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## **Literature Review**

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**PlugMap UK**

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## Introduction

The expansion of the electric vehicle (EV) market underscores the urgent need for advanced, user-friendly charging infrastructures. PlugMap UK emerges as a solution in this realm, catering specifically to EV owners. The application transcends conventional route planning by integrating location-based charging stations into its navigational framework, thereby addressing a key concern in EV usage. The conservative algorithm of Plugmap is strategically designed to alleviate range anxiety, a significant barrier to EV adoption highlighted by (Noel et al 2019). *“This barrier, as the paper indicates, is a major hindrance in the shift from combustion engines to electric power.”* Despite the growing awareness and needs for sustainable vehicles. (Noel et al 2019) observes that global EV deployment remains disconcertingly low, constituting less than 1% of the global fleet.

Plugmap’s core objective is to mitigate this fear and encourage a wider adoption of EVs, which are notably more sustainable. This literature review explores various dimensions of research, from electric vehicles, route planning, route optimisation and range anxiety. to the rationale behind its development. By analyzing industry reports and existing literature, the review assesses how Plugmap contributes to fostering an environmentally sustainable and technologically advanced vehicular ecosystem. It seeks to provide a comprehensive understanding of Plugmap’s role in enhancing the EV infrastructure and its potential to transform the future of transportation.

## Summary Of Related Literature

Paper	Focus	What did they do?	Results
<i>Noel et al 2019</i>	Range anxiety	<p>277 semi-structured interviews with experts at 201 institutions.</p> <p>A survey with 5000 responses.</p> <p>Conducted 8 focus groups across 17 cities in 5 nordic countries.</p>	<p>Fear-driven arguments, like “jeopardy thesis” regarding range anxiety might weaken solutions. This could reshape how we approach increasing electric car usage.</p>

<i>Pevec et al., 2020</i>	Range Anxiety	Conducted a survey with 200+ people. To collect data on perceptions of EV charging station infrastructure, range anxiety and the influencing factors.	Found that both EV and non-EV owners prefer shorter distances between charging stations in urban areas.
<i>Baum et al., 2014</i>	Route planning Optimization	Planned a route planning algorithm integrating energy consumption optimization and realist battery charging models included with driving speed adjustments.	Created an algorithm that can work on a large-scale transportation system that is balanced between travel time / energy consumption.
<i>Yuan et al., 2018</i>	Range Anxiety	Conducted a survey to study range anxiety and the affected behaviors caused by range anxiety. Created a safety buffer to measure the anxiety impact on driving.	Identified a relationship between safety buffer and trip mileage. Found driving experience, recharge accessibility influences range anxiety levels.
<i>Redirect Notice, n.d.</i>	EV charging technology	Reviewed and explained electric charging pile concepts, and evaluated recent advances in EV technology and charging methods.	Provided an overview of electric vehicle technology, showing the importance of charging techniques.

<i>Logtenberg et al., 2018</i>	BEV Vs ICEV cost Analysis	Examined the annual fuel and maintenance cost of ICEVs and BEVs in Canada.	Found that BEVs save Canadian people an average of 715 in fuel and maintenance over 10 years. Making the savings total to between \$23,000 to \$36,000 in the EVs lifetime
<i>Chen et al., 2021</i>	BEV adoption impact analysis	Conducted an impact analysis of BEV adoption, using demand estimates and economic models, focusing on fuel cost and battery manufacturing.	Found that BEV adoption boosts GDP and lowers CO2 emission. Recommends combining BEV with green manufacturing for optimal emission reduction.
<i>Soulopoulos, 2017</i>	Cost analysis between BEV - ICEV	Examined the cost of materials for electric cars focusing on battery components.	Predicted BEVs will be cheaper than ICEs in 2035. Batteries are the most expensive part of EVs and are expected to drop in price.
<i>Hayes, 2023</i>	Range Anxiety	Exploring common misconceptions about EV range compared to ICE vehicles, looked at government statistics on average car trip lengths and discussed the practicality of EV ranges for average daily use.	Showed that the average driving distance in the UK is well within the range of most EVs. Discussed how increasing battery ranges and charging infrastructure improvements are making EVs more viable for longer trips.

<i>At a Glance: Electric Vehicles, 2023</i>	EV benefits and range analysis	Reviewed EV benefits like fuel economy, lower operating costs and reduced emissions. Discussed starting prices of EVs and analyzed their range	Highlighted that EVs are cost efficient in the long run despite higher initial costs. Most EVs have a range between 110mi to 300 mi in a single charge.
<i>A Comparative Study of Vehicles' Routing Algorithms for Route Planning in Smart Cities   IEEE Conference Publication   IEEE Xplore, n.d.</i>	Route planning algorithms in smart cities	Reviewed algorithms for route planning in real-time. Proposed approaches to enhance algorithms effectiveness in dynamic road networks.	Showed 3 categories of route planning algorithms and proposed new criteria to enhance their effectiveness.
<i>Fescioglu-Unver &amp; Yildiz Aktaş, 2023</i>	Machine Learning in EV charging services	Reviewed studies that apply machine learning models to enhance EV charging services. Focusing on infrastructure planning, charge scheduling, pricing and routing	Showed that increasing the use of machine learning in EV charging operations, highlighting forecasting, clustering based models as key methods.
<i>Lokhandwala &amp; Cai, 2020</i>	EV charging infrastructure Optimizations	Proposed a framework for optimizing charging infrastructure development considering autonomous vehicles adoption. Used NYC taxis as a case study to evaluate charging station configs for different EV adoption.	Found that traditional fleets need fewer charging stations because of their battery range. Future fleets will benefit from more scattered stations. Shows that EV adoption can significantly reduce CO <sub>2</sub> .

<i>Lu et al., 2019</i>	Route planning algorithm	Looked at route planning algorithms like A* & Dijkstra, Evaluated their travel time, charging time and cost with these algorithms then proposed a better algorithm using other methods.	Veiled algorithm for optimal EV charging routes, effectively responding to real-time price changes
<i>Deep Reinforcement Learning for EV Charging Navigation by Coordinating Smart Grid and Intelligent Transportation System   IEEE Journals &amp; Magazine   IEEE Xplore, n.d.</i>	Implementing a deep learning algorithm	Developed a deep learning algorithm for navigation system to minimize travel time and improve cost efficiency.	Validated the effectiveness of the DL algorithms approach to optimizing EV charging navigation.
<i>Rauh et al., 2014</i>	Impact of driving experience on range anxiety	Conducted a study with 2 sets of people. Person 1 is experienced at driving EVs and person 2 is inexperienced. The study consisted of tests where the person would be driving at a certain battery % and their cognitive, emotional and behavioral levels were monitored	Found that experienced BEV drivers exhibit less symptoms of range anxiety while inexperienced drivers are significantly higher..
<i>Xu et al., 2020</i>	Optimal routes for fast EV charging for city travel considering drivers range anxiety.	Designed a model to identify optimal EV charging station locations, factoring in the EV range limits and driver anxiety. Aiming to reduce overall range anxiety within budget constraints.	Proposed an efficient route approximation to solve the issue of range anxiety.

<i>Li et al., 2023</i>	EV routing	This research showed the importance of rational route choices by EV users that consider traffic factors at the time of departure. The study highlights the need for strategies to guide EV routes effectively.	The study concluded that adopting appropriate strategies to guide EV routes can lead to reduction in travel time for users.
<i>Tran et al., 2021</i>	Exploring EV range	Reviewed multiple range extending technologies for BEVs there advantages and disadvantages and how they work. They also compared the technology.	The study shows significant improvements in range extending technology better than combustion engines because of their weight.

## Electric Vehicles

### Creating a new way for a sustainable & Autonomous future in Transportation

Electric Vehicles (EVs) are slowly growing in popularity as governments and companies seek sustainable alternatives to the traditional combustion engine. This shift is largely driven by the pressing need to address global environmental issues and the push towards renewable energy sources. As highlighted by (*Literature Review of Electric Vehicle Technology and Its Applications | IEEE Conference Publication | IEEE Xplore, n.d.*) “With the increasingly severe environmental problems around the world, exploitation of clean and renewable energy has been a crucial topic.” EVs are a significant advancement in the field of automobility, offering a more energy-efficient and environmentally friendly solution compared to combustion engines that burn fossil fuels to create power.

The motivation behind electric vehicles also extends beyond environmental issues including adjusting to the changing dynamics of energy usage and incorporating new technologies for a sustainable lifestyle. The adoption of EVs is considered a critical strategy in reducing environmental / economic impacts. This transition to electric mobility has gathered attention across various sectors, from your average motorcar, to large scale deployments on large delivery trucks like lorries. EVs are the beginning of self-driving vehicles as well. This integration of electric mobility with autonomous driving technology represents a significant leap forwards creating a safer, smarter and more efficient method of transportation. With advancements in charging technology and battery technology which plays a crucial role in the adoption of EVs defined by (*Literature Review of Electric Vehicle Technology and Its Applications | IEEE Conference Publication | IEEE Xplore, n.d.*) “The electric vehicle is more energy efficient,

*environmentally friendly, and cleaner than the vehicles that rely on fossil fuels.*” The growth in EV adoption is significantly linked to advancements in charging and battery technology and also the expansion of the charging infrastructure. The shift towards EVs marks a change in how we view transportation as a whole creating a new and intuitive technology that improves our whole species environmental footprint. It's not just about cutting down emissions but about the future of our energy grid and how it will change and advance over time. As the UK national grid will expand to more rural areas as EV adoption becomes even more widespread for example farm land.

## The Positives impact Of Electric Vehicles

### Electric Vehicles Cost-effectiveness

Electric vehicles (EVs) are gaining recognition not just for their environmental sustainability but also for their cost-effectiveness. A notable report from Canada compares the economic benefits of EVs with traditional combustion engines. As highlighted by (Logtenberg et al., 2018) *“Vincentric’s data reveals a 47% average cost savings in maintenance of operating a BEV over an ICEV (Internal Combustion Engine) in Canada”* Interestingly, despite this “relatively” new technology compared to the combustion engine, it results in a lower maintenance cost. The same study also shows significant fuel savings (Logtenberg et al., 2018) *“On average the population weighted savings on fuel costs from operating a BEV is 80%”* This indicates a substantial reduction in lifetime expenses for Canadian EV users. Furthermore, (Logtenberg et al., 2018) Also suggests that residents in Alberta could save between \$2084 and \$3316 annually on maintenance and charging, making a compelling case for the broader adoption of EVs.

Figure 3: Results from (Logtenberg et al., 2018) Average annual fuel cost per household

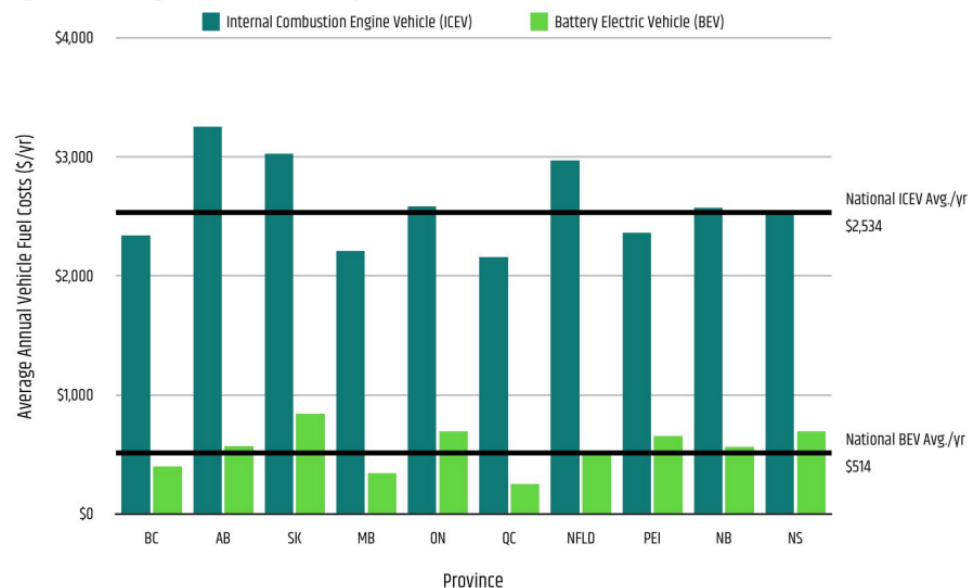
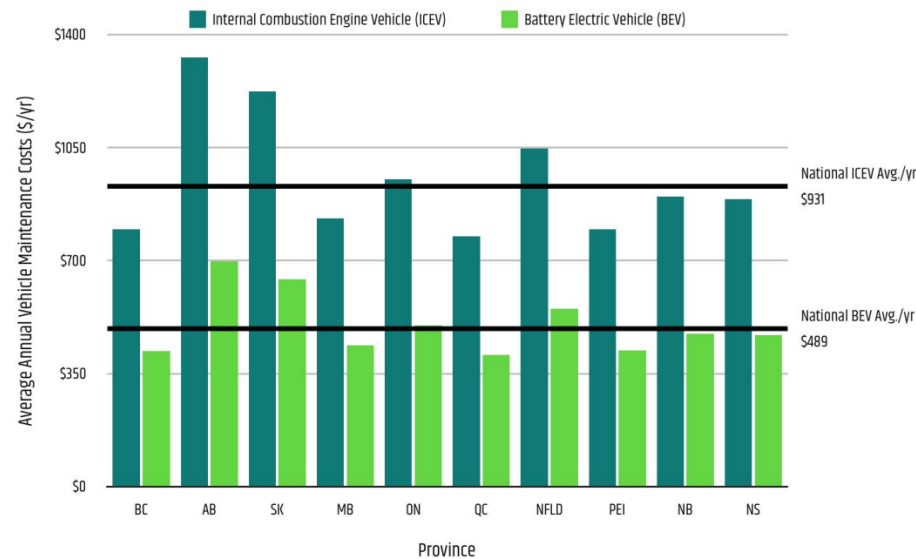




Figure 4: (Logtenberg *et al.*, 2018) Average annual vehicle maintenance cost household



## Electric Vehicles sustainability towards the environment

### The Negative Impact Of Electric Vehicles

#### Initial Cost Factors Of Electric Vehicles

The evolving landscape of electric vehicles compared to internal combustion engine vehicles is highlighted by (Soulopoulos, 2017), who notes the initially higher costs of BEVs. Soulopoulos points out that in 2016, BEVs were “*more expensive than equivalent internal combustion engine vehicles for the next 7 - 9 years*” This initial cost disparity, with electric cars being roughly \$15,000 more expensive than ICE cars. However, Soulopoulos presents an interesting estimation he projects that “battery electric vehicles will be up to 15% cheaper than the equivalent ICEs by 2030.” This projection seems to be accurate as the current trend in 2023 sees EVs decreasing in value this aligns with the UKs plan to phase out ICEs in favor of BEVs by 2035 showing the UKs shift towards a more sustainable transportation system.

#### Exploring Battery Range And Charging Capabilities

The progression of battery range and charging capabilities in electric vehicles is constantly improving. Initially, EVs were limited by the amount of time it takes to charge and very limited range typically around 110 mi on a full charge. However, advancements in technology have led to significant improvements. According to the (US Department of

energy, 2023), Modern EVs in 2023 boast varying ranges from “110 mi to around 300 mi” while this marks substantial improvement however its important to note that the average range of ICE cars is about 400 mi with some diesel models capable of reaching up to 500 mi on a single tank. (Hayes, 2023) emphasizes that battery and charging technology will continue to evolve. The existence of different charging levels, ranging from Level 1 to DC fast charging, further shows advancements in this area, with higher levels indicating faster charging capabilities.

## Route Optimization & Planning

### Integration of Real-Time data

Real-time data plays a pivotal role in effective route planning for EVs, particularly in identifying suitable charging stations with the appropriate charger types. Applications commonly use Application Programming Interface (API) technology to acquire essential data. PlugMap UK utilizes the Open Charge Map which is a publicly accessible repository of charging station information, to gather data necessary for calculation routes from point  $A \rightarrow$  Charging station location  $\rightarrow B$ . Additionally, PlugMap Incorporates data from the Google Maps Platform, specifically the Routes API, to obtain information on routes, traffic conditions and accidents. This helps in determining the quickest yet most efficient routes while taking into account the challenges of range anxiety, the algorithm avoids options that would result in low battery level upon arrival. The integration of API technology is fundamental to PlugMap, providing the real-time data needed for the algorithm to work effectively.

### Current route optimization algorithms

When it comes to route optimization algorithms, there are a variety to choose from. The main focus will be upon 2 of the most known ones. Dijkstra algorithm and the A\* algorithm.

#### Dijkstra Algorithm

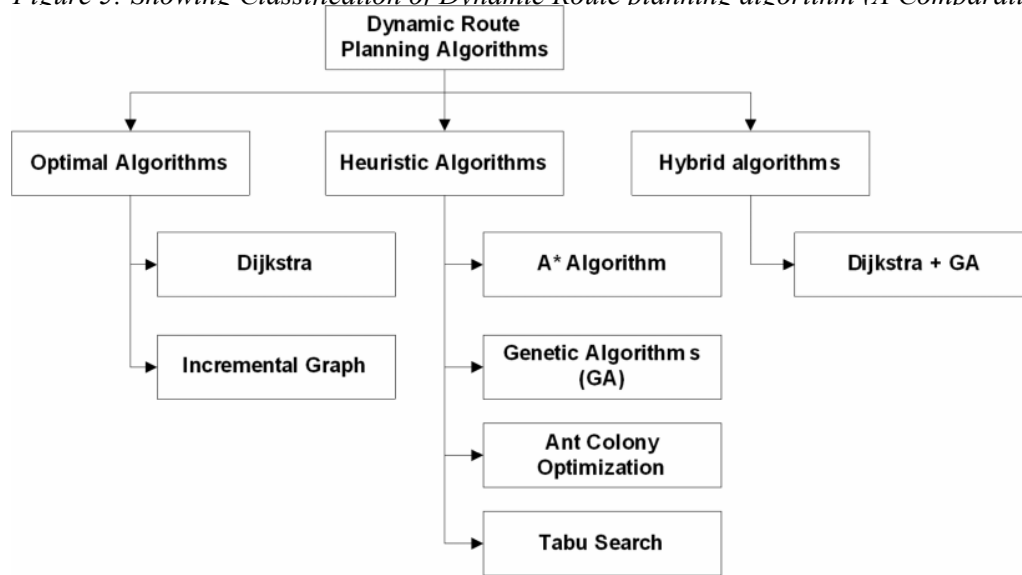
The Dijkstra Algorithm was created by Edsger W. Dijkstra is used in computing to find the shortest path through a network of nodes. As highlighted by (*A Comparative Study of Vehicles' Routing Algorithms for Route Planning in Smart Cities | IEEE Conference Publication | IEEE Xplore*, 2012) “Dijkstra algorithm is a process of finding the path with the lowest cost (i.e usually refers to the shortest path) from one node to all nodes in a city map.” The time complexity of Dijkstra is  $O(n^2)$   $n = \text{number of nodes}$ . This makes the algorithm efficient in this particular task as it is a shortest task problem which  $O(n^2)$  is efficient in. Dijkstra terminates when it labels the destination node, signifying the identification of the shortest path. Dijkstra is different from other algorithms that require calculating the entire shortest path tree to find the optimal route.

#### A\* Algorithm

The A\* Search algorithm is an algorithm that is built upon the foundation of the Dijkstra algorithm. A\* search differs from Dijkstra as it uses a heuristic approach rather than an “optimal search mechanism” as highlighted in (*A Comparative Study of Vehicles'*

*Routing Algorithms for Route Planning in Smart Cities | IEEE Conference Publication | IEEE Xplore, 2012*), enables A\* to effectively narrow its search space, reducing the time required to compute a route. For example in traffic scenarios, A\* can efficiently concentrate on areas with significant congestion. There is an improved version of A\* called IDA (Iterative Deepening A\* Search) which is optimized to use less system RAM. thereby reducing the computation power a computer system needs to use to get a route. This enhancement in the IDA\* search is really useful in real-time applications where resources are slim and the need for efficiency is high.

*Figure 5: Showing Classification of Dynamic Route planning algorithm (A Comparative)*

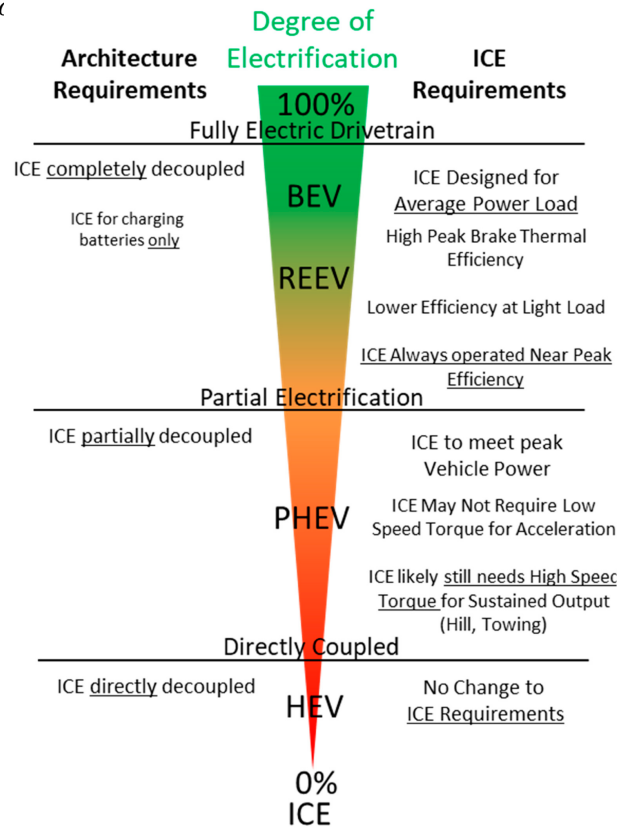


### Ways to mitigate Range Anxiety using route optimization

Range anxiety stems from a number of factors such as inaccurate range estimations, evolution of battery technology, and limited charging infrastructure. Combating range anxiety is key to ensuring EV operates optimally. One way of mitigating range anxiety is building different types of charging infrastructures with easy availability and high compatibility and affinity (Xu, Yang & Wang, 2020). For instance, in electric vehicles with battery capacity above 60 kWh, the accessibility of chargers reduces delay in the journey and prevents range anxiety. Secondly, there is a need to optimize the location of charging infrastructures by creating an analogous model, using a Geographic Information System that can install many charging stations and allow smart route selection to scale the transportation network. With the Internet of Things, real-time forecasting application has been possible in an effort to secure security privacy. In places with home charging facilities, workplace charging has reduced failure rates to great levels by more than 25% (Rauh et al., 2015). However, the value of the workplace charging depends on the location of an area. Primarily, high mileage commuter workplace charging increases utility. The other way of mitigating range anxiety is upgrading charging infrastructures to enhance efficiency and level of charging (Rauh et al., 2015). Not reaching the destination at the right time induces range anxiety. It implies the range prediction system has to consider real-time factors and

integrate the effect of the gradient to accelerate and promote driving behavior as depicted in EVs degree of electrification shown in the figure below. Finally, a range extender is an approach that can help mitigate anxiety. Range extender reduces the requirement for large batteries and public chargers. Progress in battery technology is gradually getting rid of range anxiety and ensuring EV operators benefit from improved range capabilities. Moreover, data-driven EV management can significantly reduce range anxiety. This involves leveraging real-time data from EVs to allow drivers to operate routes, monitor battery performance, and plan charging stops.

Figure 6: Degree of Electrification and ICE Requirements (Tran et al., 2021)



### How Route planning algorithms impact EV adoption

EVs are a great mobility option for the potential benefits of energy consumption and emission reduction. Optimal energy for EVs is highly required to guarantee efficient and timely trips by fully taking into consideration the impacts of battery remaining capacity, charge features of battery, locations, and service levels of charging stations. To begin, according to route planning optimization and traffic conditions, the route with minimum travel cost, time, and energy required is estimated using the Dijkstra Algorithm, a dynamic programming method. Here, re-exploration is much of a necessity because it is key as a substitute optimal route considering that recharging is decided through a comparison between battery capacity and the much-needed energy (Lu et al., 2019). With a route planning algorithm, it becomes easier to forecast EV's energy consumption and minimize the overall traveling distance as evident in the electric taxi demand model that

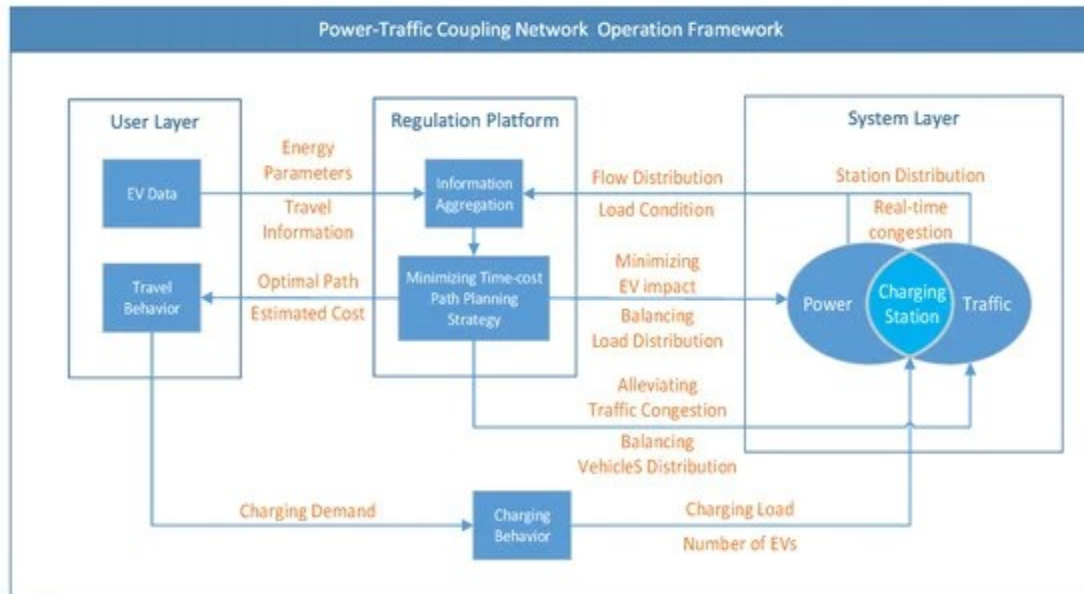
constitutes the measure of electric taxi. To meet the requirements of electric taxis, for instance, a layout optimal model known as electric vehicle supply equipment (EVSE) aims at reducing the cost of charging and the range cost for charging. However, because of the traffic congestion on the roads, the principal path that minimizes the overall travel distance of the EVs does not produce their minimum all-inclusive electric power consumption.

Route planning algorithms consider the vehicle motion dynamics based on energy consumption, efficiency, and recovery by testing solutions on both small, medium, and large-scale real scenarios to reveal the influence of elevation and intersection nodes. With route planning, the goal is to minimize energy consumption and deliver optimal solutions, for which the EV's driver can select the right path based on their preference (Lokhandwala & Cai, 2020). Furthermore, route planning algorithms minimize travel time, including driving and charging and charging costs. The idea is to encourage drivers to plan their time with battery electric vehicles with a multi-objective purpose to save on time, energy, and cost.

### Using Machine Learning and AI to optimize routes & charging locations

Machine learning models apply to EV charging-related challenges. In a smart grid, for instance, machine learning helps in grid power quality, balancing, load estimation, security, and energy storage system integration. In the view of EV users, charging duration, charging cost, and charging service location are critical factors in electric vehicle adoption decisions (Fescioglu-Unver & Aktas, 2023). One of the stakeholders in an electric vehicle charging system is the power grid operator that collects energy and manages interactions. With machine learning, it is much easier to charge control and charge station selection (Fescioglu-Unver & Aktas, 2023). However, the challenge is the strain on the power grid infrastructure that comes with the deployment of electric vehicles on a large scale. The solution to the strain lies in the use of smart scheduling dynamic programming methods to help control the growing public charging demand. Using machine learning algorithms is vital in data processing and ensuring the quality of predictive models. To avoid power grid failures, uncoordinated charging behavior needs to be avoided. The charging behavior predictions are integrated to stabilize the power grid and predict the energy requirements as evident in the network operation framework below;

Figure 7: Power-traffic coupling network operation framework (Li et al., 2023c)



In the user layer, for instance, electric vehicle users taking part in route planning provide the model with vehicle battery requirements and other key data while in the system layer, the power distribution network offers information on the distribution of power flow. The control platform calculates the information received to limit user time costs. With machine learning, the optimal planning results are sent to the user layer. This creates balance in the spatial distribution of electric vehicle charging loads on the transportation networks and power distribution.

The use of machine learning is critical in infrastructure planning, optimization of problems, charge control and coordination, and service operations planning. Building the right and effective infrastructure involves selecting the location and sizing of charging stations (*Fescioglu-Unver & Aktaş, 2023*). For EV Smart Charging, the use of information and communication technologies suffice. The time spent looking for a public charging station is a risk to EV adoption. Fast charging can reduce range anxiety. Moreover, fast charging is a cost-effective approach when compared with increased battery proficiency. AI route optimization involves planning the most efficient routes for EVs using machine learning and AI algorithms (*Qian et al., 2019*). AI algorithms can generate optimal routes that help road users save fuel, resources, and time by evaluating factors such as traffic conditions, distance, and delivery time.

The AI route optimization software integrates with other systems and employs machine learning to generate ideal routes and perform routine tasks, taking into consideration variables such as traffic jams, weather conditions, and the capacity of the vehicle. As new information on traffic, weather, delivery timings, and vehicle capacity becomes available, route planning can be changed in real-time. For entities that offer time-sensitive delivery, AI-powered planning is key, especially when giving customers and other users accurate delivery schedules and managing route planning operations as well as ensuring satisfaction to all. Also, AI uses map data on congestion and current charging stations to suggest optimal areas for establishing new electric vehicle charging stations, ensuring convenience, comfort, and better coverage for electric vehicle users.

The Dijkstra Algorithm model is only suitable for fixed road network data, where the limiting factors on vehicle movement such as the length of the road do not change. In the process of path passing over the energy use of each road segment is related to the traffic flow at the moment. This implies that the process of data collection, cost calculation, and dynamic routing becomes necessary for improved planning.

## **Range Anxiety**

### **What is range anxiety? Solving EV issues with a technical solution**

“Range Anxiety” is a prevalent concern when it comes to electric vehicle adoption. This term specifically refers to the anxiety experienced by EV drivers about the possibility of draining the battery on the vehicle before reaching an EV charging station as defined by (*Pevec et al., 2020*)

*“The range anxiety phenomenon i.e EV drivers fear of running out of electricity before reaching another available charging station.”* This concern highlights the longevity of battery life but also underscores the perceived limitations of current charging infrastructure. This plays a significant role in changing consumers' attitudes towards EV transportation adoption making it a critical aspect to address if governments / companies want a much wider adoption rate of EVs in the future. This shows in the statistics as (Noel et al 2019) said *“global EV deployment remains distressingly low, representing less than 1% of the global fleet.”* PlugMap UK aims to mitigate the effects of range anxiety through the development of a conservative algorithm. This algorithm is designed to map out routes for long journeys, ensuring that they include stops at EV charging stations. This approach is not only innovative but also cost-effective, as developing such a technology is more economical than enhancing the existing real-world charging infrastructure. This strategy reflects a practical and efficient solution to address the concerns of EV users regarding battery life and charging station availability.

### **Conservative algorithms effectiveness towards range anxiety**

A conservative algorithm may effectively reduce range anxiety in electric vehicles (EV) users. (Baum et al., 2014) has already pointed out the challenges faced by EV drivers, such as *“small battery capacities together with a sparse availability of charging stations and charging times of several hours make long-range journeys with electric vehicles infeasible as yet, and the term “range anxiety” is often used to describe wariness of customers towards electric vehicles”*. However it is important to note that since 2014, there have been significant improvements in battery technology, significantly improving battery charging capabilities and the range of the battery, thereby making longer journeys more feasible. (Baum et al., 2014) also emphasized the importance of algorithmic route planning *“Therefore, several recent works consider algorithmic route planning approaches.”* By designing an algorithm to find optimal charging locations, ensuring drivers have a higher battery percentage upon arrival at stations. This approach addresses major concerns of EV travel. Such strategic planning not only alleviates the fear of running out of power mid trip, but also strengthens the reliability of electric vehicles for extended road trips. Tackling these key issues head on could notably increase driver confidence and support the broader adoption of electric vehicle technology.

### **Real world testing based on questionnaire**

Here (Yuan et al., 2018) in their exploration of range anxiety. (Yuan et al., 2018) employed a detailed questionnaire that has *“two major parts”* The first section collected basic demographic information like age, gender & driving experience. While the second part used *“5-point Likert scale and multiple choice questions”* A likert scale is basically a statement given to a participant and is asked to answer by giving it a quantitative value the values are on a scale hence the term *“Likert scale”*. The scale was used to gauge the influence of range anxiety. The questionnaire was distributed among BEV drivers (Battery Electric Vehicle Drivers), primarily recruited from the Autohome forum, ensuring a targeted and relevant respondent group. This methodical approach resulted in 208 valid responses. Providing a solid base for the analysis.

The results of (Yuan et al., 2018) study shed light on the real world implications of range anxiety. The researchers detail the demographics of their participants “Among the 208 interviewees, 156 are male (75% of all) and 52 interviewees are female (25% of all).” Further, they note that “the mean maximum range of the BEVs owned by interviewees is 222.31km” Showing the battery capacity dealt with by the BEV drivers. The study found driver satisfaction levels as reported in the Likert scale. Reveal that “there are more participants with satisfaction level above the average than those with satisfaction level below the average.” This indicates a general trend to contentment among EV users despite concerns about range. Additionally the exploration of safety buffers by (Yuan et al., 2018) provides valuable insight into how EV drivers manage range anxiety in practical scenarios, with a tendency for drivers to prefer larger safety buffers on shorter trips. This data highlights the need for a solution like efficient route planning algorithm that can help mitigate range anxiety by ensuring accessible charging options during travel.

Figure 1: result table 4 from (Yuan et al., 2018) showing different behaviors displayed.

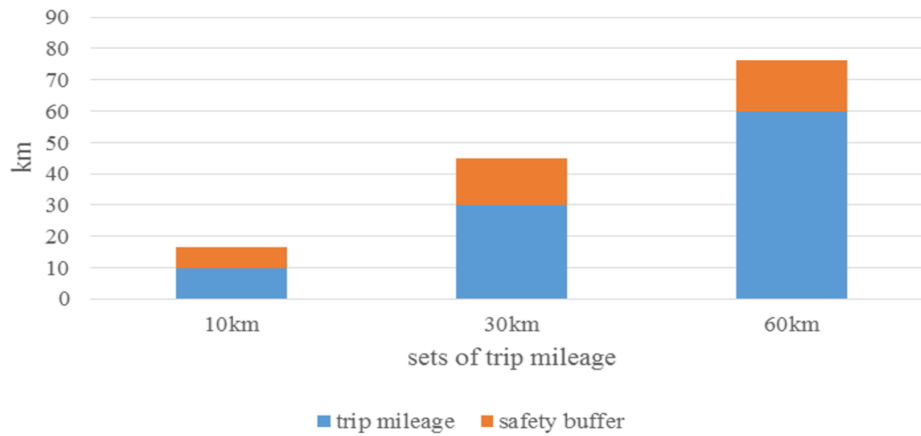


Figure 2: results from (Yuan et al., 2018) showing trip mileage and safety buffer.

<b>Table 4</b> Statistics of driver's behaviors taken related to range anxiety.							
Behavior	Distracted by anxiety	Rearrange the route	Seeking nearby charging-pile	Change behaviors	Speed reduction	Get more disturbed	Grab lines
Number of interviewees taking the behaviors above.	26 (12.5%)	40 (19.2%)	52 (25.0%)	70 (33.7%)	97 (46.6%)	47 (22.6%)	26 (12.5%)

### Impact of Range Anxiety on EV Market Adoption

As observed by (Noel et al 2019) EV deployment is still very low globally it sits at less than 1% of the global fleet. Their study brings into focus the widespread issue of range anxiety. This anxiety is a major obstacle to the wider adoption of EVs. (Noel et al 2019) conducted research including interviews, surveys and focus groups across various nordic cities to understand this issue. In (Noel et al 2019) study they found that both regular consumers and industry experts tend



to use negative arguments, especially focusing on the idea of jeopardy, to oppose the use of EVs. This approach helped them identify common arguments against EV adoption and how they are expressed.

This study highlights a crucial area where PlugMap UK could offer a significant improvement. By providing real-time data and efficient route planning that includes reliable charging stations, PlugMap directly tackles the core issue of range anxiety. It presents a practical solution to a problem that (Noel et al 2019) says “*not just technical but also psychological and rooted in societal attitudes.*” Plugmap UK has the potential to shift the dynamic around EVs beyond a technical solution. By addressing one of the key barriers to EV adoption PlugMap UK could play a role in changing consumers perceptions, even though it does not directly engage with the psychological or societal aspect of range anxiety as said by (Noel et al 2019) however PlugMap UK can contribute significantly to broaden EV adoption around the globe.

## Conclusion

Within this literature review a range of topics have been discussed from range anxiety to routing algorithms. The results from the energy cost analysis is interesting as BEV owners only spend \$489 annually charging their car. Compared to ICE vehicles at \$2,534 per annum. Other key findings include; how prevalent range anxiety is and how despite advancements in EV batteries, there still remains a perception that EVs offer limited range which increases range anxiety. The latest EV models now match the range of the traditional combustion engine. It is also interesting that only 1% of transportation is EV, most likely because of “range anxiety” due to the lack of EV charging infrastructure.

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