

UK Energy Strategies Under Uncertainty

Policy Making under Uncertainty in the Demand for Electric Vehicles

Working Paper

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Abstract

The introduction of Electric Vehicles (EVs) into the passenger vehicle market has, in recent years, become viewed as a primary solution to the significant carbon emissions attributed to personal mobility. Moreover, EVs offer a means by which energy diversification and efficiency can be improved compared to the current system which is dominated by internal combustion engines powered by oil based fuels.

The UK and EU Governments have played an active role in steering the development and market introduction of EVs. Policies have been formulated and introduced to engage the consumer by raising awareness of these alternative options, incentivise adoption through fiscal measures and establishing the necessary infrastructure. However, a great deal of uncertainty remains regarding the effectiveness of these policies and the viability of the EV technology in the mainstream automotive market.

This paper investigates the prevalence of uncertainty concerning demand for EVs. This is achieved through the application of a conceptual framework which assesses the locations of uncertainty. UK and EU Government policy documents are assessed through a rapid evidence review alongside contributions from academia to determine how uncertainty has been reduced.

This assessment offers insights to decision makers in this area by evaluating the work done to date through a landscape analysis. Results from the analysis identified six different locations of uncertainty covering [1] consumer, [2] policy, [3] infrastructure, [4] technical, [5] economic and [6] social.

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1 Introduction

Electric Vehicles (EVs) represent a vehicle category which utilises advancements in battery technology to reduce the energy and carbon (CO₂) intensity attributed to passenger vehicle mobility. EVs are viewed as a primary means by which the UK and EU Governments will meet their commitments to reduce CO₂ emissions in the transport sector (OLEV, 2013; EC, 2012a). Specifically focusing on the UK, legally binding legislation has been passed which requires CO₂ emissions to be reduced by 80% based on 1990 levels by 2050 (Climate Change Act, 2008) with five year carbon budgets established to ensure the UK is on a trajectory to meet this commitment (HMGov, 2009). EVs represent a form of disruptive innovation (Christensen, 1997; Zapata and Nieuwenhuis, 2010) meaning their introduction has the potential to destabilise existing market conditions. As a result of the disruptive characteristics of EVs, there is a significant degree of uncertainty surrounding the proposed transition to these vehicles (Struben and Sterman, 2008; Sovacool and Hirsh, 2009).

This paper investigates this issue of uncertainty by examining how it manifests in respect to demand for EVs. Specific attention is given to household EV demand though passing references are also made concerning uncertainty in the fleet market. A conceptual framework which illustrates the different locations of uncertainty is developed and described. Each location represents a specific domain of uncertainty, where different actors operate, with the conceptual framework illustrating how these locations are potentially connected. A rapid evidence review of UK and EU Government policy documents combined with research output from the academic sector is used to produce a landscape of this research area. To structure the analysis, two research questions have been specified:

- What are the main locations of uncertainty in the demand for EVs?
- How has policy been used to reduce uncertainty in the demand for EVs?

This paper first presents the background to the concept of uncertainty and the approach employed to conceptualise it before stating where the policy and supporting documents relevant to this study were sourced. Following this, the conceptual framework assessing the locations of uncertainty is developed and then applied in reference to EV demand. Having presented the results of the rapid evidence review, the research questions initially outlined are approached to demonstrate the contribution of the analysis. To conclude, the key points from the analysis are summarised.

2 Background and Approach

Uncertainty manifests itself as any form of deviation from the unachievable ideal of complete deterministic knowledge of a system (Walker *et al.*, 2003). The concept has been conceptualised in different formats, ranging from pure statistical approaches (Greenland, 2001) to the influence it has over human decision making (Tversky and Kahneman, 1974). Additionally, the concept of uncertainty has been examined in certain areas of transportation, with its influence over the estimation of greenhouse gas emissions from the transportation sector (Kioutsioukis *et al.*, 2004; Int Panis *et al.*, 2004) and its prevalence in traffic forecasts (Waller *et al.*, 2001; de Jong *et al.*, 2006) being well established. In an effort to provide a unified basis for the investigation of uncertainty, Walker *et al.* (2003) developed a matrix which defines uncertainty according to three main characteristics. Firstly, the location of uncertainty can be established through the development of a model of the relevant environment. Secondly, the level of uncertainty can be assessed on a continuum ranging from absolute determinism to total ignorance. Thirdly, the nature of uncertainty can be explored to assess if a particular instance of uncertainty is epistemic, and thus reducible through the acquisition of additional knowledge, or variable and thus reflecting a natural deviation present in the system.

In this paper, specific focus is given to defining the locations of uncertainty in EV demand through an assessment of the topics which have been discussed in UK and EU Government policy and academic documents. To develop a database of relevant policy documents, a rapid evidence review was conducted. In reference to UK documents, the internet portal gov.uk was used to identify relevant government documents. In addition, the Low Carbon Vehicle Partnership's resource library was reviewed to provide additional material such as supporting documents and consultancy reports. For EU documents, a similar procedure was followed with the EU bookshop internet portal being the principal source of documents. In all instances, the review process was exhaustive, with each portal searched in its entirety for documents concerning transport, energy demand and EVs. To complement this, relevant academic literature was sourced from an extensive literature review previously conducted in EV demand (Morton, 2013).

3 Conceptual Framework of Uncertainty

To determine the locations of uncertainty regarding demand for EVs, a framework of uncertainty which was initially outlined by Meijer *et al.* (2006) and subsequently applied to micro CHP (Meijer *et al.*, 2007) is used as a starting point. In this paper, the structure of Meijer *et al.*'s (2006) framework is updated to account for the nuances of the EV market. These updates are informed by the points of discussion which are prominent from an assessment of the government policy documents. The framework is illustrated in Figure 1 and contains six primary locations. Of the six primary locations, four are internal to EV demand and comprise [1] consumer, [2] policy, [3] infrastructure and [4] technical whilst two are external consisting of [5] economic and [6] social.

Additionally, the conceptual framework of EV demand has been informed by the method specified by Walker *et al.* (2003), with the locations of uncertainty being further refined by considering uncertainty in reference to framework structure, what represents an internal and external location and how these locations are related. This distinction between internal and external location reflects the volitional control of policy makers, with internal locations being controllable to some degree whilst external locations are less controllable.

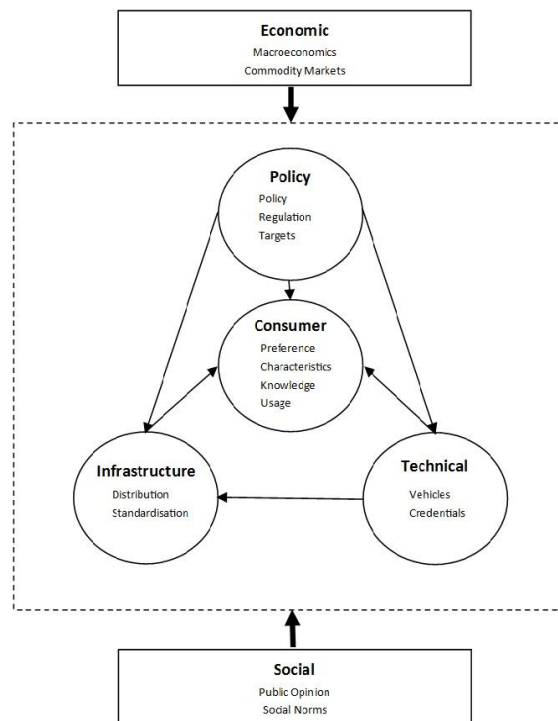


Figure 1: Conceptual framework of the locations of uncertainty in the demand for electric vehicles

4 Locations of Uncertainty

This section details the specific uncertainties which exist in reference to EV demand by applying the conceptual framework detailed in the proceeding section to the Government policy documents and academic literature sourced from the rapid evidence review.

Consumer Uncertainty

Forming the focal point of the framework, consumers represent the principal component of interest due to the close proximity between consumers and demand. With adoption rates of EVs in the UK remaining markedly low (DfT, 2013a), an appreciation for consumer uncertainty may highlight issues limiting uptake. Four aspects of consumer uncertainty are of specific interest in reference to EV demand.

Firstly, consumers have preferences towards different vehicles based on the subjective utility they assign to different vehicle characteristics (Lave and Train, 1979). In reference to EVs, consumer preferences represent an area of significant uncertainty, with extensive research attempting to quantify preferences for the unique attributes of EVs (Beggs *et al.*, 1981; Calfee, 1985; Dagsvik *et al.*, 2002; Caulfield *et al.*, 2010) and estimate likely market shares (Train, 1980; Bunch *et al.*, 1995; Eggers and Eggers, 2011; Cluzel *et al.*, 2013). This issue has received attention by the UK Government, with King (2007) exploring how consumers make choices between different cars.

Findings suggest that encouraging consumers to select the appropriate class of car for their needs and ensuring that the car selected is best in class for CO₂ emissions holds an emissions abatement potential of 15% and 25% respectively. Similarly, the importance of understanding consumer preferences has been acknowledged at the EU level (EC, 2010a). Doubts have been raised regarding consumer willingness to pay for technology aimed at reducing car emissions (EC, 2005) whilst choice experiments have determined that consumers tend to upgrade range and reduce purchase price rather than increase top speed or improve recharge times in EVs when given the option (EC, 2012b).

Secondly, consumers can be categorised by their defining features to allow manufacturers and governments to target market interventions. The common characteristics of EV adopters represents an area of uncertainty, with low sales volumes meaning data on actual purchasers is difficult to attain. This has led researchers to employ research methods based on psychometric surveys (Borthwick and Carreno, 2012) and census data (Campbell *et al.*, 2012) to assist in identifying likely adopters. The UK Government commissioned a report to examine the emerging EV market (Slater *et al.*, 2009) with findings suggesting that early adopters have a higher willingness to pay for EVs. A premium of £2000 was viewed as being acceptable which is in keeping

with other research findings (Potoglou and Kanaroglou, 2007), whereas mass market consumers were unwilling to pay extra to support new low-carbon technologies.

Thirdly, the level of awareness consumers have regarding EVs and the degree to which knowledge needs to be improved to accelerate EV demand represents an aspect of consumer uncertainty. Increasing awareness of and knowledge concerning a product tends to be viewed as an effective strategy to increase adoption (Lavidge and Steiner, 1961). Axsen and Kurani (2008) examined consumer awareness of plug-in hybrid EVs in California and found that knowledge concerning the vehicles was markedly low and confusion between hybrid EVs and plug-in hybrid EVs was common. These results are supported by recent research which found that non adopters of EVs generally lacked knowledge regarding the difference between EVs and plug-in hybrid EVs, charging requirements, vehicle range and models available (Hutchins *et al.*, 2013) leading to only 20% of UK drivers being familiar with EV technology (Cluzel *et al.*, 2013). King (2008) highlights the importance of providing consumers with easily understandable information regarding vehicle CO₂ emissions to allow them to make informed purchasing decisions. Recent research has demonstrated that miles-per-gallon remains the preferred metric of fuel efficiency for car buyers and also a proxy for environmental impact (Lane and Banks, 2010), though empirical analysis indicates that this metric is not optimal in conveying efficiency information (Anable *et al.*, 2009).

The UK Government has expressed a commitment to diffusing knowledge concerning eco-labels, ensuring industry adoption and regulating the information provided (HoC, 2009). Research has examined the effectiveness of eco-labels with consumers tending to react to eco-labels at the model rather than the class level (Noblet *et al.*, 2006) and information presented on sliding scales found to be the most effective transmission method (Teisl *et al.*, 2006). This issue has also gained traction at EU level (EC, 2007a; EC, 2010a) with mandatory minimum standards on promotional literature stating 20% of all vehicle advertisement space must be dedicated to fuel efficiency information (EC, 2007b). However, uncertainty still remains regarding the degree to which manufacturers are prioritising the importance of eco-labels in the purchasing environment.

Fourthly, with EVs representing cars with unique characteristics which are likely to affect driver behaviour, it remains unclear how drivers will use and fuel these vehicles. To address this issue, UK and EU Governments have commissioned a series of public EV trials to explore usage patterns. The EU's green eMotion initiative involves a demonstration project which examines all aspects of the transition to EVs (EC, 2011a). This project runs between 2011 and 2015 and is set to trial 2,000 EVs across 14 locations. In the UK, the government established an Ultra-Low Carbon Vehicle Demonstrator programme which operated between 2009 and 2012 and utilised 350 low carbon vehicles across 8 consortia projects. Findings from the programme are that users tend to extend their daily range as they become more experienced with the vehicle

(Cabled, 2010a), with two-thirds of journeys being less than 5 miles (Cabled, 2010b) and an average trip length of 5.1 miles compared to a national average of 7 miles (Carroll *et al.*, 2013). In reference to vehicle charging, the average charge duration is less than 2 hours (Cabled, 2010a) with the vehicles being plugged-in 21.7% of the time. Additionally, users tended to let their batteries run down more with increased experience (Everett *et al.*, 2011) whilst 10% of charging was conducted at public infrastructure points (Carroll *et al.*, 2013). In terms of location of charging, the use of public infrastructure tends to be in the minority of events both for private household and commercial fleet users (Robinson *et al.*, 2013).

Policy Uncertainty

With the passenger vehicle market representing a sector of significant economic importance (Eddington, 2006), it proves to be an area which is actively managed by the UK and EU governments. The management strategy utilised is multifaceted, covering areas related to vehicle regulation, taxation and usage. Political behaviour and policy formation represent a specific location of uncertainty. In this framework, the issues of specific interest have been reduced to three main categories covering policy, regulation and targets.

In reference to EVs, the UK Government has stated an initial investment of £400 million between 2009 and 2015 (DfT, 2009) with an additional commitment of £500 million to 2020 (DfT, 2013c). To oversee the transition to EVs, the Low Carbon Vehicle Partnership (DfT, 2002) and the Office on Low Emission Vehicles (BIS, 2013) were established to act as communication platforms, to support research and development and coordinate funding. Similarly, the EU expressed its policy in reference to EVs under a European Strategy for Clean Energy Efficient Vehicles (EC, 2010a; EC, 2010b; EC, 2011b) and has established the European Green Cars Initiative (EC, 2012c; EC, 2012d) which was launched in 2008 with a €5 billion funding pledge. These schemes assist in reducing policy uncertainty by demonstrating government commitment to EVs through prolonged financial backing of the technology.

Secondly, government has the option to regulate the market environment by manipulating taxation and fiscal programmes. Through an alteration of the taxation scheme, government can create incentives for the adoption of one vehicle type whilst reducing the merits of others. The UK was the first country to introduce vehicle circulation taxes (VED) based on CO₂ emissions. However, questions had been raised in the early years of implementation regarding the effectiveness of the scheme, with lack of driver awareness and insufficient differentiation in the tax bands cited as limitations (HoC, 2004; HoC, 2006). Recently, UK VED have been altered with the introduction of eight additional bands, which have increased the resolution and monetary separation of the scale, alongside a first year tax rate (the premium of which can be considered a purchase tax) aimed at penalising heavy emitting vehicles (HMTreasury, 2008). However,

these changes have been criticised for lacking the ambition required to generate significant behavioural change and for being inadequately publicised with the general public who remain unaware that this represents a form of environmental taxation (HoC, 2008). Moreover, recent updates to UK company car tax (CCT) (HMTreasury, 2012) have reduced the incentive for fleets to purchase low emission vehicles by removing first year tax allowances, a move which may cause instability in the market and send mixed messages about the UK Government's commitment to low emission vehicles (HoC, 2012a). However, the perceived ineffectiveness of these alterations to vehicle circulation and registration taxes could originate from consumers tending to consider these issues unimportant, with VED and CCT ranked least important in reference to purchase evaluations among households and fleets in the UK (Lane, 2005).

Related to this issue of vehicle taxation is the increasing popularity of purchase incentives for EVs. These incentives are aimed at reducing the upfront costs of purchasing an EV, which are viewed as a significant barrier to demand (Beggs *et al.*, 1981). The UK Government has introduced a £5,000 Plug-in Car Grant (PiCG) for vehicles emitting less than 75 grams of CO₂ per kilometre (gCO₂/km). Uncertainty exists regarding the effectiveness of this scheme, with questions raised regarding if the incentive is enough to spur demand (HoC, 2012a).

Assessing the impact of the policy, research commissioned by the Department for Transport (Hutchins *et al.*, 2013) found that the presence of the purchase grant was stated as being an important issue with 85% of household and fleet EV adopters who tended to consider the magnitude of the grant to be appropriate. However, non-adopters of EVs tended to find the purchase price to remain a significant barrier even with the incentive whilst general awareness of the scheme was regarded as being low. Moreover, doubts regarding the impact of purchase incentives have been raised in academic research, with findings suggesting that the price of petrol is significantly more important in reference to the adoption of hybrids vehicles compared to purchase incentives for US consumers (Diamond, 2009). Furthermore, subsidies produce no significant addition to market uptake over what is produced by vehicle regulation (Harrison and Shepherd, 2013) whilst the metric of assessing which vehicles qualify for an incentive does not significantly influence adoption rates (de Haan *et al.*, 2007).

To ensure that purchase incentives operating in the EU comply with state-aid regulations and do not adversely affect the single market, the EU (2013a) has proposed guidelines to coordinate and harmonize schemes operating in the community. Incentives are to be technological neutral, be based on CO₂ tailpipe emissions and not to exceed the price premiums of the vehicles above a comparable conventionally fuelled alternative. These guidelines will likely reduce policy uncertainty by ensuring that the magnitude of incentive does not significantly differ between member states.

Lastly, governments can sanction targets to operate in a market environment, which state a desired destination for specific aspects of the system. In the automotive market, targets have been actively utilised with the UK Government specifying a 16% reduction in domestic transport emissions by 2020 (DfT, 2009) whilst the EU has expressed an objective to replace 20% of conventional transport fuels with alternatives by 2020 (EC, 2001). Specifically relating to cars, The UK Government, under their Powering Future Vehicles Strategy of 2002, stated a goal of having 10% of new car sales in 2012 emitting less than 100gCO₂/km (DfT, 2002) with an actual sales figure of 8.6% being achieved (DfT, 2013d). At the European level, the EU has established targets for average new car emissions being no greater than 130gCO₂/km by 2015 (EC, 2007c), decreasing to 95gCO₂/km by 2020 (EC, 2009) with a long term ambition of 70gCO₂/km by 2025 (EC, 2007). Official targets for EV sales are less clear, with the UK Government stating that adoption targets for EVs are not appropriate (HoC, 2012b) whilst the EU has expressed an objective to have between 8 and 9 million EVs on the road by 2020 (EC, 2013b). Taking a slightly different approach, the Committee on Climate Change has estimated how many EVs will be required in order to meet the UK's carbon budget commitments and has set a target of 240, 000 EVs and plug-in hybrid EVs on the road by 2015, increasing to 1.7 million by 2020 (CCC, 2009). However, with only 4, 100 EVs being registered in the UK in 2012 (DfT, 2013a), it is unlikely the first of these targets will be realised.

Infrastructure Uncertainty

In order for new fuels to become a viable market alternative, infrastructure to support them needs to be established. In the case of EVs, infrastructure is partly installed through an extensive high voltage and local distribution grid. However, uncertainty exists over whether additional provision is required, the quantity of this provision and its optimum location. This issue has been addressed in academic research with Campbell *et al.* (2012) assessing the spatial distribution of likely EV adopters to determine appropriate locations for infrastructure whilst Pridmore and Anable (2012) examine hot spots of adoption as a precursor to exploring the interaction with infrastructure availability. The EU considers this to be a significant issue and has set targets for infrastructure installation for member states (EC, 2013c) with the UK required to install 1.2 million EV charge points with 122, 000 of these being publicly available by 2020. To provide a sense of the challenge these targets offer, only 3, 000 chargepoints have been installed in the UK by 2012 (HoC, 2012a).

The UK Government has stated its specific policy regarding the installation of EV infrastructure, rolling out a Plugged-in Places Initiative (PiP) which has installed charging posts in eight selected sites in an effort to develop front-running locations for EV adoption and to give consumer confidence in the ability to recharge EVs in public places (OLEV, 2011). The effectiveness of this initiative has been brought into question, with no significant relationship found between installed infrastructure and EV adoption (HoC,

2012a). Responding to this, the UK government commissioned research into the effectiveness of the PiP initiative with the findings indicating that 40% of households and fleets stated public charging infrastructure is an important issue but that awareness of the initiative during adoption was low and not a factor in the purchase decision (Hutchins *et al.*, 2013). Recommendations are made to ensure infrastructure is installed at likely destinations and across the strategic road network.

A related issue to this concerns different vehicle manufacturers having selected alternative plug architectures to charge their EV battery packs. This can cause confusion with consumers, who may not be aware of the technical differences leading to challenges in selecting the best option for their situation. Linked to this, it is currently uncertain what the required mix between standard, fast and rapid charge points is and the role of more novel innovations such as inductive charging. To address this, the UK Government has expressed a desire for charge plug standardisation to mitigate this adoption barrier (HoC, 2012a). Furthermore, the EU has conducted stakeholder engagement and expert reviews to identify the most appropriate technical specification for charge points to ensure universal compatibility (EEGTF, 2011a).

Technical Uncertainty

The technical attributes of EVs have been repeatedly identified in empirical research as representing a significant barrier to EV demand with consumers tending to consider EVs to be cars of the future as opposed to viable options in the present market (Caperello and Kurani, 2012). In this paper, two specific aspects of technical uncertainty in demand for EVs are highlighted for discussion.

Determining the likely development curve and long-term viability of the technology is viewed as an important issue to inform policy makers and to improve consumer confidence in EVs (EC, 2010b). Roadmaps for the estimated improvements in EV technology (SMMT, 2002; IEA, 2011; Cluzel and Douglas, 2012; Cluzel *et al.*, 2013) alongside scenarios of possible futures (AEA, 2009; GFEI, 2009) have been popular approaches. The UK Government commissioned an influential report which assessed the technical and economic viability of different powertrains (NAIGT, 2009).

Findings from this report suggest that EVs will be viable in the mass market by 2020, though this will depend on breakthroughs in energy storage. At the European level, the future technological development of EVs has been assessed with an action plan to 2050 established (EEGTF, 2011b). The importance of harmonization of standards, installation of fast charge infrastructure and sustained support for research and development are highlighted as necessary in order to make EVs viable options. Ultimately, if EVs can reach comparative technical performance to conventional vehicles, consumers appear willing to shift to the technology platform (Eggers and Eggers, 2011).

Focusing on a specific technical aspect, questions have been raised concerning the environmental credentials of EVs (Graham–Rowe *et al.*, 2012), with drivers expressing concerns that the increased emissions in vehicle production and in the generation of electricity, which leads to diminished appeal of the vehicles. Research conducted for the Low Carbon Vehicle Partnership demonstrated that, even with current UK electricity grid fuel mix, EVs are associated with significant life cycle emissions reductions compared to conventional cars (Gbegbaje–Das *et al.*, 2013). Moreover, as more renewable energy comes online and the carbon intensity of the grid decreases, CO₂ emission savings attributed to EVs will increase. However, more research on this issue is required to develop better understandings of production emissions, end of life recycling emissions, marginal generation and emissions associated with the provision of infrastructure (Contestabile *et al.*, 2012). This issue is repeated across a number of related technical areas, with EV demand being reduced by uncertainties surrounding EV battery life, claimed fuel efficiencies, achievable ranges and operational capabilities in cold weather conditions.

Economic Uncertainty

External to the EV market is the wider economic environment which comprises regional, national and international levels. This wider economic environment can have significant external effect over the EV market, most notably at the level of national markets which have minimal influence over global automotive manufacturers. The variability of the economic environment can introduce uncertainty into the EV market in two primary ways.

The first of relates to the general economic situation which is often evaluated by macroeconomic indicators. The recent worldwide financial recession, which has coincided with significant reductions in new car registrations in Europe (ACEA, 2013), provides an appropriate example of the vulnerability of the mainstream automotive industry to economic instability. At the consumer level, individuals are likely to become more uncertain during times of economic recession (Mishkin, 1978), leading to more conservative purchasing behaviour. With EVs representing a form of disruptive innovation (Christensen, 1997), it is likely the recession has discouraged a proportion of potential EV adopters from bearing the additional risk represented by these vehicles. However, the reduction in the carbon intensity of new vehicles registered in the UK since the recession has been outperforming expectations (CCC, 2011), though concerns have been raised regarding whether or not this trend is likely to be sustained as the UK enters economic recovery.

A second aspect of economic uncertainty likely to influence demand for and supply of EVs relates to international commodity markets. Notably, the variability and future projections of the price of oil is likely to substantially affect the viability of conventional ICE vehicles. Consumer expectations of future oil prices levels and the prospects for new

oil reserves are likely to influence their perceptions of EVs (Sangkapichai and Saphores, 2009; Ozaki and Sevastyanova, 2011). Moreover, the availability of rare earth metals has emerged as an issue of concern (EC, 2005), which is reinforced by the current spatial concentration of producers (Humphries, 2010). Research activity has responded to this issue, with new worldwide reserves identified and catalogued (BGS, 2011; USGS, 2011). Additionally, regulations have been put into place to ensure that used batteries are recycled (BERR, 2009) which will likely stimulate the recovery and reuse of the rare earth metals embedded within them.

Social Uncertainty

Positioned outside the EV market, society incorporates aspects which range from the comparatively stable issue of dominant ideology to relatively more variable aspects of political agendas. In reference to uncertainty in EV demand, two social issues are of particular significance.

Firstly, with cars representing an aspect of society which is associated with a large degree of discourse, public opinion represents an important issue in the emerging market for EVs. Authors have assessed the nature of public opinion of EVs, with findings demonstrating that negative exposure of in specialised media reduces preferences towards clean fuelled vehicles (Gould and Golob, 1998) whilst increasing awareness of environmental issues assists in putting the regulation of vehicle emissions on the political agenda (Collantes and Sperling, 2008).

Charting public opinion is an area of government activity, with the both UK and EU Governments having departments who assess the opinions of citizens (EC, 2012e). Specifically relating to transport, over two thirds of European citizens would be willing to compromise on car speed to reduce emissions whilst car price represents the least flexible issue (EC, 2011c). In the UK, drivers tend to be attracted to lower emission vehicles but are unwilling to reduce their car use (DfT, 2013e). Moreover, UK public opinion on using the tax system to encourage drivers to buy more fuel efficient vehicles is split whilst the main expressed barriers to EV adoption are reduced range and lack of public charging infrastructure (DfT, 2012). However, recent research examining social stratification in the automotive market has demonstrated that significant variation exists in the attitudes of different segments of the market (Anable, 2005), which brings into question the robustness of measuring public opinion at the market, as opposed to segment, level.

Secondly, the presence of commonly held frames of reference can display significant influences over human interaction and decision making. These frames of reference are generally referred to as social norms (Sherif, 1936) and form a primary aspect of social psychology (Cialdini and Trost, 1998). The incidence of norms in the automotive market has received academic attention with Lane and Potter (2007) describing their prominent

position in cognitive models of decision making to conceptually demonstrate their influence over car buyer behaviour. Empirically applying the Value Belief Norm theory, Jansson *et al.* (2011) examined adoption of alternatively fuelled vehicles in Sweden and found that personal norms, such as a perceived moral obligation, act are a significant indicator. In a similar piece of research, Peters *et al.* (2011) applied an extension of the Theory of Planned Behaviour to explain vehicle CO₂ intensity and found that social norms are a significant determinant of personal norms in the car buying market. However, assessing how social norms connected to EVs are likely to develop remains an unexplored area, leading to uncertainties regarding the social interpretation of these vehicles.

5 Discussion

The structure of the conceptual framework presented in this paper is not exhaustive, but rather a simplified illustration of a complex system. Indeed, the locations it includes and how they relate to each other is likely to prove an area of debate, with certain locations capable of being defined in different formats. This is often referred to as model uncertainty and involves what is included in the model (and by extension, what is excluded), what represents an internal feature and what is external, how the different components of the model are connected and the magnitude of the relationships. Moreover, certain features of the modelled environment will be static and have set parameters whilst others will be dynamic. This dynamic aspect is itself an aspect of uncertainty, with different locations of uncertainty likely to increase or reduce in importance dependent on the stage of the market introduction.

Table 1: Summary of the locations of uncertainty in reference to the demand for EVs and associated policy response

| Locations of Uncertainty | Government Policy Response |
|--|---|
| <i>Internal Sources of Uncertainty</i> | |
| Consumer | <ul style="list-style-type: none"> • Quantitative and qualitative research concerning consumer preferences and characteristics • Information campaigns – eco-labels and Act-on-CO₂ • EV trials to assess usage profiles |
| Policy | <ul style="list-style-type: none"> • Policy statements expressing support for the technology • Funding commitments to accelerate adoption • Establishment of institutions to oversee transition • Target setting to establish transition pathways |
| Infrastructure | <ul style="list-style-type: none"> • Installation of chargepoints in urban locations • Standardisation of charging technical architectures |
| Technical | <ul style="list-style-type: none"> • Assessments of long-term technical viability of EVs • Development of technical roadmaps and scenarios • Enforcement of technical standards to reduce green-washing |
| <i>External Sources of Uncertainty</i> | |
| Economic | <ul style="list-style-type: none"> • Monetary and fiscal macroeconomic policy |
| Social | <ul style="list-style-type: none"> • Monitoring of public opinion |

Returning to the original research questions, this paper has taken an existing framework of uncertainty (Meijer *et al.*, 2006) and adapted it to account for the specific nature of EV demand. The main features of uncertainty in EV demand have been bounded into six different locations. These locations cover characteristics and preferences of consumers, attributes and potential of the technology, policy strategy and commitment, infrastructure provision, economic variability and social dynamics. Table 1 summarises the main locations of uncertainty and the related governmental policy response.

To a certain degree, UK and EU Government policy has responded to all of the specified locations of uncertainty internal to the framework. Both governments have committed substantial funding to stimulating the market for EVs and have set targets to allow other actors operating in this market to form medium and long-term plans. Grants have been put in place to incentivize EV adoption with the taxation system adapted to provide additional advantage to EVs. The installation of EV charging infrastructure has been a proactive area, with the UK Government establishing initiatives to coordinate activity whilst the EU has put in place policy to ensure harmonisation of standards to prevent market fragmentation.

The technical potential of the EV powertrain has been investigated, with the long-term viability of the technology pathway assessed and research and development targeted at improving characteristics of importance to consumers. However, the effectiveness of a number of these policies have been brought into question, with commentators implying that uncertainty has not been mitigated enough to enhance demand with this view being supported by low levels of EV sales to date. This lack of policy effectiveness may originate in part from the uncertainty related to which government departments are responsible for what aspects of the transition to EVs. Indeed, the complexity of the situation requires a greater degree of department cooperation which may not fit with existing working practices.

In reference to components external to the conceptual framework, it is challenging for the UK and EU governments to respond to external uncertainty due to the inherent variability present in the economic and social systems. However, these governments have demonstrated their awareness of these issues, have attained an understanding of their likely influence over consumer demand for EVs and are monitoring the relevant indicators. In this sense, whilst reducing the exposure to external uncertainty might prove difficult, mitigating the possible consequences is a more realistic aim.

6 Summary

This paper has explored how the concept of uncertainty has manifested in reference to demand for EVs and detailed the UK and EU Government policy response. A conceptual framework containing six locations of uncertainty was developed to structure the discussion incorporating consumer, policy, technical, infrastructure, economic and social uncertainties. Government policy documents were sourced and evaluated to determine what efforts policy makers have so far made to reduce uncertainty in EV demand.

Results of the analysis have demonstrated that, in certain areas, UK and EU Governments have taken the lead in reducing uncertainty in EV demand through the enactment of policy. In the UK, purchase incentives for EVs have been introduced to mitigate the financial risks of EV adoption. This has been combined with a favourable registration and circulation taxation system to encourage the purchase of a low emission vehicle. The UK Government has been proactive in examining the need for and optimum location of EV charging infrastructure to provide reassurance to EV adopters. In other areas, research conducted by academic institutes and consultancies have offered a primary contribution to the reduction of uncertainty. Assessments of the technological potential of EV powertrains have been conducted to demonstrate the long-term viability of the platform. Market research has taken place to assess the preferences of consumers and how they respond to novel EV attributes. Structural analysis has been employed to develop an understanding of the likely characteristics of early adopters and their spatial locations.

However, continued low sales figures for EVs are a possible indicator that a significant degree of uncertainty still exists in the EV market. Criticisms have been levelled at the UK and EU Governments in reference to a lack of ambition, ineffective integration and collaboration across different department alongside a simplistic approach to consumer dynamics in policy development. It is evident that more focused research is required to improve the likelihood of realising a wide scale transition to EVs. The conceptual framework developed in this paper offers a starting point for this renewed research effort, by providing a novel perspective on how uncertainties can represent barriers to EV uptake and that the reduction of uncertainties can be considered a possible method of accelerating EV adoption.

7 References

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