrast, in rural zones with no or weak access to the power grid, available chargers will be those with sufficient available power produced or stored locally by the owner. In a preliminary simulation study, we verified the advantages of crowdsourced charging options. Figure 4 shows the influence of multiple 7 kW home chargers on an environment consisting of one fast charger station. The figure shows that by having 30 or more crowdsourced chargers, along with a 150 kW DC charger, the system can turn from an unstable one with ever-increasing delay to a stable one, in the same scenario of Figure 1.

Crowdsourced charging options can create a strong charging network, resulting in improved road accessibility, especially in rural areas. For this reason, it can be an excellent solution to managing the rising burden of EV charging, in addition to the difficulties some countries may face due to their geographical characteristics. Crowdsourced charging distributes the charging impediments spatially, and people who want to see different places can be accommodated almost everywhere with less parking burden. As people often run errands while charging their EVs, using crowdsourced charging would be a desirable option instead of finding a station in a place with no POIs around. However, pricing will be complicated, as it should depend on the burden that the sharing imposes on the owners and the demand in a particular spatial area, but it must also be sufficiently predictable for the buyers. Providing optimal route planning using crowdsourced stations, considering people's preference for fast charging vs short wait times, covering the privacy and trust issues of both owners and drivers, taking the influence of the crowdsourced charging behavior on the power grid into account, considering fairness — particularly when regions have low capacity power lines — and monitoring the impact of people's power-consuming behavior are among the most important open problems for the crowdsourcing model that require attention.

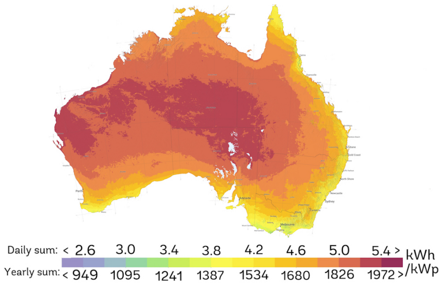

Figure 5: Photovoltaic electricity potential map [21]. In most parts of the country, there is availability to produce more than 1,500 kW per year from a small solar system designed to produce 1 kWh electricity at its peak time.

3.3 Distributed generation charging stations

Increasing the use of distributed energy resources will result in fewer charge points that require grid power. EV charging stations can use renewable energy on their property, thereby reducing demand on the electrical grid and addressing the station's installation challenges due to special geographic conditions. Additionally, charging stations can have grid-scale batteries to meet the electricity demands of peak periods, or periods of low sun and wind. Providing renewable energy would be a perfect solution to establishing charging stations in low-density areas with low-capacity power lines and remote areas where no power lines exist.

In a real-world scenario shown in Figure 5, the most parts of the unreachable areas (red marked roads in the Figure 3) have an appropriate potential to provide more than 5kWh electricity daily from a small solar system designed to produce 1 kWh electricity at its peak time. Generally, a 1kWp solar system requires around 5 square meters of solar panel, so a 300 kWh battery and a land area of approximately 300 square meters would be sufficient to power a charging station to charge four cars per day. This area of research will be driven by factors such as the uncertain nature of renewable energy production, the cost of batteries and infrastructure, the difficulty of finding a suitable location considering solar, maximizing supply consistency while combining solar and wind power, and crowdsourcing power from people's properties.

3.4 Wireless and mobile charging solutions

Shortly, roads may be wired to produce an electromagnetic field that will enable an EV to receive energy from a transmitter and charge its battery while moving without having to stop. With dynamic charging, EVs would have smaller batteries, making them more affordable and faster [22]. Charging lanes supplied with distributed generated power would be an excellent option for charging EVs in the area lacking POIs and a power grid. Also, crowdsourced generated power can significantly be used in this type of charging. Furthermore, In low traffic roads with no access to the grid, it is not economic to have a wireless or regular charging station. If all the previous options do not work for an area, mobile charging stations would be a feasible option. Mobile EV chargers include portable chargers, charging vans, temporary chargers, and swapping battery. A study [17] explored the possibility of locating mobile charging stations that can move to different locations. The mobile charging infrastructure is complementary to the permanent charging infrastructure, and their temporary locations are mostly selected in areas lacking or with limited fixed stations. If the range of the mobile charging vehicle is the same as a typical EV, this can effectively double the radius served by a remote fixed charging station.

4 CONCLUSION

The EV industry will continue to grow in the years to come, and diverse innovative charging solutions will be required. We have categorized the main challenges associated with the EVs and their charging locations and presented our vision of some adjuncts to regular charging stations to address the challenges discussed along with our preliminary experimental studies and analysis.

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