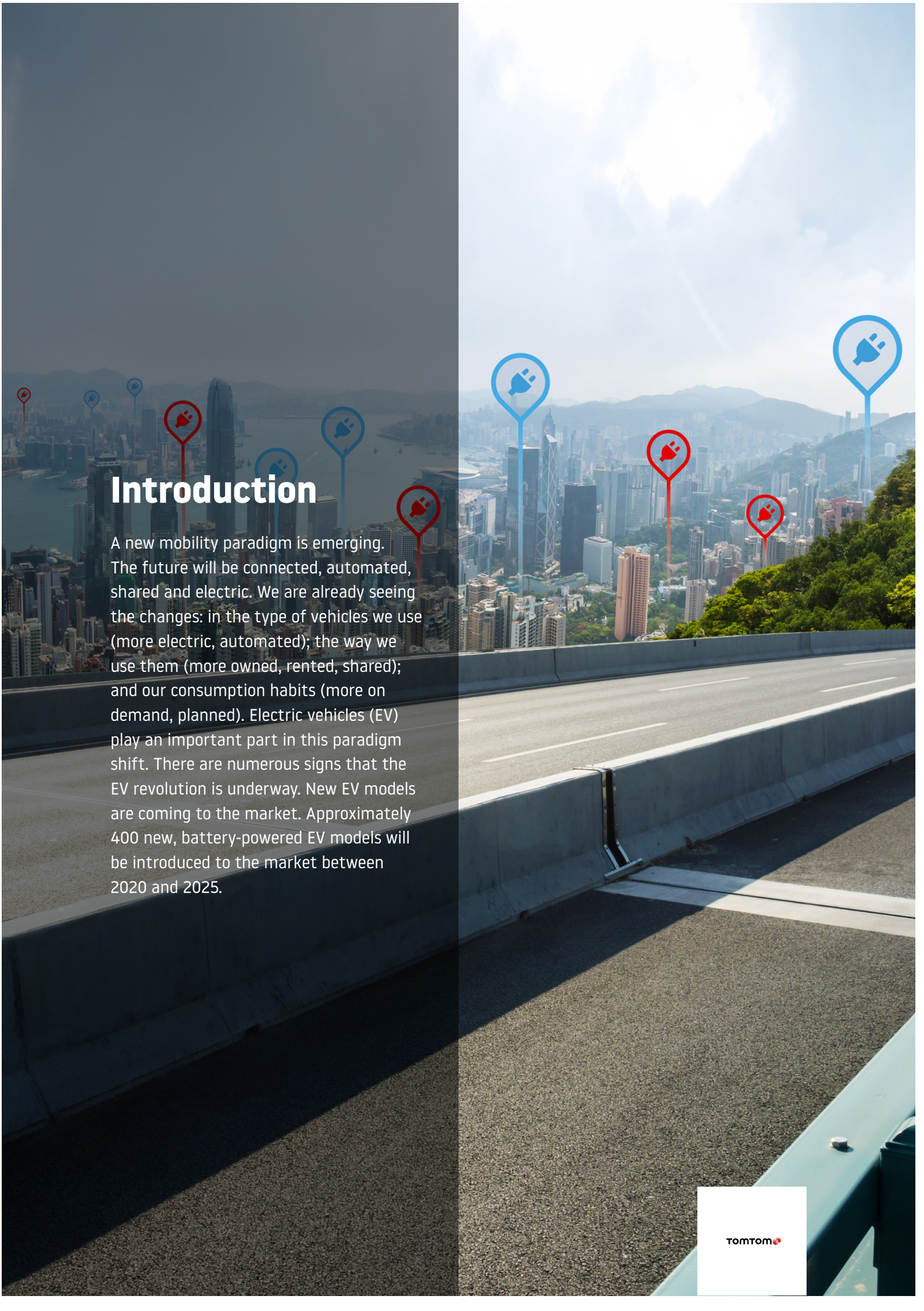
TOMTOM

# Supporting the electric mobility revolution

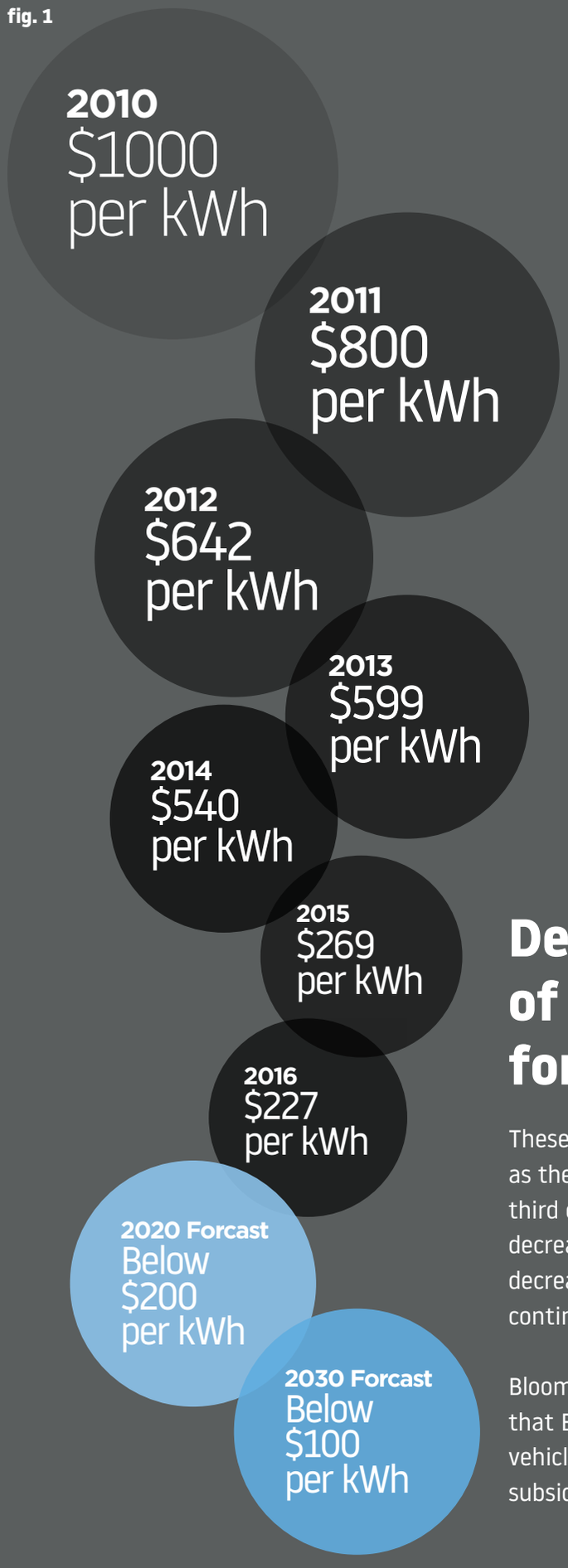
## Technologies to address range anxiety



# Introduction

A new mobility paradigm is emerging. The future will be connected, automated, shared and electric. We are already seeing the changes: in the type of vehicles we use (more electric, automated); the way we use them (more owned, rented, shared); and our consumption habits (more on demand, planned). Electric vehicles (EV) play an important part in this paradigm shift. There are numerous signs that the EV revolution is underway. New EV models are coming to the market. Approximately 400 new, battery-powered EV models will be introduced to the market between 2020 and 2025.

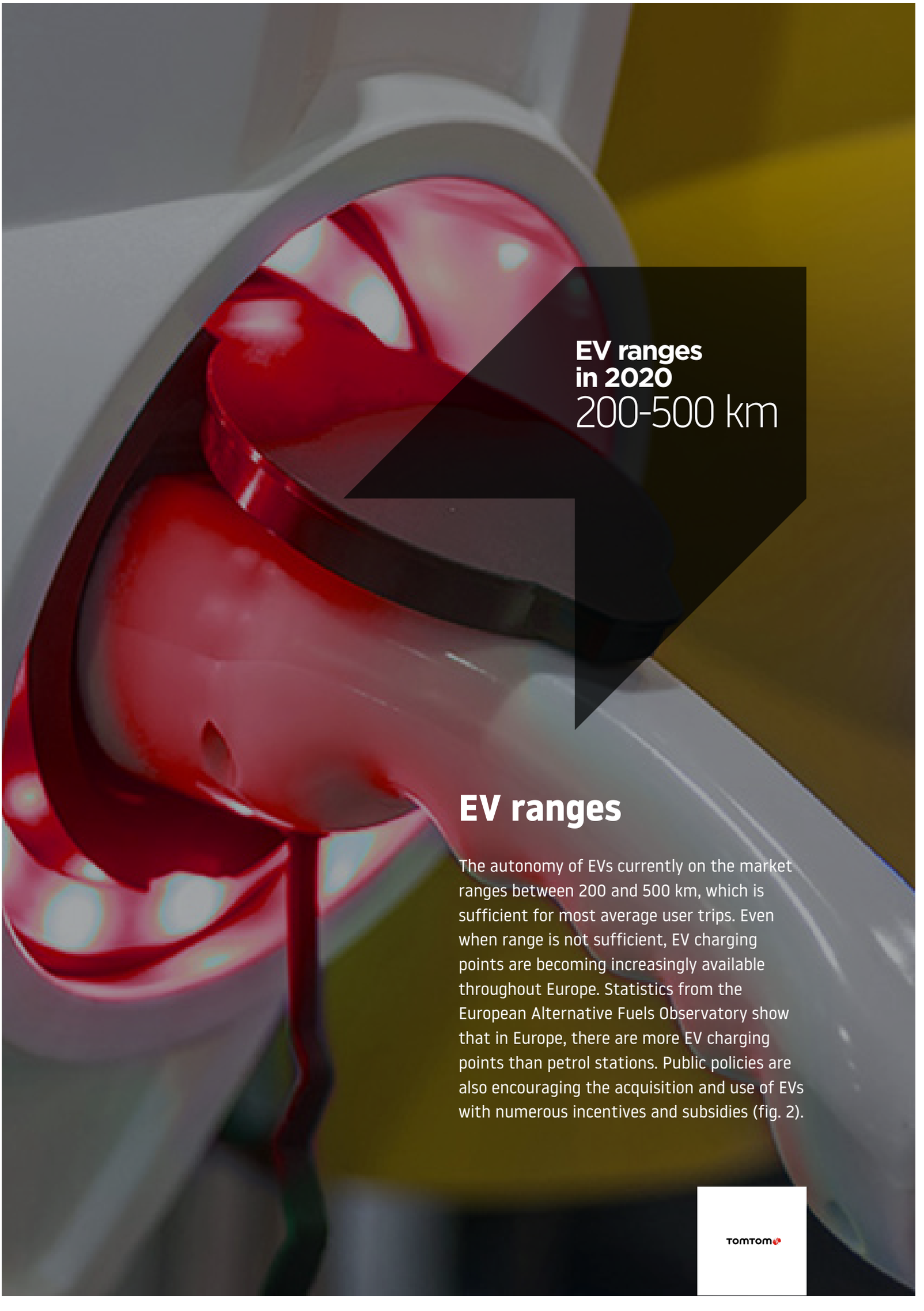
fig. 1




# Decreasing costs of batteries for EVs

These vehicles are increasingly affordable, as the cost of batteries – which is up to one third of the total cost of an EV – 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 EVs will be as affordable as fuel-powered vehicles in the next five years, even without subsidies or incentives.

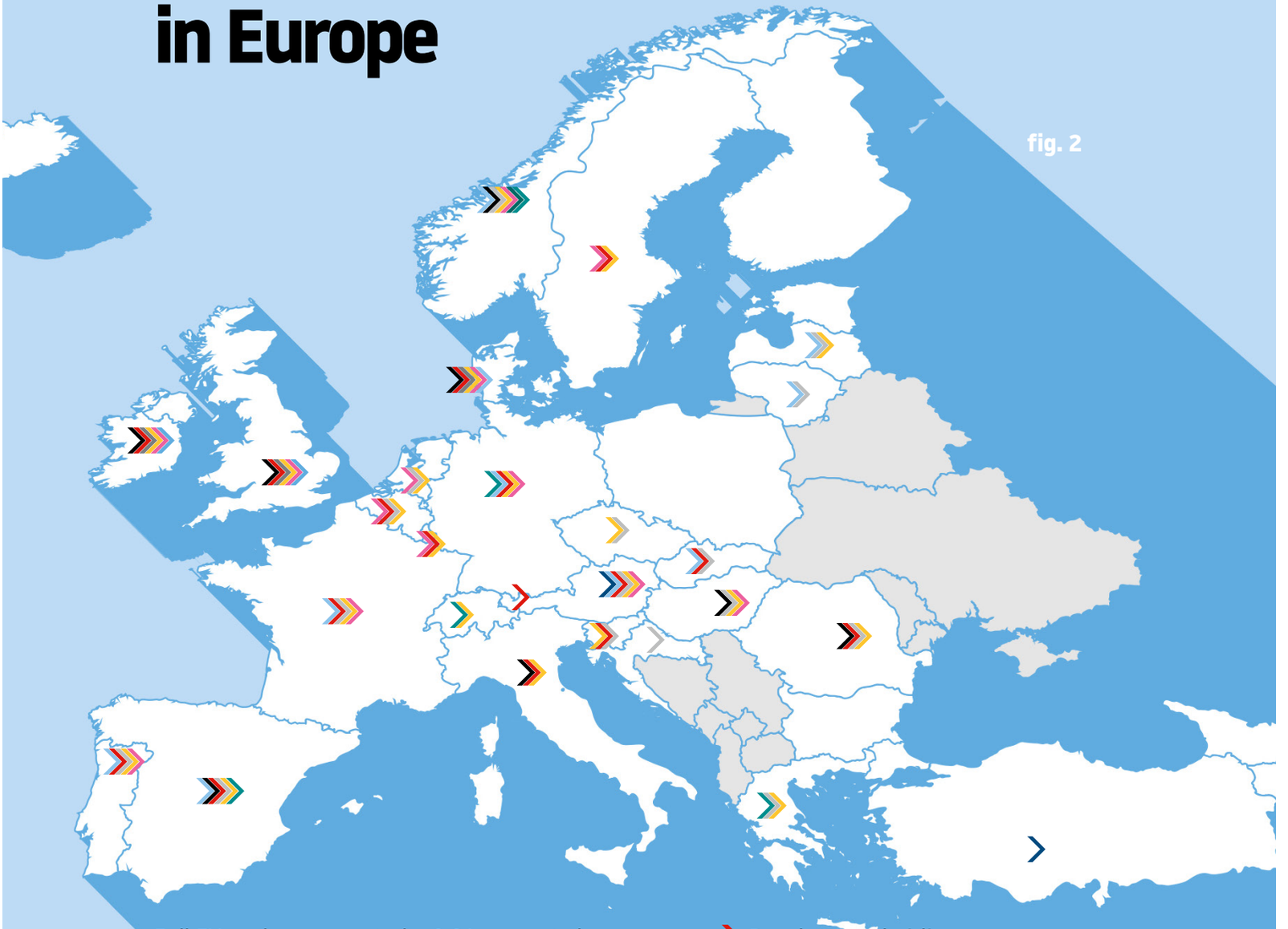



# EV ranges

The autonomy of EVs currently on the market ranges between 200 and 500 km, which is sufficient for most average user trips. Even when range is not sufficient, EV charging points are becoming 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 EVs with numerous incentives and subsidies (fig. 2).

# Public policies supporting EVs in Europe

fig. 2



Full EVs only represented a 0.64 percent share of the European market in 2017, with a mere 300,000 passenger EVs 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?

- Purchase subsidies
- Registration tax benefits
- Ownership tax benefits
- Company tax benefits
- VAT benefits
- Other financial benefits
- Local incentives
- Infrastructure incentives

# 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 widespread adoption of EVs.

**Much like horse riders in the 1900s hesitated to buy automobiles because of the lack of paved roads and petrol stations, potential EV 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 will 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.

# The role of location tech

TomTom conducted a series of interviews with EV 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 EV, 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 EVs as well as user journey mapping to understand the experience and pain points. TomTom's interviews resulted in a number of driver profiles and a list of questions and frustrations that the drivers most often ask themselves or experience, including:

- **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 EV drivers address them. 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 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 alternative 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 EVs. 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 EVs 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 the cause, but rather the quality of the tools available to plan the journey.

# Innovative solutions to range anxiety

Based on their research, TomTom identified several pain points that could be addressed with location technology and developed the following solutions for range anxiety.

# Reachable range: calculating realistic and accurate autonomy

TomTom's research highlighted that the autonomy claimed by EV 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. The range of EVs needs to be estimated 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 EV for a given route, providing the actual reachable range of an EV from its current location, with a given battery level. 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 EVs. By taking vehicle characteristics 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. Using a specific routing algorithm developed to address this problem, TomTom's eco-routing mode minimizes energy consumption while balancing time. Similar to the reachable range technology, this eco-routing solution takes into account different parameters to find the most energy-efficient route, based on the road network characteristics and traffic patterns previously described. Developers can use TomTom's range model to specify their vehicle characteristics in detail, using TomTom's highly accurate map, traffic and navigation technology to calculate a vehicle's range at a given location or along a given route. Already, the eco-routing model has shown to use up to 15 percent less energy than an alternative fastest route, and it can be used with fuel-powered vehicles to, for example, help trucks minimize fuel consumption and CO2 emissions.

# Finding the right charging station, at the right time

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 EV driver to predict whether he or she will be able to charge at a specific charging point. In response to these circumstances, TomTom developed a suite of EV services that provides the following information:

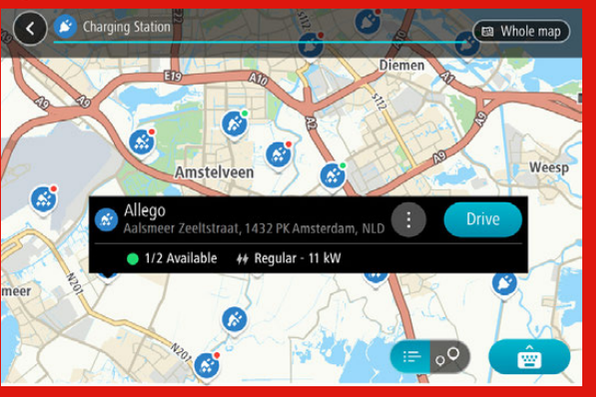
> Accurate location of charging stations
> Plug and payment types
> Accessibility
> Operator (brand) names
> Real-time availability of charging points

The data is collected, aggregated, validated and formatted by TomTom, resulting in accurate and exhaustive information for 325,685 charging points in 54 countries, of which 125,722 provide real-time availability information across 15 countries. This information enables drivers to easily find compatible charging points, reducing the number of unpleasant surprises while increasing their confidence in EV journeys (fig. 3).

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.

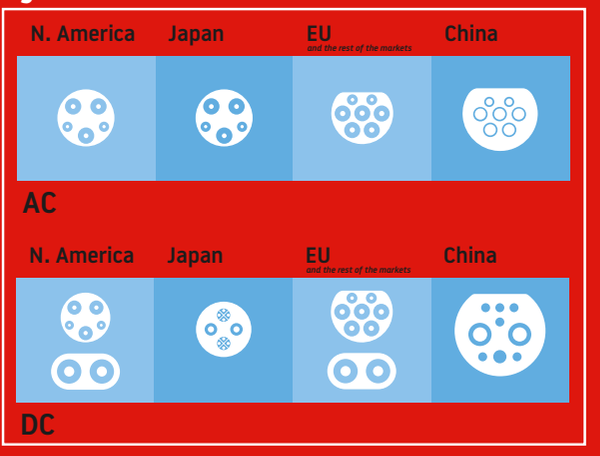
Some are only accessible at specific times of the day. Some only accept certain types of payment or subscription. Some only support specific types of plugs and voltages, making them incompatible with some vehicles. And, availability is not indicated, leaving drivers at a charging station that is already full.

**fig. 3**




Plug types are also an important factor to consider and can make finding a compatible charging station a difficult task because of the wide variety of connectors (fig. 4). Source: EV Bitz

**fig. 4**




# EV navigation: planning routes with optimized charging stops

As discussed, EV drivers can struggle to find the correct, available charging point along their route. So, how can they better plan long drives without worrying about where and when they will charge? 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 EVs 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 is able to model these charging curves to offer the best charging advice for particular vehicles and to manage expectations around the necessary charging time (fig. 5)
This aims to minimize time spent on the road, while maximizing convenience – by enabling efficient, worry-free charging for EV drivers.

**Expected impact:** The innovations presented in this paper are designed with scalability in mind, thanks to TomTom's global map and traffic data available in 164 countries and 35 territories, currently in 2020.

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 TomTom's self-service developer portal. TomTom is using location technologies such as these to accelerate the EV revolution by lifting psychological barriers to wide-scale EV adoption.

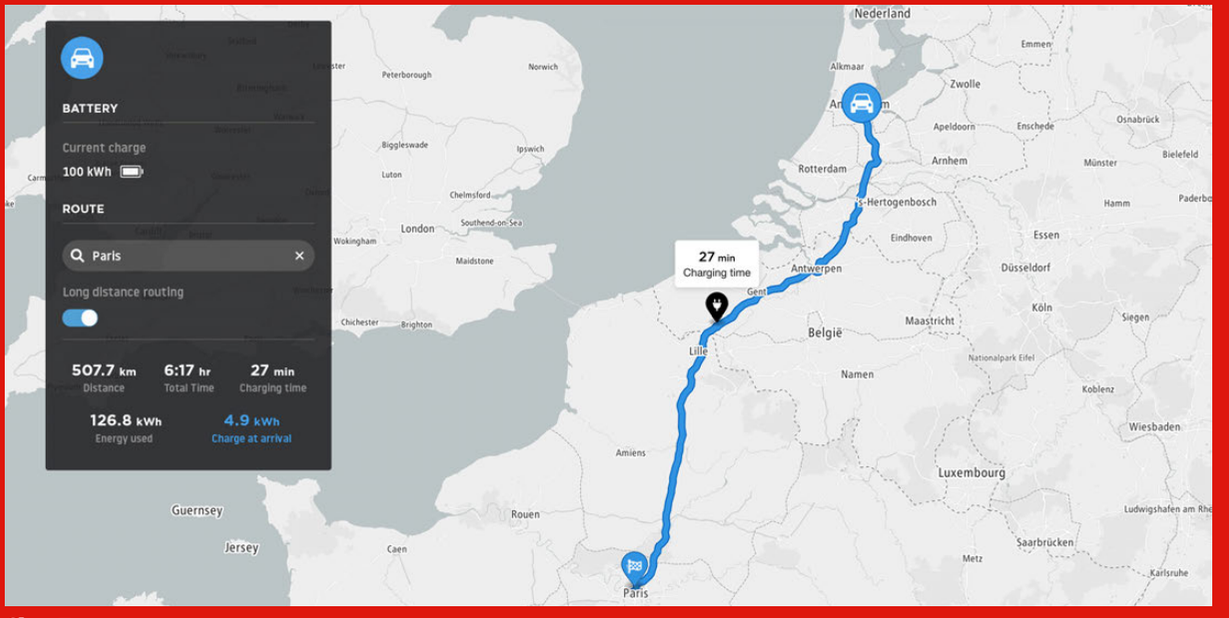



**fig. 5**

# About TomTom

TomTom is the leading independent location technology specialist, shaping mobility with highly accurate maps, navigation software, real-time traffic information and services. To achieve our vision of a safer world, free of congestion and emissions, we create innovative technologies that keep the world moving. By combining our extensive experience with leading business and technology partners, we power connected vehicles, smart mobility and, ultimately, autonomous driving. Headquartered in Amsterdam with offices in 30 countries, TomTom's technologies are trusted by hundreds of millions of people worldwide. www.tomtom.com

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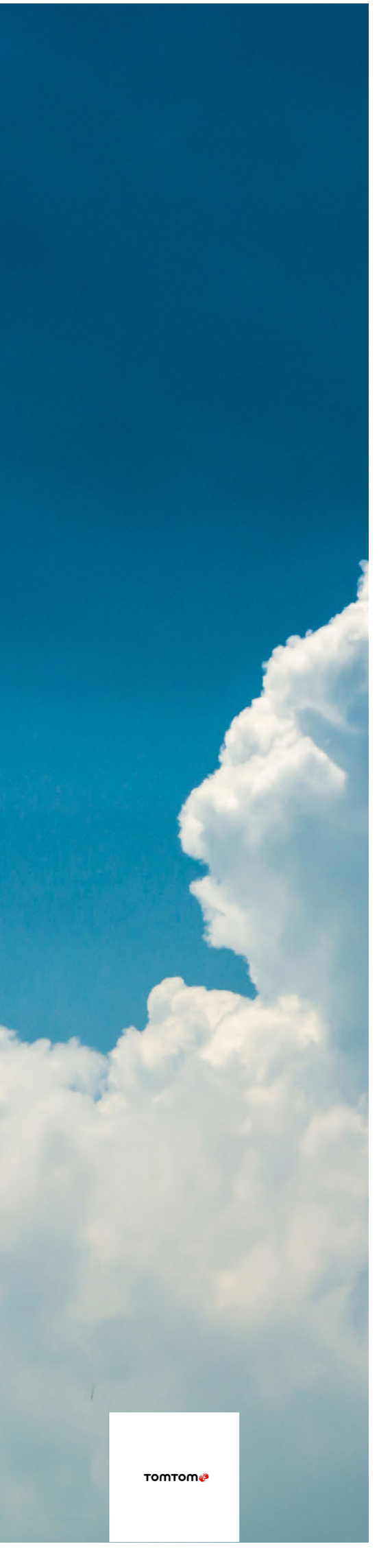

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