Supporting the Electric Mobility Revolution: Technologies to Address Range Anxiety – TomTom White Paper

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Abstract
Electric vehicles (EV) are winning considerable market attention, supported by new, more affordable models, better autonomy, availability of charging stations and favorable public policies. Combined, these factors should form a perfect storm leading to an EV revolution. Yet, electric vehicles represent less than 1% of the sales of new passenger cars in Europe. One factor preventing wide-scale adoption is an issue called 'range anxiety'. To alleviate range anxiety, TomTom conducted research to better understand its causes. Based on their findings, TomTom developed new technologies to help reduce range anxiety: algorithms to calculate the actual reachable range of electric vehicles taking into account vehicle characteristics, traffic patterns and road network characteristics (including elevation); a service offering real-time availability of charging stations; as well as new routing algorithms specifically designed to minimize battery consumption and stops at charging stations. This paper goes over the main findings of TomTom's research and provides a look into how location technology can lift the psychological barriers to wide-scale EV adoption.

Keywords: ELECTRIC, MOBILITY, RANGE ANXIETY

Introduction
A new mobility paradigm is emerging. The future will be connected, autonomous, shared and electric. We are already seeing the changes: in the type of vehicles we use (more electric, autonomous); the way we use them (more owned, rented, shared); and our consumption habits (more on demand, planned).

Electric vehicles (also referred to as 'EV' in this paper) play an important part in this paradigm shift. There are numerous signs that the EV revolution is underway. New electric vehicle models are coming to the market. Over 25 new electric models were launched in 2017. These vehicles are increasingly affordable, as the cost of batteries – which makes up to one third of the total cost of an electric vehicle – is rapidly decreasing. The average price per kWh decreased by over 77 percent since 2010 and continues to do so (fig. 1). Bloomberg New Energy Finance forecasts that electric vehicles will be as affordable as combustion powered vehicles in the next six years, even without subsidies or incentives.

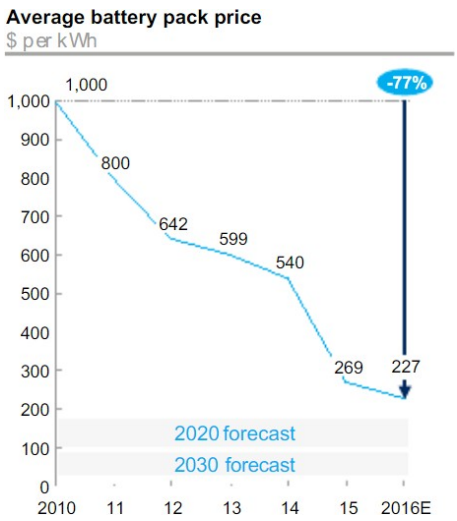

Fig. 1 Decreasing costs of batteries for electric vehicles
Source: McKinsey

Electric vehicles are also reliable. The average petrol-powered car has more than 2,000 moving parts, while EVs have much less complicated drivetrains, decreasing the probability of mechanical failures. Range is also improving fast, with some vehicles on the market offering up to 540 kilometers of autonomy (fig. 2).

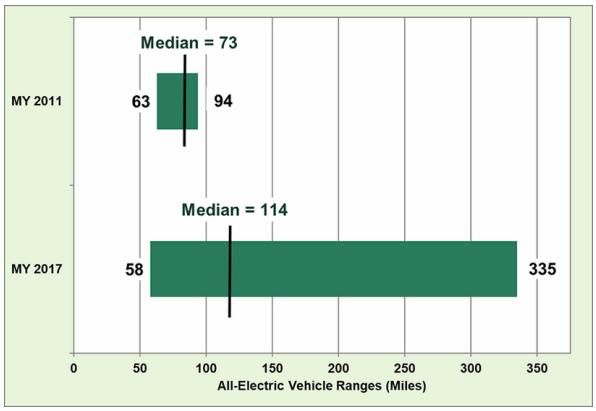

Fig. 2 Comparison of Range of electric vehicles 2011-2017
Source: U.S. Department of Energy

Research from MIT concluded that the autonomy of EVs currently on the market is sufficient to cover 87 percent of the average user trips. Even when range is not sufficient, EV charging points are increasingly available throughout Europe. Statistics from the European Alternative Fuels Observatory show that in Europe, there are more EV charging points than petrol stations. Public policies are also encouraging the acquisition and use of electric vehicles with numerous incentives and subsidies (fig. 3).

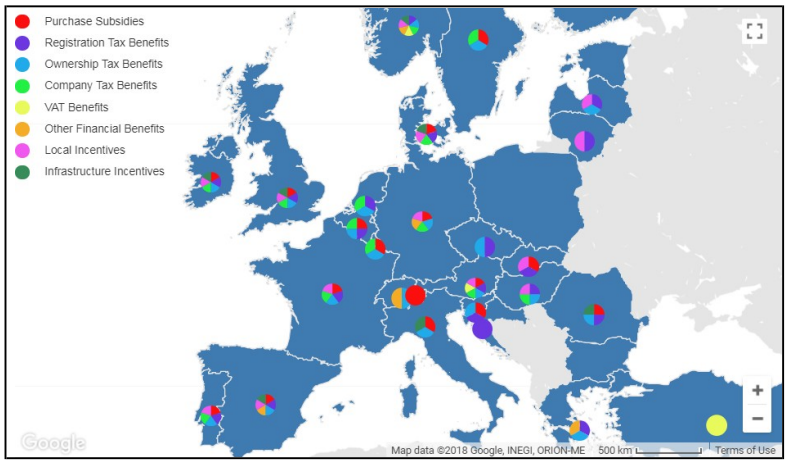

Fig. 3 Public policies supporting EVs in Europe
Source: European Alternative Fuels Observatory

Combined, these driving factors should form a perfect storm leading to an EV revolution. Yet, the adoption of electric vehicles remains relatively slow. Fully electric vehicles only represented a 0.64 percent share of the European market in 2017, with a mere 300,000 passenger electric vehicles in circulation out of more than 198 million passenger vehicles in total (source: European Alternative Fuels Observatory). So, what is preventing the EV revolution from taking off?

The issue with range anxiety

One of the main barriers appears to be psychological: as early as 2010 industry analysts indicated that a phenomenon called range anxiety would be an important limiting factor to the wide spread adoption of electric vehicles. Much like horse riders in the 1900s hesitated to buy automobiles because of the lack of paved roads and petrol stations, potential electric vehicles buyers fear that they will find themselves stranded on a roadside when their batteries run out, with no way of charging up. Bigger batteries and more charging stations can partially address these issues, but as previously highlighted, autonomy of vehicles and availability of charging points are already sufficient to support most of the average user needs. This indicates that range anxiety might not be solely an infrastructure problem.

Location technology has a role to play

TomTom conducted a series of interviews with electric vehicle drivers to better understand range anxiety. The qualitative interviews took place at the participants' homes and lasted approximately two hours. The interviews covered a wide range of topics: reasons to use an electric vehicle, the way they use their vehicle, what kind of trips are done with the vehicle, the way they charge it, the tools and applications used, etc. It included drive-along tours in the electric vehicles as well as user journey mapping to understand the experience and pain points.

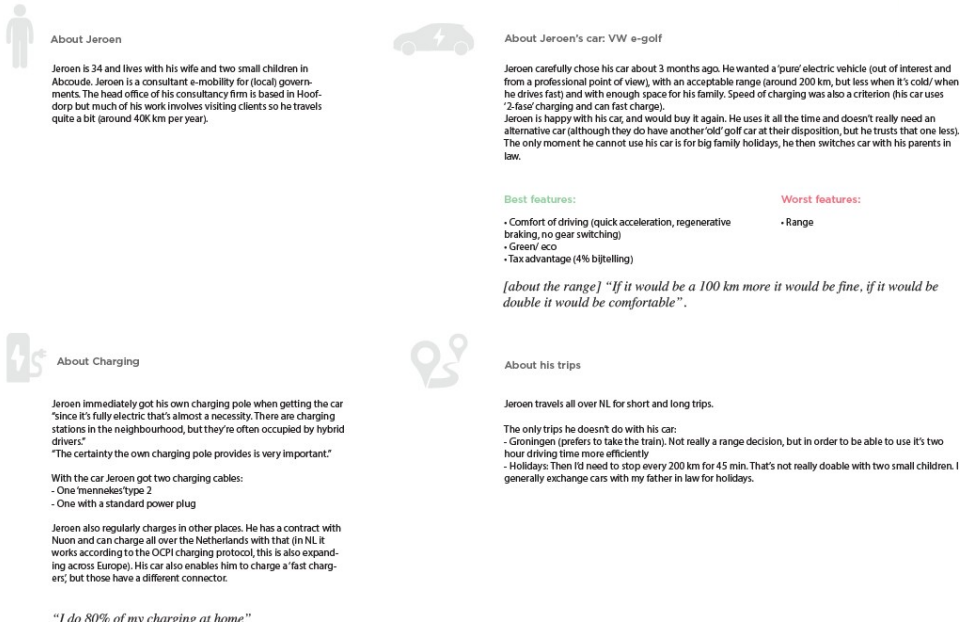

Fig. 4 Type of information collected during interviews Source: TomTom

TomTom's interviews resulted in a number of driver profiles as well as a list of questions and frustrations that the drivers most often ask themselves or experience:

How far can I realistically go with my current battery level? What is the real autonomy of my vehicle? Will I have enough battery to reach my destination and come back home? Where can I charge along the way? Will the charging station be compatible with my car? Is the charging station available? What if there is traffic along my route and I need to make a detour? How much battery will I have left when I reach my destination?

By mapping the user journeys for different types of trips and vehicles, TomTom was able to better understand the pain points and how electric vehicle drivers address them.

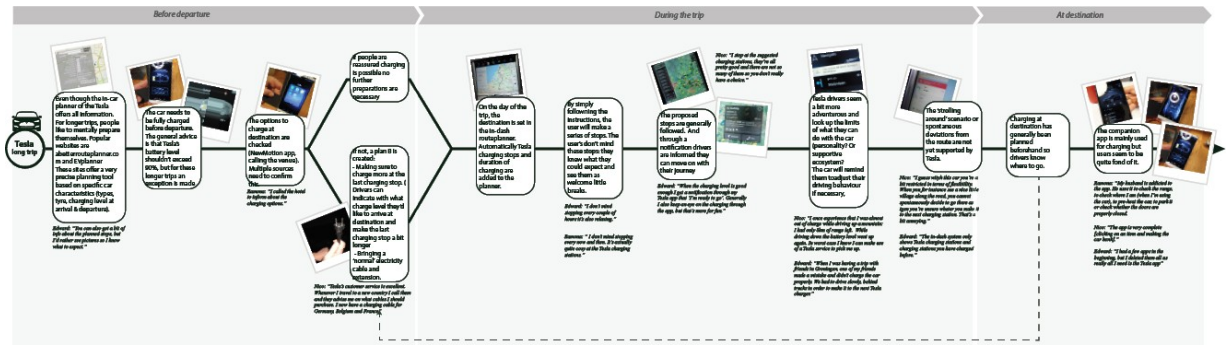

Fig. 5 Example of journey map for a trip in an electric vehicle Source: TomTom

TomTom's research highlighted different behaviors for different trip lengths. Trips are considered 'short' by EV drivers when they can be achieved without charging. One interesting finding is that drivers indicated a preference to charge at home and hence consider the battery need for their entire journey, i.e. getting to their destination and back. 'Long' trips by contrast require at least one charge – either along the way or at destination before returning. For these long trips, EV drivers tend to plan and prepare for their journey using a wide range of applications and tools, including popular trip planning apps and websites, specialized websites for EV drivers, charging station apps and apps provided by car manufacturers. Drivers tend to use several applications to double-check information such as the location of charging stations, indicating a lack of trust in the existing services. Drivers indicated that longer trips cause them more anxiety. As a result, many of them use alternatives modes of transportation for these journeys: petrol-powered cars or public transportation.

The research also highlighted a significant difference in terms of usage and behavior between owners of Tesla vehicles and owners of other electric cars. It appeared drivers of Tesla vehicles were more likely to make long trips that take them across borders and require charging along the way. On the other hand, drivers of other brands of electric vehicles tended to avoid trips that were longer than their vehicle's maximum range. Further analysis concluded that it was not the reliability or autonomy of the vehicle itself that was in cause, but rather the quality of the tools available to plan the journey: companion applications, trip planning with charging stations; remaining battery estimates at destination; time to charge, etc. Tesla drivers tended to do their entire trip planning using the navigation system provided with their vehicles. Other electric vehicle drivers would use separate apps and websites for their long trip planning, or avoid long trips entirely. These findings show that with adequate trip planning tools and accurate information, drivers dare to go further with their electric vehicles.

Innovative solutions to range anxiety

Based on their research, TomTom identified several pain points that could be addressed with adequate location technology. The following section will describe the innovative solutions TomTom developed to address range anxiety.

Reachable range: calculating realistic and accurate autonomy

TomTom's research highlighted that the autonomy claimed by electric vehicle companies is often too optimistic and perceived as unreliable by EV drivers. With little trust in the announced autonomy, drivers tend to be very cautious with their energy budget, taking a large buffer that limits their actual range. There is hence a need to estimate the range of an electric vehicle in a realistic and accurate way.

Based on these findings, TomTom developed a solution to range anxiety, taking into account the following parameters:

Vehicle characteristics: weight, energy consumption at different speeds, acceleration and deceleration efficiency, uphill and downhill efficiency

Battery capacity and current charge

Road network characteristics: type of roads (highways, small streets, etc.), road elevation (ascents, descents), curves, intersections and stops

Traffic patterns: using historical traffic data collected over a 10-year span that is augmented by real-time traffic updates, TomTom is able to predict the average speeds on different roads at any time of the day, which plays a major role in the actual energy consumption of a vehicle

The resulting model accurately predicts:

The consumption of an electric vehicle for a given route

The actual reachable range of an electric vehicle from its current location, with a given battery level

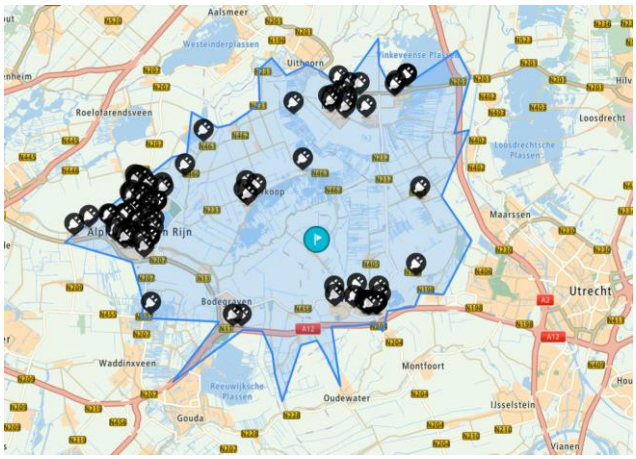

Fig. 6 – A visualization of the range of an electric vehicle
Source: TomTom

With accurate range calculations, drivers can make better informed decisions, reducing their risk of running out of battery and encouraging them to go further with their electric vehicles. Because it takes all the characteristics of the vehicle into account, the range calculations can be fine-tuned to any type of vehicle, including electric shuttles, buses or robo-taxis.

Eco routing: providing routes that minimize battery usage
While increasing rapidly, EV autonomy remains a challenge in certain situations. One example could be a trip that is longer than expected due to unforeseen events: a detour caused by a closed road, traffic congestion or an unplanned stop. In these cases, it becomes necessary to minimize battery consumption to extend the range of the vehicle.

TomTom developed a specific routing algorithm to address this need: an eco routing mode that minimizes energy consumption while balancing time. Similar to the reachable range technology, this eco routing algorithm takes into account different parameters to find the most energy efficient route, based on the road network characteristics and traffic patterns previously described.

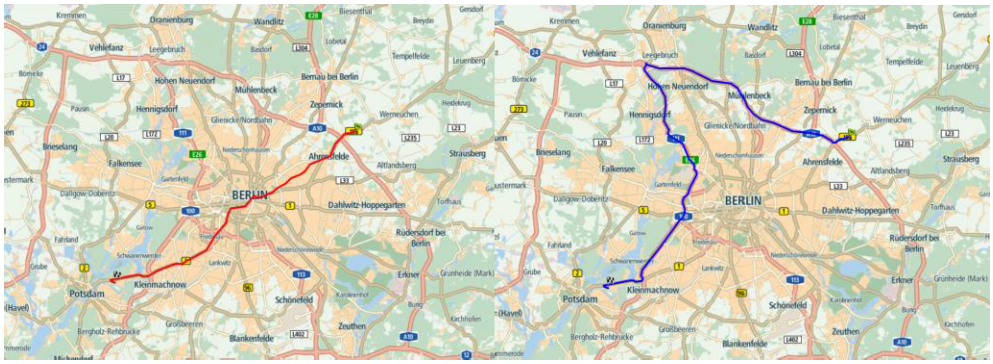

Fig. 7 – Eco routing compared to a traditional, 'fastest' route
Source: TomTom

In the example in figure 7, eco routing on the left uses 15 percent less energy than the alternative fastest route. This eco routing technology can also be used to calculate routes for petrol-powered vehicles, including trucks, thereby minimizing fuel consumptions and CO2 emissions. It is already in used in over 100,000 electric vehicles from a German car manufacturer.

TomTom EV Service: finding the right charging station, at the right time
EV drivers highlighted a number of issues in regards to charging stations. While different services exist to locate charging stations, the information provided by these services is often outdated and incomplete:

Some charging points are entirely public, others are private or semi-private
Some are only accessible at specific times of the day
Some only accept certain types of payment or subscription
Some only support specific types of plugs and voltages, making them incompatible with some vehicles
Availability is not indicated, leaving drivers at a charging station that is already in use by another vehicle

Plug types and voltages are an important issue. There is little standardization in connector types or voltage, making finding the right charging station a difficult task (fig. 8).

Fig. 8 Main types of electric vehicle connectors currently on the market
Source: EV Bitz

Further, information services tend to be limited to a specific region, OEM or operator, which limits their usefulness and scalability. Without accurate and complete information, it is difficult for an electric vehicle driver to predict whether he/she will be able to charge at a specific charging point. In response to these circumstances, TomTom developed an EV Service that provides the following information in real time:
Accurate location of charging stations
Plug and payment types, accessibility and operators
Availability of charging points

The data supporting this service is collected, aggregated, validated and formatted by TomTom, resulting in accurate and exhaustive information for 62,583 charging points in 36 countries, of which 45,811 points provide real-time availability. This information enables drivers to easily find charging points that they can actually use, reducing the number of unpleasant surprises and increasing their confidence levels. Based on feedback from users, TomTom is investigating developing a functionality to book and pay for a charging point in advance.

EV navigation: planning routes with optimized charging stops
How do you drive from Amsterdam to Barcelona with an electric vehicle? How many times will you need to stop? Where and at what battery level should you stop along the way? Unlike finding petrol stations for a traditional vehicle, the lack of charging stations outside of large cities makes planning long trips a daunting task for EV drivers. Yet, the interviews conducted by TomTom revealed that when provided with adequate trip planning tools, drivers tend to go further with their vehicles, as their uncertainty is reduced.

TomTom has designed an entirely new and exclusive Long Distance EV Routing service that aims to answer these questions. This new Long Distance EV Routing service uses the technologies presented in this paper to offer the best routing advice to EV drivers before and during their trips, including:
When and where to stop for a charge, using the consumption models mentioned under reachable range and eco routing

To what level a battery should be charged at each stop, taking into account the charging curves of different electric vehicles and their batteries
How long charging will take and what facilities are available around the charging points, enabling users to plan other activities while their vehicle is charging (lunch, shopping, etc.)
Continuous range monitoring that takes driving behavior and traffic conditions into account

One particularly innovative aspect of this technology is that it takes into account the charging curve of a vehicle battery to optimize charging. These charging curves have an important impact on when and how much a vehicle should be charged: an empty battery recharges faster than a full one; old batteries charge slower than new ones. The TomTom Long Distance EV Routing algorithm will be able to model these charging curves to offer the best charging advice for particular vehicles and to manage expectations around the necessary charging time.

TomTom's Long Distance EV Routing advice aims to minimize time spent on the road while maximizing convenience – by enabling efficient, worry-free charging for EV drivers. This service is in development and will be progressively made available in the coming months. TomTom plans to continue developing the location and navigation technology necessary to support EV drivers at every step of their journey: planning, driving and charging.

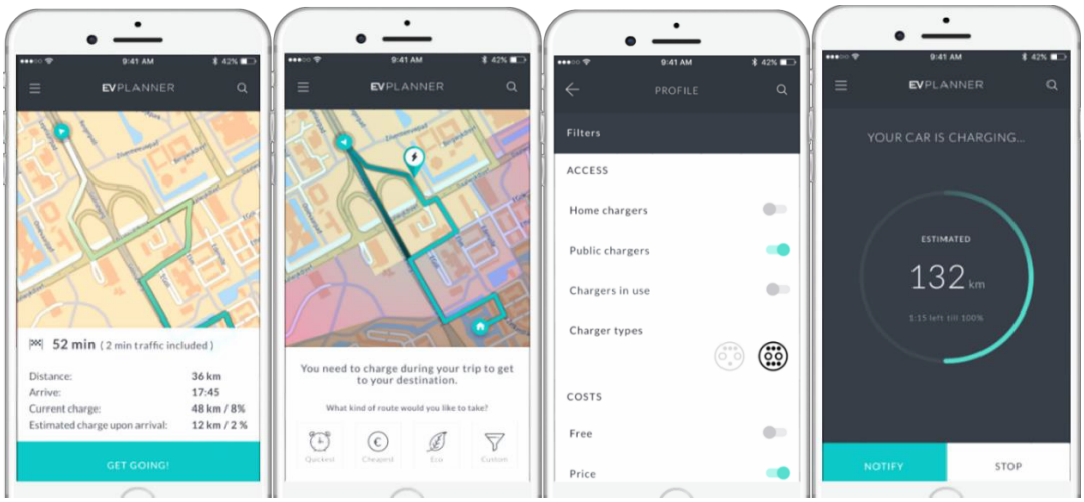

Fig. 9 EV navigation concept including planning, driving, and finding and using charging points Source: TomTom

Expected impacts
The innovations presented in this paper are designed with scalability in mind, available in more than 140 countries thanks to TomTom's global map and traffic data. The services are made available via APIs and software development kits hosted in the cloud, all using industry standard formats. This ensures they can be used by any company, large or small, to develop innovative services that offer a safe, reliable and stress-free user experience to EV drivers.

Car manufacturers are already evaluating or implementing these technologies. Innovative start-ups around the world are also able to make use of the functionalities to innovate, as they are made available to developers worldwide via a self-service portal. TomTom is using location technologies such as these to accelerate the EV revolution by lifting psychological barriers to wide-scale EV adoption.

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