Assessing the transition towards battery electric vehicles: a Multi-Level Perspective on drivers of, and barriers to, take up.

Nigel Berkeley[a]
David Bailey[b]
Andrew Jones[a]
David Jarvis[a]

[a]Centre for Business in Society, Coventry Business School, Coventry University, Priory Street, Coventry CV1 5FB, United Kingdom

[b]Aston Business School, Aston University, Birmingham, B4 7ET, UK.

Contact:

n.berkeley@coventry.ac.uk
d.jarvis@coventry.ac.uk
andrew.jones3@coventry.ac.uk
d.bailey@aston.ac.uk

Abstract

The Multi-Level Perspective (MLP) framework on transitions is used to interpret European electric vehicle take up and auto mobility transition. It finds that environmental and energy security pressures have created a favourable landscape 'push' for Battery Electric Vehicles (BEVs) that in turn has encouraged and facilitated serious commitment from some manufacturers. Yet BEVs, as a niche product seeking to disrupt an entrenched and established regime, face significant multi-level forces acting as barriers against such a transition, which the paper explores. This combination of factors creates a situation where BEV market penetration remains far below the level required for mass market transition. For BEVs to 'cross the chasm' and gain an established foothold in the market and hence significantly disrupt the regime, more holistic and effective solutions are required. It is argued that, so far, this has yet to be fully taken on board by policy makers.

Keywords: Multi-Level Perspective, Transitions, Battery Electric Vehicles, Barriers, Automobility.

1. Introduction

Many governments seeking to reduce carbon emissions and oil dependency, and given urban air quality concerns, have invested significantly to support the transition to a greener, more sustainable automobility. In so doing, they have implemented a range of policy instruments to stimulate the design, manufacture and take-up of hybrids, fuel cell and especially battery electric vehicles (BEVs). Manufacturers have responded by exploiting new technologies to produce alternatively fuelled vehicles (AFVs) that facilitate travel in smarter and more sustainable ways. However, to date the take-up of AFVs has been slower than anticipated, attaining only modest market share, nowhere near the level required to push such vehicles into the mainstream. This issue has stimulated considerable debate in academia and beyond in recent years, suggesting a range of issues that are influencing the take-up of AFVs as well as offering potential solutions that might help pave the way for a transition to mass market take-up in the short-medium term. However, a key research problem persists in that to date an in-depth conceptualisation of the complex multi-level forces that impact upon transition is lacking. Such analysis is critical to better inform solutions that can more effectively smooth the path to widespread adoption.

The aims of this paper are to address this gap using the Multi-Level Perspective (MLP) framework (Geels and Kemp, 2012) as a lens through which to interpret European BEV take up and automobility transition. The paper provides a meta-analysis of trends in Europe (through a detailed literature review, review of policy papers, demonstrator project results along with our own research) in order to present an holistic understanding of the complex socio, economic and technical forces operating at landscape and regime level that both push toward and pull against transition; whilst also informing more effective solutions that can drive transition beyond niche spaces toward real disruption of the established ICE regime. In concluding we offer reflections on the usefulness of the MLP framework as a lens through which to interpret pathways to transition and inform effective policy solutions. In identifying levers, barriers and solutions in particular at the national scale, we also note that in terms of BEV transition, protected niche space is often provided at the city and local/regional scale; this suggests that the MLP framework needs to better engage with place and space.

The paper focuses specifically on BEVs. BEVs have an all-electric drivetrain and are powered by a rechargeable electric battery. BEVs are argued to have many societal benefits including lower operating costs, lower pollution in terms of both global warming (CO_2 emissions) and

in terms of urban air quality (such as NOx emissions) and less frequently mentioned aspects such as "extending the human range of mobility" for groups in society less able to access mainstream private transport (Ulrich, 2005). These benefits, coupled with pressure from environmental and energy security drivers, have encouraged governments at the local, national and supra-national level to implement policy instruments that are designed to encourage consumers to switch to BEVs. Estimates suggest that some $13-$16 billion has been spent globally on such instruments between 2008 and 2014, almost half of which has supported R&D (GEO, 2015, Hao et al., 2014, Wesseling, 2016).

The paper is structured as follows. Section 2 outlines the methodology. Section 3 draws on data to present a 'state of the market' analysis for Europe which is mostly lacking from the present academic literature. Section 4 outlines the Multi-Level Perspective (MLP) framework used to analyse the transition towards BEVs and identify a range of levers pushing BEV adoption and barriers to BEV adoption. Section 5 examines in more detail the levers or 'drivers' that have created the landscape for BEVs to emerge as an alternative product in the automotive ecosystem. Section 6 uses the MLP framework to analyse existing literature, both academic and non-academic, and presents a typology of barriers to take-up. Section 7 briefly outlines a typology of potential solutions highlighted in the academic literature, which are identified as a target for future research. Section 8 summarises and concludes.

2. Methodology

To address the research problem, a comprehensive literature review was undertaken. Whilst others such as Rezvani et al (2015) have previously conducted an in-depth review of the literature relating to electric vehicle adoption, their study focused solely on papers (16 in total) drawing on empirical consumer data and results. The intention here is to provide a more holistic review of the literature to fully capture the debate on barriers and drivers to EV adoption. The process followed in constructing the review began with searching a set of academic databases comprising Elsevier Science Direct, Springer, Sage, Taylor & Francis online, and Wiley; in addition to search engines such as Google Scholar. In interrogating these databases, a range of keywords were used. These included: automobility, electric vehicles, pure electric vehicles, battery electric vehicles, barriers, financial barriers, technical barriers, consumer barriers, adoption, solutions, consumer attitudes, transition to electric vehicles, and policy.

For the purpose of this study, the most influential articles were those discussing the transition to electric vehicle technology as well as those which identify the levers and barriers to adoption faced by consumers, consumer attitudes and behaviour, and policy, for example in the form of investment in the EV ecosystem and consumer incentive schemes. The analysis also recognised those studies which drew on the results of small scale demonstrator trials or larger surveys of consumers as being important. Outputs which discussed more technical elements of BEV design, such as well-to-wheel emissions or energy consumption, were deemed not relevant to this investigation. Additionally, the analysis also discounted those studies of other automotive technologies such as hydrogen power as being beyond the scope of this paper. As a result, over one hundred outputs in the form of journal articles and book chapters were utilised in the review of literature which underpins our holistic assessment of the levers and barriers to EV adoption presented through the lens of the Multi-level perspective framework.

In addition to academic literature, the paper draws upon EV sales and registration data to inform a 'State of the Market' Analysis. These were initially drawn and analysed from several sources: the Automotive Industry Data Newsletter, which since 2012 has published monthly statistics on EV sales and market share in western European countries; the National Automobile Manufacturers Association (ACEA) which publishes quarterly statistics for the full range of alternatively fuelled vehicles registered in European countries; and IHS Automotive which has produced statistics on EV sales and market share for leading countries globally. The purpose of using multiple sources was to provide robustness and reliability in the findings presented. Analysis revealed that there was good consistency in data across sources. Given their more regular publication, data from the Automotive Industry Data Newsletter were ultimately used and are presented below.

Alongside the sales data, reports from the Amsterdam Roundtable Foundation and McKinsey on *Evolution: Electric vehicles in Europe: gearing up for a new phase?*, the 'Global EV Outlook' and various media reports provided additional contextual data for the section on Levers pushing EV adoption.

3.   State of the Market: The European BEV Market to date

Despite the scale of public support and investment, and while there are encouraging signs, the European BEV market is failing to 'spark' into life in a way that would suggest potential for mass market transition (Table 1). Whilst sales of BEVs are increasing, witnessing growth of 271% between 2012 and 2015 and over 50% growth between 2014 and 2015; 90,000 BEVs were sold in 2015, this represents an overall market share of just 0.7%.

Looking beyond the overall western European picture reveals considerable variation by country. Four countries – Norway, France, Germany and the UK – account for 75% of BEV sales in 2015, with Norway alone accounting for almost 30%. More strikingly, Norway achieved a market share for new sales of BEVs of over 17% in 2015, with Demark and Switzerland being the only other countries to break the 1% barrier. At the same time the UK and Germany both had market shares well below the European average. Positively, most countries have enjoyed considerable growth in sales since 2012, albeit from very low bases. Most notably Norway, Denmark, the UK and Switzerland have achieved growth in sales of over 300%.

Insert Table 1 here

Norway's success, in the context of high living standards, cheap electricity and favourable environmental policies, is based on its package of consumer incentives that puts BEVs on a par with internal combustion engine (ICE) cars in terms of their price (see below). In addition to generous incentives, Norway has also seen significant investment in charging infrastructure, especially in cities. Cobb (2015) puts this success in context suggesting that if the US had performed at the same level as Norway in terms of BEV sales for the first six months of 2015 then it would have recorded sales of just short of 2 million; it actually achieved around 50,000.

This state of the market analysis has shown that especially in established car markets, a transition to a more sustainable automotive future is some way from happening. The paper now proceeds to explore and conceptualise why this might be the case, examining key dimensions of levers and barriers, and concluding with solutions that could make a difference to the transition pathway. First, it briefly examines the MLP framework on transitions.

4. The Multi-Level Perspective Framework on Transitions and its relevance to BEVs

The Multi-Level Perspective (MLP) has been posited as a perspective to study socio-technical transitions in the automotive sector (see for example, Malinen, et al, 2013). This approach recognises that regime transitions are complex and involve multi-dimensional, co-evolving interactions between government, industry, technology, markets, culture and society (Geels and Schot, 2007; Geels and Kemp, 2012). Against the background of the contribution of motorised transport to environmental problems, in the regime of automobility a true sustainable transition would involve a radical shift from 'car-based mobility to alternative mobility systems that are less car-centred' (Geels and Kemp, 2012, p 49). Whilst this might seem unlikely, a less radical shift towards car-based mobility that is greener is perhaps more deliverable (Geels et al, 2012). Orsato et al (2012, p.225) suggest that a "a trajectory of electrification of cars is underway", one that is underpinned by a combination of levers such as: environmental and energy security drivers that have created a favourable policy landscape promoting new forms of automobility; serious commitment from manufacturers, alongside technological developments, for example in battery performance and charging infrastructure; and a favourable societal landscape characterised by the desire for convenience, the mainstream use of mobile technologies, and an increased acceptance of electric/hybrid vehicles amongst a broad range of users (see also van Bree et al, 2010). A key research question for this paper is whether this somewhat favourable 'socio-technical landscape' involving multi-level actors, agencies and perspectives is one which could facilitate a transition to a new regime of automobility in which electric cars dominate (Geels et al, 2012; Orsato et al, 2012) with actors outside the regime having a prominent role, initiating new actors' practices and networks. Alternatively, BEVs might disrupt the established internal combustion engine (ICE) regime, but remain a minority and effect a transformation of the regime as elements of it are incorporated by existing regime actors, with the latter sustaining user car practices, infrastructure and so on (ibid).

The literature suggests that successful transitions require the overcoming of barriers that extend well beyond technological and economic dimensions (Geels, 2005), with a range of dimensions such as institutions, infrastructure and society being seen as just as significant. In the case of the transition towards greener automobility, for example, a range of actors can be identified, including automotive assemblers, supply chain firms, infrastructure providers, government, finance providers, and car drivers (van Bree et al, 2010; Mazura et al, 2015). The Multi-Level Perspective (MLP) pictures transitions in terms of the interactions between

different dimensions. In so doing, it identifies three different levels with the system: landscape, regime and niche, in a form of nested hierarchy with niches embedded within regimes, which are in turn embedded in the landscape (Geels, 2005).

In this framework, the 'landscape' serves as a backdrop for regime and niche level developments, and refers to forces at work in the broader environment and society that impact upon the regime and niche levels but cannot be considered part of them as such. Occasionally landscape events can combine in a "landscape shock" that prompts regime changes and open up a "window of opportunity" (van Bree et al, 2010; Verbong and Geels, 2010). At the next level, a 'regime' is seen as a socio-technical mechanism, which may retain certain innovations (with them becoming dominant) while rejecting others (Geels, 2002). It goes beyond technical dimensions, and is viewed in the MLP framework as a 'socio technical regime'. Regime stability depends on the degree to which there is alignment or tension across rules and whether actors adhere or not to rules (Geels, 2005). Incumbent, vested interests may seek to maintain and prolong the existing regime, and so may be a barrier to innovations that threaten regime change; this may be a particular issue in terms of transitions to sustainable automobility.

In contrast to regimes, 'niches' are seen in the MLP framework as the micro-level where radical novelties appear. These novelties are "initially unstable sociotechnical configurations with low performance" (Geels and Schot, 2007), with niches seen as 'seedbeds' (Mazura et al, 2015) or 'incubation rooms' protecting novelties against mainstream market selection (Geels and Schot, 2007; Geels, 2002). These niche-level innovations are developed by small networks of dedicated actors, who may be fringe players or outsiders. Actors may find niches challenging to work in if the innovations being developed do not match with existing regime dimensions (Geels, 2011). In the context of sustainable automobility this might be because of the lack of required infrastructure, the regulatory framework, or consumer behaviour and culture (see Sovacool, 2017) that is hostile to niche development, for example. It should be noted that niches are not always in competition with the regime, however; in some cases niches may be absorbed by the regime and effect a change in the regime. The speed of change in innovation is in turn seen as being linked to niche resource availability (Geels, 2002), with the strategic nurturing of niches termed 'strategic niche management' (SNM). Niches can also provide space to build the social networks that can support innovations, such as lobby groups, user associations and new industry networks (Geels, 2005).

The MLP perspective has however been criticised for neglecting place and space; see Smith *et al* (2010), Coenen and Truffer (2012), Wesseling (2016) and Gibbs and O'Neill (2017). Yet as Truffer and Coenan (2012: 15) note, cities and regions may emerge as "powerful promoters of sustainability transitions… providing crucial resources for successful innovation processes." In a similar vein, Coenen *et al*., (2010) and Truffer (2008) highlight how niches can emerge at local and regional scales. More recently Badinger *et al* (2016) identify regions and cities as being crucial in facilitating sustainability transitions. Gibbs and O'Neill (2017) give regional examples that fit both Smith and Raven's (2012) 'fit and conform' perspective (where niche innovations are aligned and competitive with existing contexts and so are incremental) as well as a 'stretch and transform' perspective, whereby niches are empowered to challenge the incumbent regime. Other local case studies have been offered at the city level, for example by Hodson and Marvin (2010), and in the BEV case by Haley (2015). The place and space issue is addressed in this paper recognising, and by drawing upon examples, how at regime and niche levels the environment to stimulate BEV transition can vary significantly.

Thus, in seeking to conceptualise the complex multi-level forces that (with the notable exception of Norway) continue to negatively impact upon transition to a greener sustainable automobility, this paper draws on the MLP framework whilst also recognising the dynamics of place and space (see Figure 1). On the one hand at the landscape level, it can be observed that there are numerous socio-political-technical levers that are providing the environment to push EV adoption: international policy drivers such as environmental regulation and energy security; national policy drivers pushing BEV R&D, infrastructure and incentivising consumer take-up; and a favourable societal landscape driven by technology and the need for convenience. However, whilst theoretically these drivers create the right conditions for transition, the reality is likely to vary from place to place as local and regional governments act differently in their visions, policies and incentives for BEV deployment (Nykvist and Nilsson, 2015). Landscape conditions are explored in depth in Section 5 below.

Insert Figure 1 here

On the other hand at the regime level there are numerous socio-economic-technical 'barriers' pulling against transition. BEVs are not establishing a new market as such; they are a niche product seeking to disrupt an existing one. On both the supply and demand side, society is 'locked' into an automotive ecosystem, environmentally, socially, economically and politically,

where mutually reinforcing powerful interests are working to maintain the status quo (Geels et al, 2012). The way in which cars are produced, driven, refuelled and recycled as well as the flexible, independent mobility they provide has created entrenched patterns of behaviour in the way that people work and consume that have endured for a Century. Introducing new niche innovations to disrupt an established regime is not straightforward and this is well illustrated in the automotive sector with improvements in battery technology proving difficult to achieve, batteries themselves competing with developments such as fuel cells, whilst the efficiency of ICE vehicles continues to improve. This combination of factors create risk and uncertainty amongst manufacturers and consumers, and result in a multitude of barriers that act against the electric vehicle transition pathway. However, again the extent and reality of these barriers will not be uniform, with spatial variations in part underpinned by local / regional landscape conditions. Regime barrier issues are explored in depth in Section 6.

The effect of the interaction of this landscape push and regime pull is, as illustrated in Figure 1, a chasm through which nations seeking to increase market share and transition BEVs into the mainstream need to cross. To do so requires the effective interaction between landscape and regime levels providing the right environment for niche activities to be stimulated at local and regional scales. This suggests the need for the development and implementation of effective strategies and policies that might usefully involve, for example, those designed to increase BEV visibility, through investing in charging infrastructure and EV experience events for consumers; whilst also providing R&D support to encourage niche actors to flourish. To date, there are good examples of how such policies have been successfully implemented at local scales, and these are explored in Section 7.

5. A favourable socio-technical landscape? Levers pushing BEV adoption

Within the framework of the multi-level perspective there are a range of drivers operating at different spatial scales of the landscape level that are, in theory, creating the opportunity for BEVs to emerge and facilitate a transition to a more sustainable automobility (Figure 1). At the level of the international landscape, Serra (2012) posits three key factors driving political motivation for governments at all levels and in turn seeking to shape industrial, societal and consumer attitudes. The first of these factors is energy security, the argument being that petroleum reserves are being depleted at an unsustainable rate creating risks for the established ICE ecosystem, whilst BEVs offer a more secure alternative drawing on grid energy supplies with a wide mix of electricity generating technologies. The second is the environment

and the debate over the impact of man-made CO2 emissions on accelerating climate change, and the role of automotive transport in this process; as well as concerns over air pollution and its effects on health resulting from urban traffic congestion, particularly in the wake of the Volkswagen 'dieselgate' scandal (Bailey, 2016). Thirdly, Serra offers an economic imperative: the notion that a shift to electric vehicles offers new and different opportunities for innovation, growth and employment in the automotive industry amongst manufacturers and the supply chain (Serra, 2012). This was particularly pertinent in the late 2000s when the global economic crisis led to considerable stress and challenges for the established automotive industry (Bailey et al, 2010; Jarvis et al, 2012). Longer-term however, there is the potential for negative downstream employment consequences from widespread adoption given the more limited repair and maintenance regimes required for BEVs.

These energy, environmental and economic pressures at the international landscape, have created the rationale for governments to act at the national landscape level, with some $13-$16 billion invested between 2008 and 2014 in policies and incentives designed to stimulate the market and ensure that BEVs are cost competitive against other types of vehicle (GEO, 2015; Hao et al., 2014, Wesseling, 2016).[1] This favourable policy landscape can be characterised by three key instruments: research & development grants; investment in charging infrastructure; and purchase incentives in the form of grants, tax credits or rebates (Green et al., 2014). Research and Development has seen the largest slice of investment, worth around half the total, and is designed to stimulate innovation and the supply of vehicles and their components by the automotive industry. This investment was seen initially through developments in battery technology and public demonstrations and trials of early BEVs that typically involved vehicles with battery drivetrains 'bolted-on' to existing ICE architecture. More recently, as technology has evolved, many major automotive manufacturers have launched bespoke electric products with the market being dominated currently by Nissan, Renault, BMW, Tesla and Volkswagen. Support for infrastructure, mainly in the form of public charging stations has been worth around $3 billion and is designed to stimulate both supply and demand. Direct purchase grants, tax credit and rebate schemes are effectively employed as subsidies which help to lower the cost of the vehicle to the consumer and hence are used as instruments to stimulate demand. Around $5 billion has been spent globally on fiscal incentives (GEO, 2015), although the scale of support varies significantly by country

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[1] Although this is tiny compared with the $4.9tr spent globally on energy subsidies in 2013 (Coady et al, 2015 in Wesseling, 2016).

(Wesseling, 2016), with countries with stronger car industries tending to favour R&D subsidies to enhance the development of BEV capabilities in domestic industry, whereas 'non-car countries' favour sales incentives to encourage BEV diffusion (ibid). Estimates suggest that the five-year benefit of the purchase subsidy per electric vehicle ranges from €16-17,000 in Norway and Denmark; around €6-7,000 in countries such as France, the UK, the Netherlands, China, Japan and the USA; to as little as €200 in Germany (Amsterdam Roundtable Foundation and McKinsey & Company, 2014). Whilst the international landscape has created the conditions for policy makers at the national landscape to act, the extent and way in which they have done so varies between places. The paper now proceeds to review and evaluate some of the policy instruments that have been implemented at the national landscape level, highlighting the complexity of multi-dimensional interactions between stakeholders that has influenced their effectiveness.

As shown in Table 1 above, Norway is the BEV 'success' story. The incentives provided by the Norwegian government to encourage BEV adoption as a package are the most generous in Europe. A key component of these incentives is the tax relief provided for consumers who purchase a BEV. The incentives include an exemption from VAT and other car purchase or sales taxes, plus a 50% relief on company car taxes. In addition, non-tax incentives such as the free use of most toll roads, free battery charging at publically funded charging stations, and free parking in public parking spaces are included in the incentive 'mix', making BEVs truly price-competitive with ICE vehicles. (Mersky et al., 2016, Bjerkan et al., 2016, Holtsmark and Skonholf, 2014; Hanley, 2016; Figenbaum, 2016). In combination with the favourable policy landscape, Norway has focused significant investment in charging infrastructure in its cities and critically also enjoys a BEV friendly economy, society and culture that has created the right multi-dimensional mix for the market to take-off. Specifically, evidence on early BEV adopters in Norway points to a segment of "high-income, well-educated consumers who are looking to save money, are concerned about the environment or both" (Amsterdam Roundtable Foundation and McKinsey & Company, 2014, p. 11).

In Denmark, the tax system has been structured in a way which penalises drivers of heavy polluting ICE vehicles. Conventional ICE vehicles are subject to a 'registration tax' which is dependent upon the purchase price of the vehicle and the emissions produced. For vehicles which have high levels of emissions there is a higher tax rate than energy efficient cars which are subject to a small tax break. BEVs are not subject to this tax, which has helped to

significantly reduce the gap in prices between BEVs and comparable ICE vehicles (Christensen et al., 2012). An advantage of this policy is that government can offset any costs related to waiving the tax on BEVs with income gained through taxing conventional vehicles. Interestingly whilst the overall level of subsidy per BEV is similar to that in enjoyed in Norway, Denmark has not enjoyed the same level of success in market penetration. This might suggest that the positive combination of societal, economic, cultural and technical BEV friendly dimensions that are present in Norway are not there to the same degree in Denmark. Equally, factors of space and place, with Norway having disproportionately high urban concentrations in the south of the country and abundant cheap hydroelectric energy adds to its comparative advantage.

The Dutch government, seeking to position the Netherlands as an international test bed for BEVs, have introduced incentives which include tax exemptions and investment in charging infrastructure. Introducing a new dimension to the mix, the Dutch context also highlights the role that local government can play in influencing BEV adoption. Local municipalities are investing in charging infrastructure and switching their own vehicle fleets to BEVs in an attempt to reduce emissions, increase visibility and to set an example to encourage others to adopt (Bakker et al, 2014). Yet local authorities in the Netherlands are less convinced of the merits of the approach of allowing BEV drivers to have free access to public car parking places (as is the case in Norway), believing that this would lead to pressure on spaces (Bakker et al., 2014). The Dutch approach showed early signs of promise in 2012-13 but the market there appears to have stalled somewhat in recent years (see Table 1).

Another approach to financial incentives is the provision of direct grants to consumers to reduce the upfront price of BEVs. Grants have formed part of the UK policy with up to £5,000 available per vehicle (Graham-Rowe et al., 2012). As can be seen through the data presented in Table 1, whilst UK sales are increasing markedly, market penetration of BEVs remains modest. Within the UK, London has seen more success and is potentially an ideal BEV ecosystem. Here BEV drivers benefit, for example, by being exempt from the London congestion charge, which coupled with the purchase grant makes BEVs more appealing, especially to the early adopter segment highlighted above and said to be prevalent in 'mega- or world-cities' (Amsterdam Roundtable Foundation and McKinsey & Company, 2014, p. 11). More generally it could be argued that the UK policy has not been effective. Sections of the literature have questioned the effectiveness of direct BEV subsidies, suggesting that whilst

well-intentioned they have been introduced too soon. With BEV technology still largely in a developmental phase, consumer confidence can be low, perhaps in turn leading to negatively entrenched perceptions of BEV performance. This creates a situation that restricts demand, with consumers unwilling to trust fully what manufacturers are providing, perhaps seeing BEVs still as too much of 'stretch' compared to technology they are accustomed to (Orsato et al, 2012; Graham-Rowe et al., 2012; Egbue and Long, 2012; Krause et al., 2013). At the same time and highlighting the complexity of multi-dimensional interactions, Koetse and Hoen (2014) suggest that 'strong' financial incentives are critical to help to influence some consumers who are not wholly convinced about BEVs.

A key issue here is uncertainty over the landscape pressures,[2] for example in terms of how long financial incentives will last for BEV adopters. A key aspect of driving transition is certainty for investors and consumers over investment decisions (Bailey et al, 2015); yet the UK government for example has been criticised for a lack of certainty on incentives for BEVs (The Guardian, 2016), such as through repeated changes to tax rates on ultra-low carbon vehicles that hinders the ability of consumers to make long run decisions on take up. Such landscape uncertainty was also highlighted in the Swedish case by Nykvist and Nilsson (2015). Similalry, Nilsson et al (2016; 1366) stress that policy interventions need "predictable and gradual phase out adapted to... actual learning curves".

These complexities are further highlighted in other areas of the debate around incentives. The Norwegian model, for example, is not without its critics. Incentives are a significant burden on the public purse; as noted, each new BEV costs some €17,000 in one-time and recurring benefits over 5 years (Amsterdam Roundtable Foundation and McKinsey & Company, 2014). Sales of around 26,000 in 2015 (Table 1) would suggest a public subsidy of over €440m. Moreover, sub-national governments complain of revenue shortfalls due to the substantial stock of BEVs not paying parking fees and tolls (Jolly, 2015). Critics have also pointed to subsidies being used to buy second and third cars for wealthy households, and that BEVs are now crowding bus lanes and public parking spaces, disadvantaging public transport users and non-BEV drivers (Cobb, 2015; Diamond, 2009, Holtsmark and Skonhoft, 2014). The issue of the 'fairness' of incentives, has been highlighted in relation to free parking, tax exemptions

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[2] Incompleteness and a lack of coherence across policies is also evident. For example, the UK Government's new 2017 Industrial Strategy green paper was light on addressing the challenges for mainstreaming BEVs. There appears to be an assumption that mass market BEV take-up is a 'given' on the demand side and that industrial strategy should focus on supply side issues. Yet the reality is that the key barriers to the development of the UK's BEV market remain stubbornly and primarily a demand side issue.

and the introduction of charging infrastructure. Whilst such incentives are beneficial for BEVs they in turn can penalise drivers of conventional vehicles (Raslavicius et al, 2015). Critically from the multi-level perspective this may lead to resentment and ultimately resistance against switching to BEVs. Mannberg et al (2014) add that incentivising alternatively fuelled vehicles can create difficulties ethically if claims to their environmental benefits are not confirmed; whilst Shepherd et al (2012) suggest that subsidies would be more effectively applied towards the installation of charging infrastructure as this would help to 'tip' the market towards BEVs.

Aside from the positive climate for BEVs resulting from energy, environmental and economic drivers, there is also in a broad sense a favourable societal landscape. Modern society is characterised by convenience, the desire, underpinned by technology to do things on-demand and quickly, witnessed, for example, in the rise of on-line shopping with same day delivery, on-demand TV and movies, and home delivery of supermarket shopping. This 'convenience society' creates an ideal environment for BEVs to thrive, the ability to re-fuel your car without leaving home in the same effortless way that mobile phones are charged. This however, is set within the context of the established ICE ecosystem and the 'locked-in' way of doing things which makes behaviour change difficult to comprehend let alone achieve. Arguably though, modern society should be well placed to overcome these challenges with new generations being brought up within technology driven, environmentally conscious, high-income economies with cultures and behaviours more adaptable to different ways of doing things. The Norway 'story' shows how this can work in practice, where all these factors come together; and especially at the local and regional scale in cities where there has been significant focused investment in infrastructure.

6. **The challenge of moving beyond a sustainable automobility niche: regime barriers to adoption and take up of BEVs**

Despite impressive performance in countries such as Norway the market for BEVs has failed to take-off in most established automotive markets (Urban Foresight, 2014). Uptake has been negatively affected by a range of barriers, and conceptually these fit well with the MLP framework adopted in this paper; the complexity of socio-economic-technical, cultural and psychological issues at regime level that act against transition beyond the current small market niche (Figure 1). The discussion of barriers to BEV take-up within the literature has been extensive. According to Greene et al (2014) there are six factors which have both 'locked in' internal combustion engine vehicles and 'locked out' BEVs: the current limitations of

existing BEV technology; high costs that can only be reduced through experience; high costs that can only be reduced through economies of scale; consumer risk aversion towards novel products; lack of vehicle choice; and shortage of energy supply infrastructure. In a further assessment, Browne et al (2012) identified a range of different barriers facing BEV adoption, and stated that these fell into three broad categories; technical limitations, commercial feasibility, and market availability. In contrast, Egbue and Long (2012) stated that the BEV niche faces a 'socio-technical system' (or regime in the language of the MLP framework) which presents economic, political, technological, cultural, and social barriers. More narrowly, Silvia and Krause (2016), Nie et al (2016), Carley et al (2013), Daziano and Chiew (2013), and Axsen and Kurani (2013) focus on financial and technical barriers, the latter being strongly influenced by consumers' concerns surrounding the practicalities of operating a BEV. Meanwhile, Haddadian et al (2015) split barriers into technical, economic and consumer perception. Similarly, Todd et el (2013) discussing the electric vehicle industry in the US, identify three main hurdles to widespread deployment: their high cost, the limited availability of charging infrastructure, and consumer awareness, leading to misperceptions about BEV operation and reliability. Such attitudinal barriers are particularly influential as they potentially alleviate positive feelings towards BEVs (such as enthusiasm surrounding new technology or lower running costs).

Better understanding of barriers to BEV adoption, and the way in which they relate to, and impact on each other is critical in the context of evidence concerning key factors that consumers consider when buying a car with cost, reliability, safety, performance, running costs and appearance ranking highest; vehicle emissions and environmental concerns, ranking lowest (Geels et al, 2012). The analysis below considers the range of obstacles to BEV adoption highlighted in the academic, grey and policy literature within a framework of inter-linked socio-technical, economic uncertainty and market awareness/perception barriers as presented in Figure 2.

Insert Figure 2 here

6.1 Socio-technical barriers

A significant body of literature has highlighted the socio-technical barriers to BEV ownership as a major issue. These issues primarily revolve around the concerns and perceptions of consumers around the development and deployment of technology. One of the most

important concerns relates to battery performance and durability, and the mileage or 'range' that electric vehicles can achieve (Daziano and Chiew, 2013, Egbue and Long, 2012, Carley et al, 2013, Axsen and Kurani, 2013, Bonges and Lusk, 2016). On this issue, Egbue and Long (2012), for example, found that consumer concerns over battery range ranked above cost in terms of barriers to purchase. These perceptions are also matched by the lived experience of BEV drivers. Range 'anxiety' has been shown to have a detrimental effect on the experience of BEV owners as drivers elected not to use in-car features (such as heaters) in order to preserve battery life (Office for Low Emission Vehicles, 2013). Due to concerns over range, drivers did not attempt longer journeys and felt the vehicle would be more suitable as a second car (Graham-Rowe et al., 2012). Indeed, concerns over driving range may not be caused by misconceptions, but instead are strongly influenced by the difference in the required driving range and the actual limits of the vehicle (Jensen et al., 2013). Despite this, however, other studies found that range anxiety decreased over time (Bunce et al., 2014, Wikstrom et al., 2014, Office for Low Emission Vehicles, 2013; Rolim et al. 2012). These studies noted that BEV users were able to successfully manage daily mileages as their experience in the vehicles increased. Nevertheless, perceptions and anxiety over battery range are significant barriers with Egbue and Long (2012) suggesting widespread BEV adoption is unlikely whilst confidence in the technology remains such an acute issue.

In addition to battery performance, range anxiety is strongly linked with the availability of charging facilities. Refuelling a BEV represents a radical shift from normalised behaviour in the ICE regime, and one which is perhaps not clearly understood and appreciated by many consumers, despite evidence from BEV drivers that the recharging process is both simple and convenient (National Research Council, 2015, Bunce et al., 2014). BEV drivers can refuel, or more aptly recharge their cars at home, at work or at public charging stations utilising the electricity network. Yet, while results from BEV trials (such as Bunce et al., 2014, Wikstrom et al., 2014, Skippon and Garwood, 2011) suggested that drivers did not tend to utilise public charging stations and mostly elected to charge their vehicle at home; evidence suggests that a lack, or perceived lack, of charging infrastructure outside the home can act as a major deterrent to purchase (Lane and Potter, 2007, Egbue and Long, 2012, Browne et al., 2012, Axsen and Kurani, 2013, Wan et al., 2015, Graham-Rowe et al., 2012, Bonges and Lusk, 2016). This maybe an issue of reassurance whilst the BEV ecosystem and associated behaviour is new and drivers are less sure of range; ICE drivers are after all used to having the security of petrol stations located every few miles (National Research Council, 2015). At the same time, for

those in multi-unit dwellings where home charging is less feasible, concerns over public charging infrastructure are real (Todd et al, 2013). As such, investment in widespread charging networks is seen as a critical step towards improving BEV adoption, providing the necessary confidence and safety net for drivers (Todd et al, 2013).

Despite advancements, the current level of technology in BEVs is perceived as unproven (Steinhilber et al., 2013, Egbue and Long, 2012, Graham-Rowe et al, 2012, Axsen and Kurani, 2013, Wan et al., 2015) and until the technology is 'proven' many drivers are unlikely to switch from ICEs (Graham-Rowe et al., 2012). Not only is the technology unproven, for example in terms of battery durability, but it is also regarded as 'inferior' due to the limitations surrounding battery range and 'refuelling' times (Steinhilber et al., 2013). BEVs arguably have an 'obsolescence factor' whereby consumers are unwilling to switch to the technology due to a feeling that it may be surpassed and become dated (Egbue and Long, 2012). Such limitations in technology were further highlighted through the length of time it takes drivers to charge a BEV, which in turn acts as a purchasing deterrent (Daziano and Chiew, 2013, Lane and Potter, 2007). Manufacturers may not be willing to invest heavily in BEVs as they may not yield a long-term return (Steinhilber et al., 2013, Browne et al., 2012). There may also be a concern within the automotive industry that a transition to BEVs could result in existing experiences, skills, and systems, both upstream and downstream, not being applicable to the new technological development (Steinhilber et al., 2013).

A final socio-technical barrier for the adoption of BEV technology relates to the investment decisions made by OEMs. Prior to the very recent increase in BEV supply, manufacturers had focused investment on improving existing ICE vehicles through implementing 'cleantech' solutions such as stop-start systems (Dijk et al., 2015). Moreover, investment in BEVs was seen as 'disruptive' as the bulk of OEMs sunk costs relate to existing ICE technologies. These manufacturers were reluctant to shift support to BEV development (Dijk et al., 2013), which had implications for the quality and supply of BEVs. Additionally, there are expectations that ICE vehicles will continue to become more efficient, conditions which may not provide the basis for mass-market adoption of BEVs. (Tran et al., 2013). Also, as manufacturers have produced a wider range of vehicles to suit consumer demand, there remains effectively an 'institutional lock-in' for conventional vehicles (Van Bree et al., 2010). By way of illustration Nykvist and Nilsson (2015, p36-37) found that the strength of the ICE regime in Sweden has helped to hinder the development of BEVs, suggesting manufacturers such as Volvo are

"*strongly associated with the prevalent norms in society of what a car is and how it is used, and this cross-fertilization of regime actors and norms in both industry and consumers currently constitute a strong barrier for BEV*".

6.2 Economic uncertainty barriers

Technological barriers facing the BEV market should not be treated in isolation as they have also influenced economic barriers alongside uncertainty amongst consumers as to the operationalisation of the EV market and ecosystem. It is widely established that BEVs have a high upfront purchase price compared to their ICE counterparts, primarily driven by the cost of current battery technology, and that this issue acts as perhaps the main obstacle to adoption (Egbue and Long, 2012, Carley et al., 2013, Diamond, 2009, Heffner et al., 2007, Browne et al., 2012, Lane and Potter, 2007). Many drivers are unwilling to pay a premium price for new technology when there are still such prominent concerns surrounding range, charging, performance and battery durability (Bakker et al., 2014; Egbue and Long, 2012). Further, uncertainty over the availability of downstream maintenance, service and repair infrastructure adds to consumer confusion and raises doubts about whether the premium prices will be 'offset' by lower 'real world' operational costs (Graham-Rowe et al., 2012).

Having both a high 'list' price and perceived high maintenance and service costs raises doubts in the literature about the 'payback period' for a BEV. Participants in the study conducted by Skippon and Garwood (2011) suggested that they would be willing to have a maximum 'discount period' of four-years for the lower fuel costs to offset the higher list price. This study did not take into account any other costs in relation to the battery or servicing, and even without taking these elements into account, Skippon and Garwood (2011) believed that the price premium will be over four times greater than the annual running cost savings. This raises concerns about the economic benefit of BEV ownership, as the high premium price and long payback period do not positively influence consumer demand (Hardman et al., 2015). An additional concern, in the absence currently of any second-hand resale or recycling market, is uncertainty over residual values, which again do not help to offset high initial purchase prices (National Research Council, 2015).

A further current issue is the lack of choice and availability in the BEV market relative to the well-established ICE market with its wide array of models and styles to suit all tastes and needs (and where new offerings have proliferated in recent years such in crossover vehicles, people carriers and so on). Notably just five models accounted for 80% of BEV sales in Europe in 2015

(AID, 2016). In terms of raising awareness and visibility, the lack of availability of BEVs in showrooms and dealerships is another concern (National Research Council, 2015).

Because of high battery prices, it has been suggested that BEVs will cost up to a quarter more to manufacture than equivalent ICE vehicles until 2020 (Bloomberg New Energy Finance, 2017). Yet it should be noted that battery prices are falling rapidly, so this barrier will become less of an issue over the next decade. Nyhkvist and Nilsson (2015) and Nilsson et al (2016) highlight rapidly falling battery prices; more recently, Bloomberg New Energy Finance (BNEF, 2016) stress that Lithium-ion battery costs have dropped by 65% since 2010, reaching $350 per kWh in 2015. When the cost of battery packs falls below $200 per kWh, BEVs are likely to achieve cost parity with equivalent ICE cars, suggesting a 'tipping point' in the mid-2020s.[3] Analysts expect EV battery costs to be well below $120 per kWh by 2030, and to fall further after that as new chemistries come into play (BNEF, 2017). While this barrier may become less of factor going forward, there remains a need for ongoing policy support to incentivise consumers in the short to medium term and a longer run holistic policy approach to overcome other barriers detailed here – this is in line with Nilsson et al's (2016: p.1368) call for "strong governance measures over the coming 5-10 years" to deliver a breakthrough scenario.

6.3 Consumer awareness / attitudinal barriers

Alongside concerns expressed in relation to technology, infrastructure, finance and choice discussed above, some consumers have questioned the real environmental 'performance' of BEVs. Egbue and Long (2012) argue that those individuals who are most technologically minded were unconvinced about the sustainability of the fuel source for BEVs i.e. the cleanness of the electricity grid. Similarly, Graham-Rowe et al (2012) found that drivers who held the most concern for the environment would have to be convinced about the 'green' benefits of BEVs. Beyond issues with the electricity supply there are also concerns, for example, with battery disposal (National Research Council, 2015). Whilst uncertainty over these issues remains, scepticism amongst consumers will persist and perhaps deter purchase, particularly amongst those having a strong desire to protect the environment, who may be an obvious early adopter segment (Jensen et al., 2013, Heffner et al., 2007). At the same time for mainstream consumers evidence suggests that environmental concerns are a minor factor in the vehicle decision making process (Geels et al, 2012; National Research Council, 2015).

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[3] Nilsson et al (2016) suggest a reduction in battery costs to $200-250 per Kwh by 2020 and $150 per kWh by 2025 as a plausible driver in a breakthrough scenario.

The aesthetics and design of early entrants to the BEV market BEVs presented another barrier to adoption for consumers. Despite rapid evolution in design and choice of models this issue is one which continues to influence perceptions of BEVs. Reporting on a demonstrator trial of AFVs deployed in the south-east region of the UK, Graham-Rowe et al (2012) found that some drivers viewed BEVs as being 'soulless' and lacking in visual appeal when compared to conventional ICE vehicles. This perceived soulless design is an important issue given that the car is arguably more than technology and a mode of transport, it can be seen as an 'avatar', representing a driver's personality. These weaknesses in design have implications as both symbolic and emotional factors are shown to influence vehicle purchase decisions (Schuitema et al., 2013, Rezvani et al., 2015). Although for some consumers this issue is moot, with vehicles representing a positive environmental choice, for many design and desirability are factors that override 'green' concerns. Moreover, the reported experiences of drivers who have trialled BEVs, can also affect consumer perceptions as their shared experiences may well influence those motorists without such knowledge.

A further set of barriers can be identified broadly as relating to consumer awareness. Research in the US for example has highlighted the difficulties faced by consumers in understanding how to calculate electricity costs, when to charge and where to charge to maximise savings and efficiencies. This, it is argued, creates uncertainty and doubt and as such another obstacle (National Research Council, 2015). Whilst financial incentives are being used as a policy tool to lower the price of BEVs, there are concerns as to the extent to which consumers are aware of these, particularly in major markets such the US where research showed that just 5% of the population in the 21 largest cities were aware of BEV incentives (Krause et al, 2013). The variability, inconsistency and time-limited nature of incentives is also seen as potentially confusing for consumers (National Research Council, 2015). Given the limited number of drivers that have experienced a BEV it is perhaps not difficult to suggest that for many mainstream consumers the benefits and different experiences of driving a BEV are largely unknown. This lack of awareness leads to uncertainty, myths and misinformation such that consumers are unwilling to take the risk (National Research Council, 2015).

In adapting vehicle fleets to BEV technology other educational/awareness barriers have emerged. Wikstrom et al (2016) focusing on fleet procurement by the Swedish government posit 'operational barriers' which relate to users lack of confidence in unfamiliar technology;

ineffective education and training on issues such as range and dealing with technology failure; and the allocation of BEVs to users without prior consultation, a decision which creates resistance.

Cutting across these three barrier dimensions is the issue of a lack of niche developments at local scales. Nykvist and Nilsson (2015, p.34) have drawn attention to the lack of spaces for niche developments, actors and niche activities in Sweden as a key factor in the slow uptake of BEVs. The lack of local projects and initiatives and visibility of BEVs, for example in local government or taxi fleets results in a situation where consumers have limited exposure to and experience of BEVs thereby slowing down the diffusion of knowledge and awareness. This *"leads to misconceptions of what a BEV is, what it is capable of, and how a BEV can be used"* hindering their wider uptake.   In contrast, Haley (2015) highlights how, in Canada, Québec's social history of hydroelectricity development provided actors with reosurces for developing BEV technologies, while Van Rijnsoever et al (2013) highlight how local and regional BEV policies can be significant on infrastructure and BEV diffusion in the Dutch case. What such examples suggest is that the MLP literature needs to be better combined with multi-level governance (MLG) perspectives so as to engage with different spatial scales and place, so as to build geographical pockets where new technologies are tested - especially with regard to BEV take-up (see also Nilsson et al, 2016).

7.   Solutions: stimulating niche activities

So far, this paper has outlined the complex socio, economic, technical and cultural forces at landscape, regime and niche level which have shaped the situation where BEV market share is increasing but only marginally (Figure 2). It is argued here that in this context and in order to 'cross the chasm' from the present mostly early adopter market to widespread adoption requires innovative solutions, policies and business models from governments, industry, consumers and other stakeholders working together. The final part of this section of the paper briefly outlines some of the proposed solutions against the framework of the barriers they are designed to address. A range of solutions have been proposed and are being tested primarily at the local and regional scale in urban and city level locations across the world in order to break down barriers, support niche activities and developments, stimulate the BEV market and aid the transition to a more sustainable automobility. Drawing upon a range of academic, grey and policy literature these have been conceptualised into a typology of 'supply-side',

'awareness and education', 'targeted support and consumer incentives' solutions as outlined in Figure 3

Insert Figure 3 here.

It is not the purpose of this paper to go into detail on solutions; this is a subject for future research. What the paper does highlight is that given the array of barriers operating at regime level against BEV take up, a strategy comprising a range of mutually enforcing policies will be needed if BEVs are going to break out of their current niche position (see also Nilsson et al on the governance requirements for this). These polices might usefully include: supply side-solutions, such as investing in infrastructure and supporting R&D; targeting support and incentives on niche market segments and EV ecosystems at city-regional level so as to build geographical pockets where new BEV technologies are tested (Nilsson et al, 2016); raising awareness amongst consumers, through providing effective information and education, and sharing stories; and influencing behaviour change, through for providing opportunities for consumers to experience BEVs, for example, through public and private sector fleets, taxi fleets, promoting EV test-drive events, and car share clubs. Implementing such solutions should not be viewed as straightforward. Some policies may well have unintended side effects, whilst the length and mix of any incentives needs to be considered (Langbroek et al., 2016). For instance, Lieven (2015) highlights that there are three clusters of consumer in relation to incentives. These are those who prioritise monetary support, those who prefer charging incentives, and some individuals who prefer a mixture.

8.   Conclusions

This paper has used the Multi-Level Perspective (MLP) framework to interpret European battery electric vehicle (BEV) take up and automobility transition. While environmental and energy security pressures have created a favourable landscape 'push' for BEVs as a niche that has encouraged and facilitated serious commitment from some manufacturers, this has varied considerably across nations and regions. Furthermore, the landscape pressure has yet to create the certainty required for investors and consumers to make long term commitments to BEVs. Reflecting on Figure 1, the strength of the arrows indicating 'landscape levers' remain intermittent and uncertain. Furthermore, there are significant multi-level forces pushing against BEV take up, in MLP terms, at regime and niche level.   While some of these are declining in strength – such as via falling battery costs – so as to reduce the scale of the

'chasm', there remain a range of other factors that we identified that will mitigate BEV take up without a more holistic policy approach. The identified 'levers' pushing BEV transition and 'barriers' to adoption acting against transition were analysed drawing on the multi-level perspective as a framework through which to conceptualise progress in the transition to a more sustainable automobility. The analysis shows how the complex interaction of these push and pull factors, involving a range of actors operating at different levels creates a situation where BEV market penetration in Europe remains far below the level required for mass market transition. For BEVs to 'cross the chasm' and gain an established foothold in the market (and hence disrupt the regime), more holistic and effective solutions are required recognising the range of barriers that characterise the current ICE regime (and how these are changing over time). So far this has yet to be fully taken on board by policy makers, we would argue, except perhaps in the case of Norway.

Policy makers have used a combination of mechanisms from subsidies and grants to free parking in order to try and convince consumers to switch from conventional vehicles. Yet the paper has also provided ample evidence to question the effectiveness of incentives whilst also highlighting the presence of significant barriers to adoption. Concerns over price, infrastructure and technology are major concerns, but the paper has also explored a number of barriers from the perceptive of consumers, crucial to understand in the MLP framework. The paper briefly highlighted some of the solutions reviewed in the literature and suggested a more holistic approach for policy with a focus on: supply side-solutions, investing in infrastructure and R&D; targeting support and incentives on niche market segments and BEV ecosystems; and raising awareness amongst consumers, focusing on providing effective information and education, promoting BEV test-drive environments and sharing stories, and influencing behaviour change through for example car sharing.

The paper's meta-review of literature and policy debates found very limited comparison of these issues across countries and places. Most studies focused on one country (or region within a country) rather than presenting a comparative overview of different levers, barriers and policy agendas in different nations; rather a cross country – and region - comparison is required. It is also apparent that consumer perceptions surrounding BEVs are dynamic (i.e. Graham-Rowe et al., 2012), so more longitudinal studies would also be advantageous in explaining how key aspects evolve over time and how the various forces in Figure 1 change. Additionally, there is little in the way of robust quantitative evidence that measures the

strength of various barriers, motivations or solutions to BEV uptake, nor the inter-relationships between them. This would provide valuable data for policy makers going forward.

Reflecting on the MLP approach, how can we characterise the state of markets in Europe in terms of BEV take up given the range and scale of barriers we have identified? Overall, the MLP framework, in recognising complex relationships between multi-level actors and agencies, pushing toward, but also pulling against sustainable transition, suggests that BEVs can potentially disrupt the established ICE regime but that a range of significant, complex and inter-related barriers at regime level has so far prevented this. If BEVs were to break out of niche spaces and disrupt the ICE regime, they would likely remain a minority, compared to ICE vehicles, but might still gain a much more substantial market share in a greener automobility, as has been witnessed in Norway. Finally, it should be noted that many examples of niche level change factors from the review above, and detailed in Table 2, are at a local and regional – especially city - scale, where strategic niche management can be developed (e.g. pilots and demos, development of charging infrastructure etc.). In this regard, the MLP literature needs to be better combined with multi-level governance (MLG) perspectives so as to engage with different spatial scales and place, so as to build geographical pockets where new technologies are tested - especially with regard to BEV take up.

Table 1: European Sales of Battery Electric Vehicles: 2012-2015

Country	2012	2013	2014	2015	2015 Market Share	% growth 2012-15	% growth 2014-15
Norway	3,950	7,882	18,090	25,814	17.10%	553.5	42.7
France	5,663	8,779	10,610	17,268	0.90%	204.9	62.8
Germany	3,784	6,441	9,629	13,605	0.42%	259.5	41.3
UK	2,150	3,584	6,697	9,934	0.38%	362.0	48.3
Denmark	537	564	1,620	4,381	2.11%	715.8	170.4
Switzerland	785	1,189	1,780	3,882	1.20%	394.5	118.1
Netherlands	3,850	5,582	3,403	3,859	0.86%	0.2	13.4
Sweden	947	1,545	1,392	3,253	0.94%	243.5	133.7
Austria	427	654	1,281	1,677	0.54%	292.7	30.9
Belgium	826	574	1,358	1,621	0.32%	96.2	19.4
Spain	399	629	990	1,461	0.14%	266.2	47.6
Italy	520	870	1,101	1,460	0.09%	180.8	32.6
Western Europe	**24,150**	**38,624**	**58,582**	**89,640**	**0.68%**	**271.2**	**53.0**
Market Share (%)	**0.21**	**0.34**	**0.49**	**0.68**			

Source: Automotive Industry Data Newsletter, 2016

Figure 1: Crossing the EV Chasm to Market Penetration: A Multi-Level Perspective

Source: Adapted from Geels et al (2012); Urban Foresight, 2014; Serra, 2012

LANDSCAPE LEVERS PUSHING EV ADOPTION

International policy landscape
• Environmental
• Energy Security
• Economic

National Policy landscape:
• R&D
• Infrastructure
• Fiscal incentives

Societal landscape:
• Convenience, technology driven society

CHASM

Regime barriers pushing against landscape levers creates chasm that needs to be crossed for EVs to be mainstreamed

STIMULATING NICHE ACTIVITIES BY ACTORS AT LOCAL / REGIONAL LEVEL

• Supply side solutions
• Targeted support and consumer incentives
• Education and raising awareness - BEV experience and demonstrator events

EV MARKET SHARE (%)

REGIME BARRIERS TO EV ADOPTION

• Socio-technical
• Economic uncertainty
• Consumer awareness / attitudes
• Lack of niche activities

Year

Y-axis values: 0, 2, 4, 6, 8, 10, 12, 14

Data labels: 0.1, 5, 12

X-axis: 2010, 2015, 2020, 2025, 2030, 2035

Figure 2: Barriers to BEV adoption

Technical barriers

- Performance, range and durability of EV batteries
- Length of time taken to recharge an EV
- Availability of public charging stations
- Availability of maintenance, service and repair infrastructure
- Unsuitability of dwellings for home charging
- Parallel improvements in efficiency of ICE vehicles

Financial / Economic Barriers

- High upfront purchase price
- Anxiety over re-sale value
- Length of time to offset purchase price through savings in fuel /taxation
- Choice and availability in the EV market

Consumer awareness / attitudinal barriers

- Perceptions that EV driving range insufficient for daily driving needs
- Concern that driving behaviour will diminish range
- General awareness of the benefits of owning and driving EVs
- Concern over the 'real' environmental impact of electric vehicles
- Belief that EVs have inferior/unreliable technology and poorer design/aesthetics
- Difficulties in calculating fuel costs and potential savings of EVs
- Uncertainty concerning the process of home/public charging
- Expectation that EV technology will improve in the future so purchase is delayed
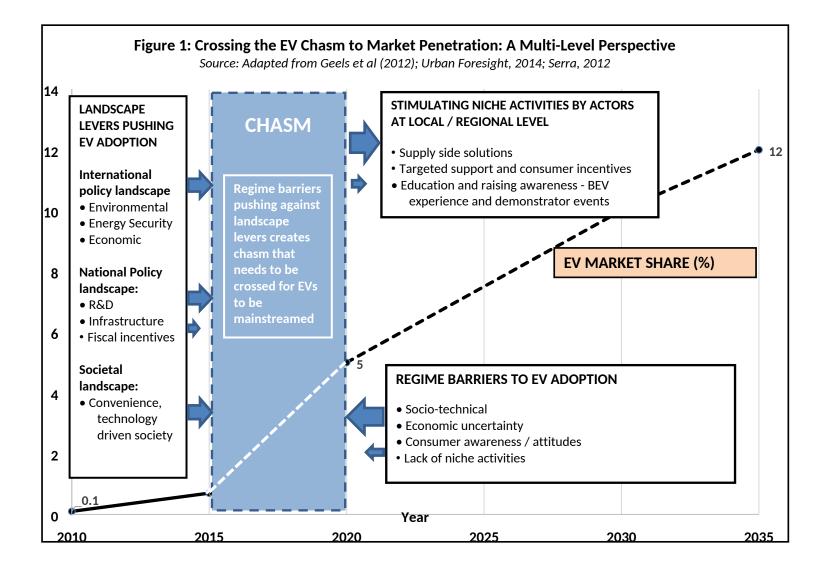- Expectation that improvements in efficiency of ICE vehicles will continue thereby offsetting environmental benefits of EVs
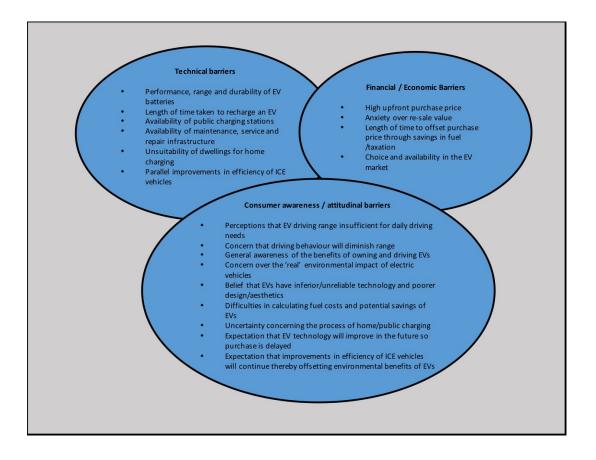
Figure 3: Solutions to tackle barriers and stimulate EV take up

Solutions	Barriers addressed / impact	Examples *(Source; Urban Foresight, 2014)*
Supply side • Charging infrastructure; fast charging; wireless charging; workplace charging, provision for multi-unit dwellings • R&D - batteries (performance and range, recycling, disposal, swapping, leasing, right-sizing) and light-weighting vehicles • Better market choice and availability • BEV ready buildings • Penalising ICE drivers (higher taxes, congestion charging)	• Reduce range anxiety • Overcome perceptions of inferior, unreliable technology • Open up BEVs to wider markets • Reduce concerns around environmental impact of BEVs • Negative effect on non-EV drivers through punitive measures	• Wireless Charging for E-buses, South Korea • Nationwide fast charging, Estonia • 'LIVE', BEV start-ups initiative, Barcelona • BMW i3 – Lightweight BEVs, Germany • Battery swapping, Hangzhou Electric Taxi fleet • Plug share through mobile metering, Berlin • BEV ready new buildings, Koto City
Targeted support and consumer incentives • Focus on niche segments / markets (e.g. buses, taxis, rickshaws; public & private sector fleets, logistics fleets; low mileage drivers; environmentally conscious; early adopters; young people; 2-car households; high-end, rich consumers) • BEV ecosystems - concentrated support in targeted BEV friendly cities, and/or international mega-events • Low Emission Zones • Car share / car club schemes • BEVs as part of integrated transport solutions • Effective incentive mix – balance of direct & indirect subsidies • Incentives linked to vehicle trade-in/substitution	• Create a BEV 'beachhead', increase awareness and visibility; potential to spillover into similar/neighbouring segment/areas • Potential to achieve significant scale of deployment • Open up BEVs to wider markets • Reduce EV/ICEV price differential • Open up BEVs to wider markets	• Electric Taxis, Bogota • E-trikes, Manilla • All-electric bus fleet, Schiphol Airport and utilising battery swapping, Rome • "Mi Muovo" mobility card, Emilia-Romagna, linking buses, trains, bike / car share, and charging points • Autolib car share scheme, Paris; Car share vending garage, Hangzhou; E-Vai Car share, Lombardy • BEV only Tourist Resort, Zermatt, Switzerland • Fiscal, non-fiscal incentive mix in Norway saving drivers not just money but also time • Ultra-low Emission Zone, London
Awareness/Education • Marketing and promotion: effective information and education; myth busting; pricing signals • BEV test drives and Sharing 'stories' from BEV drivers, trials • Charging point databases • Engaging consumers early – young people • Influencing behaviour change – new models of ownership	• Raise awareness of reality of BEV, reduce negative stereotypes • Increase visibility	• Shanghai International BEV Demonstration Zone • Formula E motor racing – 'Demonstrating the Power and Performance of BEVs', UK • Dedicated BEV resources for schools, Victoria • 'Direct to customer sales' – Tesla • Smart Charge App, BMW i3/i8

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