Tactran Regional EV Strategy: Demand Forecast Technical Paper

This note describes the approach to taken to modelling of Electric Vehicle (EV) demand for the four Local Authorities (LAs) within the Tactran region.

This note includes:

1. An outline of Light Duty Vehicle fleet projections[1] for Scotland to 2032 under different policy scenarios;
2. An estimation of the number of charge points needed in each scenario to support this EV demand;
3. A comparison of the Scottish EV market compared to other international examples of best practice;
4. A brief discussion of motivations and factors in EV adoption including evidence of how incentives and charging infrastructure provision effects purchasing decisions;
5. An overview of how EV battery technology has changed in the past decade, with an overview of the future challenges and opportunities.

1. Outline of Fleet projections

In this note, three different scenarios for electrification of the light duty vehicle fleet in Scotland are considered (see Figure 1 for fleet scenarios). These scenarios are illustrative futures, not projections of the fleet. The 'high' scenario represents a future such that the Scottish government's target of removing the need for conventional fossil fuel cars and vans by 2032. is met. The adoption of electric vehicles is assumed to follow an 'S-shaped' adoption curve (as illustrated in Figure 2). This S-shaped adoption curve is based on 'Roger's curve' where there are innovators, mass adopters then laggards in adopting new technologies. This behaviour has been well documented across many different technologies including mobile phones [1], electronics [2], and renewable energy technologies [3]. From the S-shaped adoption curve, it is evident that there is a 'surge' in adoption in the mass market, where the technology moves from the niche market to the mass market. In this model, the S-shaped adoption curve is assumed to be symmetrical, however, models of this type can be asymmetrical, meaning that it is challenging to predict when a technology will reach its inflexion point.

[1] Note that fleet refers to total car stock on the roads measured in number of registrations. Market share refers to the percentage of new light duty vehicle registrations within a particular framework.

A fleet turnover model translates market share (aka percentage of new car registrations) into fleet share (aka percentage of total on-road car registrations). The fleet turnover model here assumes the average scrappage age is 14 years in line with data from the Society of Motor Manufacturers and Traders (SMMT) [4]. It is assumed that the total number of cars registered will remain static to 2040. The likelihood of this assumption is discussed in Section 2 in the context of estimating required infrastructure provision.

The 'low' scenario in this note is chosen in line with National Atmospheric Emissions Inventory (NAEI) projections [5]. The figures given are Scotland specific but are provided in share of vkm (vehicle kilometres travelled) rather than fleet share (percentage of total car registrations). From the vkm, the market share (percentage of new car registrations) is estimated. The 'medium' scenario is a pathway halfway between the low and high scenarios.

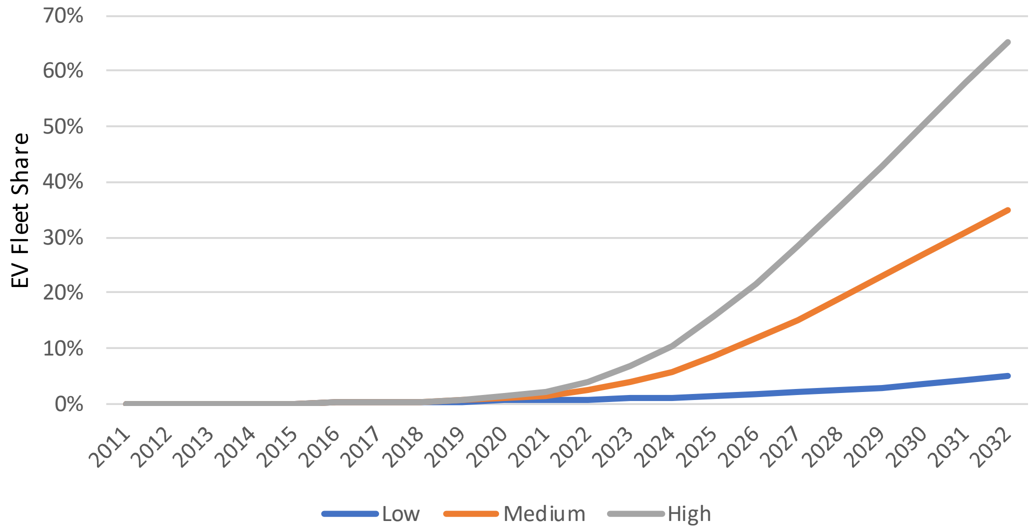

Figure 1: Scotland EV Fleet share of Light Duty Vehicles under the low, medium and high EV adoption scenarios.

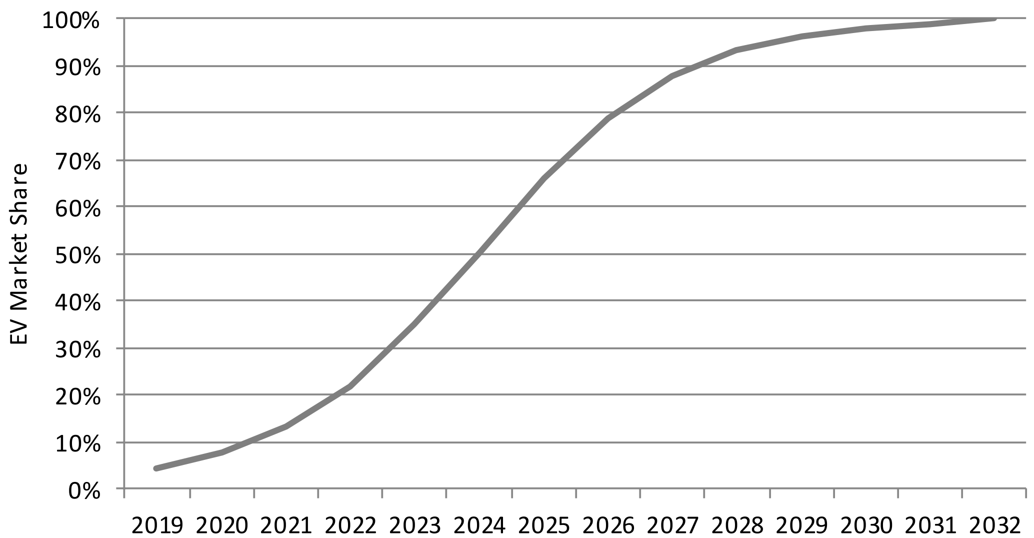

Figure 2: Scotland EV Market share of Light Duty Vehicles illustrating 'S-shaped' adoption curve for high EV uptake scenario.

2. Charging infrastructure provision

Fleet scenarios are important for planning infrastructure needs as the vehicle fleet electrifies. Charging infrastructure is key to supporting adoption of EVs across the market and the provision of charge points needs to be greatly increased to accommodate an electrified fleet. However, the exact requirements for charging infrastructure are difficult to predict. For example, the EU suggests a ratio of one publicly accessible charge point for ten electric cars under the EU Alternative Fuels Infrastructure (AFI) Directive [6]. However, countries such as Norway have only deployed 1 publicly accessible charge point for every 19 EVs [6]. Table 1 presents the projected figures for publicly available charge points under those two scenarios if we were to simply apply those ratios to the 'high' EV adoption scenario described in Section 1.

Table 1: Number of publicly accessible charge points in each local authority under the 'high' EV adoption scenario using different EV to charge point ratios.

	# publicly accessible charge points				
	2019	2025	2025	2032	2032
	Current provision	Ratio of 1 charge point per 19 EVs	Ratio of 1 charge point per 10 EVs	Ratio of 1 charge point per 19 EVs	Ratio of 1 charge point per 10 EVs
Angus	62	550	1045	2292	4355
Dundee City	133	494	941	2063	3921
Perth and Kinross	55	716	1360	2983	5668
Stirling	31	533	1013	2220	4219

Many factors will affect the necessary publicly available charge point provision in the future and could dramatically impact the estimates in Table 1:

- The AFI directive which indicates a target of a ratio of 1 charge point for every 10 EVs does not specify the type of charge points needed. The provision of different types of charge points (e.g. slow, fast, rapid) and the location (e.g. hubs vs on street) will affect the number of charge points needed as the fleet electrifies. The proliferation of rapid charging hubs will likely mean that the 1 to 10 ratio is not necessary.
- Increased electric vehicle range stemming from higher battery capacity (see Section 5 for more details of future battery technology) may mitigate the need for the higher ratios indicated in Table 1.
- At present, tariffs on the CPS network are free therefore the introduction of tariffs will likely incentivise more people to charge at home overnight.

- Without current data on home charging behaviour it is challenging to predict how home charging and public charging will interplay in the future. If the majority of private car users charge overnight then the need for publicly available infrastructure will be lower.
- Changes in mobility such as the rise of Mobility as a Service (MaaS) or the proliferation of electric car clubs could affect car ownership, therefore putting different pressures on publicly available charge points.
- Electrification of the taxi fleets will necessitate the need for rapid charging hubs in strategic locations in urban areas. Similarly, if businesses electrify their fleets this could put additional strain on public charging infrastructure.

3. EV adoption around the world

Several markets have experienced greater adoption to date than Scotland and the UK. A summary of these countries is presented in Figure 3. Higher EV market share is usually linked with national level policy such as fiscal incentives or mandates. For example, every electric car purchaser in Norway is exempt from acquisition tax, representing around £9000, as well as the 25% VAT usually payable on car purchases [7]. Norway is the most generous country in the world for EV subsidies, but with high vehicle taxes it is viable to reduce taxes for EV adopters rather than increase them for petrol/diesel ICEV (Internal Combustion Engine Vehicle) owners. In other countries, it is not deemed politically viable to increase taxes for petrol/diesel ICEVs to incentivise adoption of low emission vehicles. Other countries have chosen other policy methods to increase electrification such as mandates rather than fiscal incentives. For example, China has implemented their New Energy Vehicle (NEV) policy framework. This is an annual mandatory requirement for auto-manufacturers to achieve a certain number of NEV credits. These credits are gained by producing or importing NEV passenger cars. Manufacturers with surplus NEV credits can either be used offset corporate average fuel consumption credit deficits, sold to other companies, or banked for the following year. This system is similar to the ZEV (Zero Emission Credit) scheme in California.

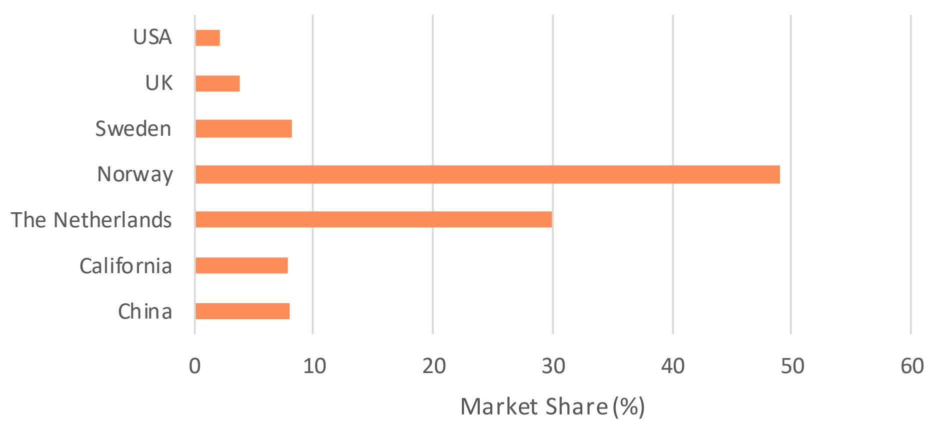

Figure 3: EV Market Share of light duty vehicle markets in 2018 (Data sourced from [6]).

4. Motivation and factors in EV adoption

A large body of literature examines the key motivations and factors affecting adoption of EVs. Several themes emerge from these studies, indicating that the purchase of a hybrid or electric vehicle is not entirely an economically rational decision but many other factors come into play. These factors can largely be categorised into three types: demographic factors such as age, gender and education; situational factors such as battery capabilities, cost, and charging infrastructure concerns; and psychological factors such as pro-environmentalism, technology oriented lifestyle and subjective social norms.

The higher capital cost is accepted as a key barrier to EV adoption [8]. However, consumers are not entirely economically rational in their decision behaviours [9], [10]. Although fiscal incentives have a positive effect on rates of adoption, the size of fiscal incentives has been found not to be directly proportional to the effect on rates of adoption.

A review of the studies investigating the effectiveness of fiscal incentives on the adoption of electric vehicles by Hardman et al. [11] showed that 32 of the 35 studies published on this topic have positive results. The fiscal incentives considered in the studies range from tax exemptions, purchase price reductions, and tax credits across different countries such as the USA, Norway, Canada and Sweden. Despite the link found between fiscal incentives and adoption of EVs, there is still criticism in the literature that some of these incentives, specifically tax rebates, are structured inefficiently or not communicated sufficiently. Evidence shows that rebates are more effective than tax credits [11]. This is likely to result from the phenomenon of 'hyperbolic discounting' where consumers value smaller financial incentives sooner than larger rewards later. The literature indicates that point of sale grants and VAT exemptions for BEVs are the most effective fiscal incentives [12].

5. Battery technology

Lithium Ion Batteries are well suited for use in EVs because of high energy density, long lifespan, rechargability and low rates of self-discharge. In the last ten years, nearly all high-performance EVs have shifted to using Lithium Ion batteries [13]. For EV batteries, Lithium Ion Battery chemistry is anticipated to be dominant in the medium term, with potential development of Lithium Air, Lithium Sulphur and solid-state Lithium batteries in the long term. Such battery technologies could offer higher density, greater capacities, and lower combustion risks with greater charge cycle life but they are still in the development stages [6], [14], [15].

Current battery capacities for cars range from 40 kWh for the Nissan Leaf (this increased in September 2018 from 24 kWh), to 100 kWh Tesla Model X [16], [17][2]. An extensive literature

[2] Rivian have announced they are manufacturing a 180 kWh Electric SUV which will shortly be available (see https://products.rivian.com/suv/).

examines the future of EV battery costs. Many of these studies consider the benchmark of when battery pack costs will fall below $100/kWh. The cost of Lithium Ion batteries has fallen from an average battery pack price of $1,000/kWh in 2010 to $209/kWh in 2017. Tesla estimates that $100/kWh could be reached for their battery packs in 2020 [18]. The battery cost projections from BNEF (Bloomberg New Energy Finance), the industry authority that produces the annual Battery Price Survey, estimate that 100$/kWh will be reached before 2024 [19]. Other sources such as McKinsey [20], Beckermans et al. [21] and Nykvist et al. [22] estimate this to be reached between 2020 and 2030. Average energy density of EV batteries is also improving at around 5-7% per year [23].

As the demand for EVs grows, the manufacturing capacity of batteries must grow with it. In the last few years, customers wishing to make the transition to electric have had issues with wait times due to demand outpacing supply [24]. To remedy this, EV manufacturers such as Tesla have built their own "Gigafactories" to ensure supply issues of batteries and electric motors do not disrupt vehicle sales [25].

These trends in battery cost, capacity and energy density feed into the need for charging infrastructure. As battery technology advances the provision for publicly available charge points will change potentially with lower ratios of charge points to EVs needed.

References

[1] C. Michalakelis, D. Varoutas, and T. Sphicopoulos, "Diffusion models of mobile telephony in Greece," *Telecomm. Policy*, vol. 32, no. 3–4, pp. 234–245, 2008.

[2] E. W. Ford, M. N., and M. T. Phillips, "Predicting the adoption of electronic health records by physicians: when will health care be paperless?," *J. Am. Med. Informatics Assoc.*, vol. 13, no. 1, pp. 106–112, 2006.

[3] K. U. Rao and V. V. N. Kishore, "A review of technology diffusion models with special reference to renewable energy technologies," *Renew. Sustain. Energy Rev.*, vol. 14, no. 3, pp. 1070–1078, 2010.

[4] Society of Motor Manufacturers and Traders, "Average Vehicle Age," *2018 AUTOMOTIVE SUSTAINABILITY REPORT*, 2018. [Online]. Available: https://www.smmt.co.uk/industry-topics/sustainability/average-vehicle-age. [Accessed: 08-Aug-2018].

[5] NAEI, "Vehicle Fleet Composition Projections (Base year 2016)," 2017. .

[6] IEA, "Global Electric Vehicle Outlook," 2018.

[7] E. Figenbaum, T. Assum, and M. Kolbenstvedt, "Electromobility in Norway – Experiences and opportunities," *Res. Transp. Econ.*, vol. 50, pp. 29–38, 2015.

[8] M. Coffman, P. Bernstein, and S. Wee, "Electric vehicles revisited: a review of factors that affect adoption," *Transp. Rev.*, vol. 37, no. 1, pp. 79–93, 2017.

[9] S. Hardman and G. Tal, "Exploring the decision to adopt a high-end battery electric vehicle: role of financial and nonfinancial motivations.," *Transp. Res. Rec.*, vol. 2572.1, pp. 20–27, 2016.

[10] T. S. Turrentine and K. S. Kurani, "Car buyers and fuel economy?," *Energy Policy*, vol. 35, no. 2, pp. 1213–1223, 2007.

[11] S. Hardman, A. Chandan, G. Tal, and T. Turrentine, "The effectiveness of financial purchase incentives for battery electric vehicles – A review of the evidence," *Renew. Sustain. Energy Rev.*, vol. 80, no. March, pp. 1100–1111, 2017.

[12] Z. Yang, P. Slowik, N. Lutsey, and S. Searle, "Principles for Effective Electric Vehicle Incentive Design," *Int. Counc. Clean Transp.*, no. June, p. 37, 2016.

[13] W. Wang and Y. Wu, "An overview of recycling and treatment of spent LiFePO4batteries in China," *Resour. Conserv. Recycl.*, vol. 127, no. 100, pp. 233–243, 2017.

[14] F. Lambert, "Solid-state battery startup secures backing from several automakers as it claims breakthrough for electric vehicles," *electrek*, 11-Sep-2018.

[15] A. Vandervell, "What is a solid-state battery? The benefits explained," *Wired*, 26-Sep-2017.

[16] Tesla, "Model 3," 2018. [Online]. Available: https://www.tesla.com/en_GB/model3. [Accessed: 10-Oct-2018].

[17] Nissan, "NEW NISSAN LEAF," 2018. [Online]. Available: https://www.nissan.co.uk/vehicles/new-vehicles/leaf.html?&cid=psmXuDSQuiR_dc%7CU&gclid=EAIaIQobChMIt9vV1_uV3gIVLLftCh1tuAELEAAYASAAEgKob_D_BwE. [Accessed: 10-Oct-2018].

[18] M. Holland, "$100/kWh Tesla Battery Cells This Year, $100/kWh Tesla Battery Packs In 2020," *Clean Technica*, 2018. [Online]. Available: https://cleantechnica.com/2018/06/09/100-kwh-tesla-battery-cells-this-year-100-kwh-tesla-battery-packs-in-2020/. [Accessed: 14-Apr-2019].

[19] L. Goldie-Scott, "A Behind the Scenes Take on Lithium-ion Battery Prices," *BNEF*, 2019. [Online]. Available: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/. [Accessed: 14-Apr-2019].

[20] McKinsey, "The new rules of competition in energy storage," 2018. [Online]. Available: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-new-rules-of-competition-in-energy-storage. [Accessed: 14-Apr-2019].

[21] G. Berckmans, Maarten Messagie, Jelle Smekens, Noshin Omar, Lieselot Vanhaverbeke, and Joeri Van Mierlo, "Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030," *Energies*, vol. 10, no. 9, p. 1314, 2017.

[22] B. Nykvist, F. Sprei, and M. Nilsson, "Assessing the progress toward lower priced long range battery electric vehicles," *Energy Policy*, vol. 124, no. October 2018, pp. 144–155, 2019.

[23] BNEF, "Electric Vehicle Outlook," 2018.

[24] N. Manthey, "Electric cars got a delivery problem across the board," *electrive*, 2018. [Online]. Available: https://www.electrive.com/2018/02/19/electric-cars-got-delivery-problem-across-board/. [Accessed: 10-Oct-2018].

[25] Tesla, "Gigafactory," 2014. [Online]. Available: https://www.tesla.com/en_GB/GIGAFACTORY. [Accessed: 10-Oct-2018].