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Inter-niche competition on ice? Socio-technical drivers, benefits and barriers of the electric vehicle transition in Iceland

Abstract

This paper investigates the drivers, benefits and barriers of battery electric vehicle (BEV) development and an ongoing BEV transition in Iceland from a sociotechnical perspective. We focus on the following research questions: 1) What are the most promising driving forces behind BEV growth? 2) Why are BEVs restricted mostly to the niche level? 3) What are the possible opportunities for BEV future development? and 4) How viable are BEVs as a solution to harnessing low-carbon renewable sources in Iceland? The study uses original qualitative data comprising 29 research interviews involving experts from a wide range of sectors. The conceptual framework of multi-mode interaction, or “inter-niche competition”, is incorporated into the MLP to illustrate the interaction between BEVs and other technologies, in particular, plugin hybrid electric vehicles. We find that BEVs may take de-alignment and re-alignment pathway or reconfiguration pathway depending on the multi-technology interaction modes.

Keywords: electric mobility, Iceland, Multi-Level Perspective, sociotechnical transitions, inter-niche competition, multi-mode interaction

1. Introduction

The transition toward a low-carbon renewable energy based transport sector is critical to achieve a confluence of energy and transport policy goals supporting decarbonisation (Sovacool *et al.*, 2019). The process requires not only technological changes, but also broader changes in mobility behaviour, traffic management, spatial planning, and infrastructure development. Moreover, the process requires an in-depth understanding of interactions between different types of changes related to culture, governance, car industry, mobility behaviour, and emerging technologies. These changes will have significant implications for achieving a low-carbon sustainable transport sector transition.

A transition to renewable transport fuels is of particular interest for Iceland. In 2015, the share of energy from renewable resources in gross final consumption of energy in Iceland was 71.1% (Eurostat, 2016). These low-carbon renewable energy resources are prevalently used in industrial, residential and commercial sectors. Over 99% of total electricity in Iceland is generated by geothermal and hydropower resources (NEA Energy Statistics, 2018). Over 90% of heating in houses is supplied by geothermal energy (NEA Energy Statistics, 2018). Nonetheless, the share of the energy from renewable sources in transport sector is merely 5.7% (Eurostat, 2016). The transport sector in Iceland still heavily relies on imported fossil fuels. With an increasing number of vehicles-per-capita, greenhouse gas (GHG) emissions from road transport sector account for 20% of the total GHG emissions in 2016 (Ministry for the Environment, 2017). Using the emissions figures in 1990 as a

baseline, Iceland's long-term vision is to reduce GHG emissions by 50%-75% in the year of 2050 (Ministry for the Environment, 2007). To reach the goal, GHG emissions from transport sector need to be reduced considerably, which poses challenges to governance, mobility behaviour, energy production, and technological innovation.

Alternative fuels are treated as possible solutions to shift to a low-carbon sustainable transport sector, including biofuels, hydrogen, and electricity, which can be produced from renewable energy sources in Iceland. Among them, the production capacity of biofuels alone is limited and unable to fulfil the demand of transport sector (Shafiei *et al.*, 2018). On the other hand, hydrogen and electricity can be produced from various renewable energy sources in Iceland. Nevertheless, compared with electricity, hydrogen is more costly as it adopts expensive production and end-use technology (Shafiei *et al.*, 2017). Therefore, the electricity generated from geothermal, hydro and wind resources in Iceland seems to be a practicable approach, which can be used in battery electric vehicles (BEVs).

For the moment the literature on the transition of BEVs in Iceland is scarce. A series of pioneering works have been conducted by Shafiei *et al.* They developed an agent-based model to study the consumer behaviors and predict the market share of BEVs in Iceland (2012). In this model the vehicle-choice algorithm is used to analyse the competition between BEVs and internal combustion engine vehicles (ICEVs) by taking into account the impact of fuel prices, vehicle taxes, future price of BEVs and recharging concerns. Moreover, Shafiei *et al.* (2014) proposed a system-dynamics model of integrated energy-transport system (UniSyD_IS) to simulate the transition to low-carbon transport in Iceland, and the results suggested electric vehicles as a winner among alternative fuel vehicles. The uniSyD_IS model was further applied to examine the interaction between energy market and alternative fuel vehicles (Shafiei *et al.*, 2014), to conduct comparative analysis of hydrogen and electric vehicles (Shafiei *et al.*, 2017), and to evaluate the effects of tax policy in Iceland (Shafiei *et al.*, 2019).

Additionally, Fazeli *et al.* (2017) combined the energy system model and the Multi-Criteria Decision Analysis to compare the implications of fiscal policy incentives promoting EV adoption in Iceland on government revenue, consumer's vehicle ownership cost, the GHG mitigation potential and energy security. Taking a case study of the Reykjavik city region, Driscall *et al.* (2012) discussed the possible confliction between BEVs and other sustainable mobility planning goals, and claimed that widespread use of BEVs may undermine the efforts to create denser urban development patterns and to promote non-motorized and public forms of transport.

However, given that a sustainable transition is a complex evolutionary reconfiguration process, the present study attempts to understand and analyse the BEV development in Iceland from the perspective of social-technical transitions. The paper takes advantage of the theoretical framework of the Multi-Level Perspective (MLP), which considers the transition as a process of co-evolution of and interaction between technology and different societal elements, with a particular emphasis placed on "multi-mode interaction" or "inter-niche competition". To do so, we used 29 semi-structured interviews with experts. The paper seeks to answer the following important questions concerning the transition of BEVs in Iceland: 1) What is the most promising driving force behind BEV growth? 2) Why are BEVs currently restricted to the niche level? 3) What are the possible opportunities for BEV future development? 4) How viable are the BEVs as a solution to harnessing low-carbon renewable sources in Iceland? In order to answer such questions, the remainder of the paper is structured as follows. The Multi-Level Perspective theory is reviewed, and our notions of multi-mode interaction and inter-niche competition explained, in Section 2. Afterwards, the research method is presented in

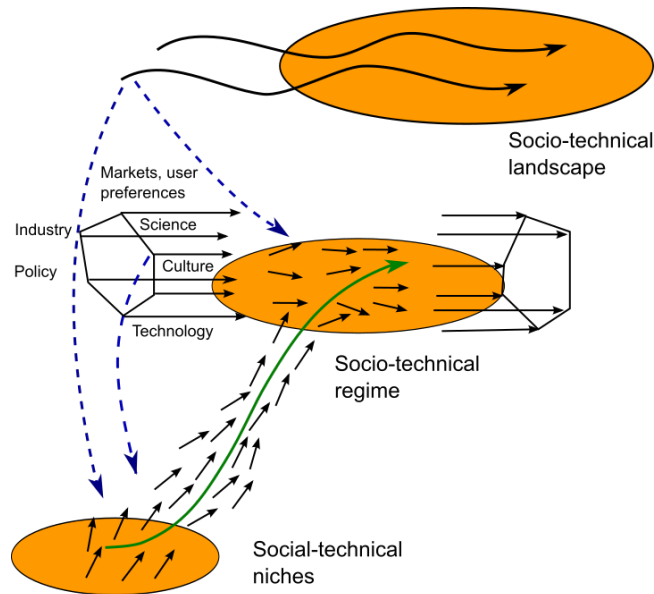
Section 3. Section 4 is devoted to the research results and discussion, followed by a discussion of competitive and co-evolutionary transport pathways in sections 5 and 6. Section 7 concludes.

2. Conceptual approach: The Multi-Level Perspective, multi-mode interaction and inter-niche competition

As an overall conceptual approach, we seek to integrate or at least theoretically triangulate (Sovacool and Hess 2017) from different frameworks in order to address the sociotechnical interactions at different points in the system and at different levels of abstraction. These core frameworks are the MLP, as well as what is termed inter-niche competition or multi-mode technology interaction.

The MLP is utilized in the paper to explore the transition of BEVs in Iceland. The first reason for adopting the MLP is that it explains historical socio-technical change from a large variety of dimensions, such as policy, culture, user practice, market, technology, industry, and science. Secondly, the MLP offers a flexible framework to understand the permeation of socio-technical change across time and space, which is crucial in understanding the transition process of technological innovations in historical and spatial terms. This is closely related to the research question of the paper, that is, why are BEVs restricted to the niche level? Thirdly, the MLP does not only focus on one specific level, but also emphasises the interactions among the landscape level, regime level, and niche level, and can thus better explain the process that a radical innovation enters regime level. Last but not least, the MLP has been successfully applied to explore the socio-technical transition of various travel and transport modes, such as steam ship transition process (Geels, 2002), the emergence of car regimes (Geels and Kemp, 2012), the transition pathways of e-bikes in China (Wells and Lin, 2015; Lin *et al.*, 2017; Lin *et al.*, 2018), biofuels in Sweden (Hillman and Sanden 2008), whole-systems passenger mobility shifts in the United Kingdom (Geels, 2018), and transition failures in the automotive industry (Wells and Nieuwenhuis, 2012). These successfully applied case studies create a strong evidence base confirming the suitability of employing the MLP to study the transition of BEVs in Iceland.

The MLP is identified as “a nested hierarchy of structuring processes” by Geels and Schot (2007), a series of processes depicted by Fig. 1. The landscape is the macro-level, which consists of slow changing elements in a wide exogeneous environment, such as climate changes, environment problems, macro-economy, and global policy (Geels, 2005). The regime is the meso-level regarding a stability of existing technological development, which is formed by the linkage between regulations, user practices, infrastructures, distribution network, technology, and so on. (Geels, 2004). The niche is the micro-level where many radical innovations are generated and protected (Geels and Schot, 2007).



Adapted from: Geels, 2002.

Figure 1: The Multi-Level Perspective on Sustainability Transitions

Fig. 2 depicts the representations of landscape, regime and landscape of automobility in Iceland. On the landscape level, population density, geography, and climate change shape the Icelandic historical, cultural, social, and political context that are the most influential elements in terms of the BEV transitions in Iceland. The important components at the regime level encompass culture and symbolic meaning of cars, travel behaviour, automobility practices, policy and regulations, and distribution and maintenance networks. It is noticed that there is no regime element of automobility industry in Iceland. On the niche level, current development and innovations of BEVs, batteries, V2G capability, and alternative fuel vehicles play key roles in the transition of BEVs in Iceland. The heterogeneous elements and interactions between landscape level, regime level, and niche level frame a unique complex and dynamic Icelandic socio-technical systems, which leads to specific social benefits and barriers of the BEV transitions in Iceland.

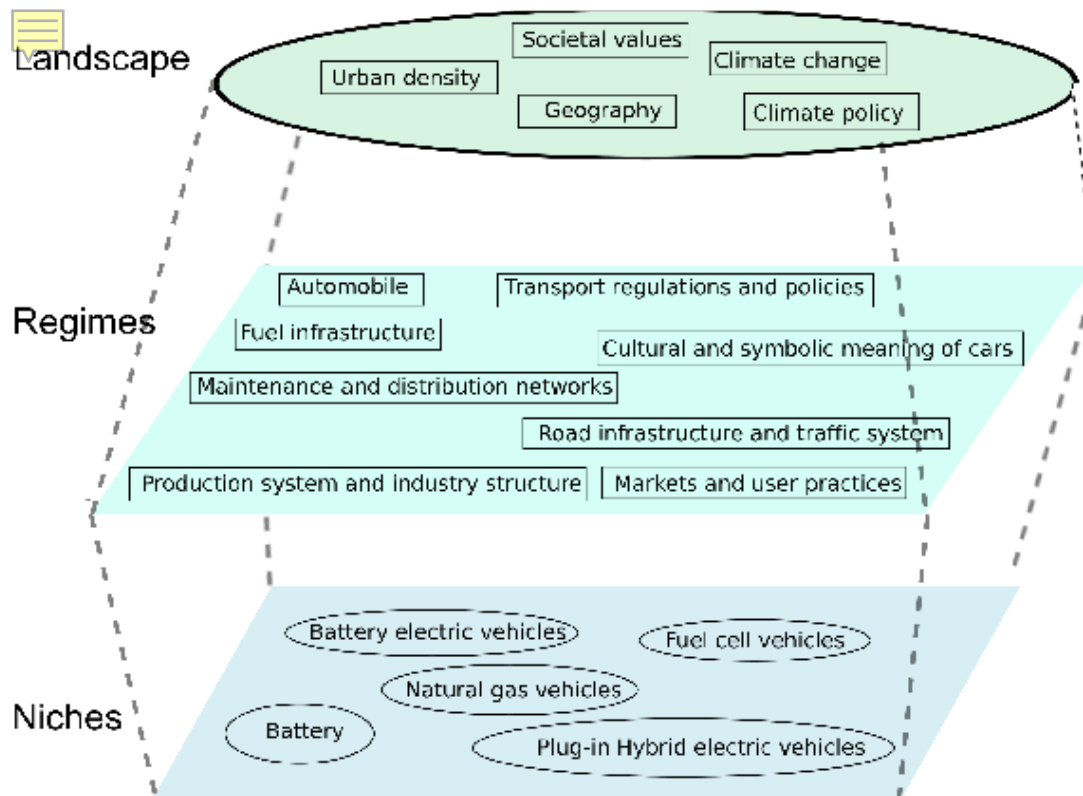


Figure 2: Simplified representations of landscape, regime and landscape of automobility in Iceland

Any given social-technical transition is commonly characterized or even defined and determined by the interaction among technologies across the niche and regime, which is often seen as the key to understanding the evolution of any technological pathway. However, many studies tend to look at a given technology in isolation. Instead, we hold that assessing multi-technology interaction may exhibit complex but equally relevant patterns and thus it offers an ability to enhance the appeal, and explanatory power of the MLP. Verbong *et al.* (2008) go so far as to suggest that “multi-niche analysis” can be inherently valuable for the comparative insights it can yield about broader transitions processes.

Given these reasons, we engage with and extend a heuristic proposed by Sandén and Hillman (2011) as a means to assess multi-mode interaction among technologies. In the present paper, we link the insights of the multi-mode interaction framework with the MLP to investigate “inter-niche competition” and its effects on the transition of BEVs in Iceland. The multi-mode interaction framework (Sandén and Hillman, 2011) is mainly comprised of the following building blocks.

First, we have *interaction directionality*. Sandén and Hillman (2011) describe six modes of technology interaction:

- Competition: Two technologies affect each other negatively.
- Symbiosis: Two technologies affect each other positively.
- Neutralism: Neither population affects the other.
- Parasitism: One technology is benefited, but the other is inhibited.
- Commensalism: One technology is benefited, while the other is not affected.
- Amensalism: One technology is inhibited, while the other is not affected.

These six modes of interaction are summarized in Table 1.

Table 1: Modes of interaction between two different technologies

Mode of interaction	Technology 1	Technology 2	General nature of interaction
Competition	–	–	Inhibition when common resource or market is in short supply
Symbiosis	+	+	Interaction favourable to both
Neutralism	0	0	Neither population affects the other
Parasitism	–	+	Technology 2 is benefited and 1 is inhibited
Commensalism	0	+	Technology 2 is benefited and 1 not affected
Amensalism	0	–	Technology 2 is inhibited, 1 not affected

Source: Sandén and Hillman, 2011.

In addition to interaction directionality, Markard and Hoffmann (2016) highlight the importance of *interaction intensity*. Thus we claim that the intensity or stability of the interaction is also a crucial constituent of the interaction relationship, which refers to whether the existing interaction mode is easy to change subject to exogenous forces.

Thirdly, any technology can be defined as a combination of upstream and downstream hierarchies of products and processes, *i.e.* a *bundle of value chains*. The overlaps of two systems in different parts of the value chain give rise to different modes of interaction.

Fourthly, the “bundle of value chains” of each technology possesses a *multidimensionality*. It can extend into material dimensions, organisational dimensions, and conceptual dimensions. The technology interaction may involve one or many dimensions.

Fifthly, the different interaction modes can exist simultaneously at different overlapped dimensions, exhibiting *dynamism*. This makes such interaction a dynamic process, and the directionality, intensity and stability of interaction will change due to time effect such as the maturity of technologies, asynchronous development of complementarities, and the structural change of the social-technical system. Indeed, the dynamism of the interaction modes are further complicated when more than two technologies are involved.

Taken together, the modes of interaction, intensity of interaction, bundle of value chains, multidimensionality, and dynamism can all give rise to socio-technical environments where pathways converge, compete, or cooperate under different circumstances and contexts. We deploy these heuristics here to underscore the competition between niches—what we term *inter-niche competition*—as a bundle of different technologies seek to challenge the transport based regime in Iceland. Indeed, whereas Hillman and Sandén (2008) examine a sort of inter-niche competition among alternative transport fuels such as ethanol or biogas in Sweden, they confine their analysis to a single sector, transportation. Here, in our study, we show how inter-niche competition can also occur across sectors, in this case within and between electricity supply, transport and mobility, and (to a degree) industry and manufacturing.

3. Qualitative Research design

With our conceptual framework established, the primary research method adopted in this study was combination of literature review and semi-structured interviews with knowledgeable experts in the transport and energy sectors in Iceland. Experts were identified as professionals in their fields, usually occupying management positions. Approximately 100 emails were sent out to contact the potential

interviewees. Almost 30 ($n=29$) of them agreed to participate. These interviewees were from private sector (automobility, electric mobility, electricity suppliers, financial firms, rental car companies and other alternative fuel companies), government (Ministry of Transport, Ministry of Environment, and Ministry of Industry and Innovation), civil society (environmental NGOs, and non-profit automotive associations), and academia (universities and research institutes), as listed in Appendix A.

The interviews were conducted in one urban location, Reykjavik, and one rural location, Akureyri. The reasons why we chose Reykjavik for performing semi-structured interviews included: 1) As the capital city of Iceland, Reykjavik is the centre of Iceland's cultural, economic and governmental activity with 65% of total population; 2) the headquarters of car dealers, energy suppliers, and Icelandic automobile associations are located in Reykjavik; 3) There are approximately 20 charging stations for BEVs in Reykjavik. The reasons why we chose Akureyri for conducting interviews are: 1) Akureyri is the most densely populated community outside Reykjavik area; 2) Akureyri is the centre of trade, culture and services in the north of Iceland; 3) There are four BEV charging stations in Akureyri.

In terms of interview process, four main interview questions were asked: 1) What do you see as Iceland's greatest energy and transport challenges? 2) What benefits do BEVs offer Iceland? 3) What impediments to BEVs need to be addressed? 4) What can accelerate BEV adoption? Follow-up questions were asked according to the answers of the main interview questions. Interviews ranged from 34 min to 86 min, with a mean time for most of 53 min. With permission, all the interviews were recorded and transcribed for further data analysis.

The qualitative data collected from interview are analysed using content analysis (Appendix B). Firstly, the transcribed interview text was divided to several condensed meaning units, each of which was labelled in the coding process. Afterwards, the codes were sorted to several categories and further abstracted to themes to facilitate the comprehension of latent meaning (Waring and Wainwright 2008). Based on the research questions of the paper, the overarching themes were identified as social benefits, social barriers, and suggestions on accelerating BEV transition. During the coding process, some higher-order categories emerged, followed by cluster codes. According to the analysis of the established coding system, our research findings were presented in a structured manner.

4. Results and discussion

This section presents the research findings and discusses the social benefits and barriers of BEV development and potential incentives of BEV transition based on the research questions and our conceptual framework. Each overarching theme as mentioned in Section 2 comprises three levels, namely, the landscape level, regime level, and niche level, followed by specific interactions..

4.1 Social benefits of BEV adoption

4.1.1 Landscape level

At the landscape level, our data suggested major benefit types centred on environmental friendliness and energy security. On the one hand, Iceland possesses plentiful cheap renewable energy which is exploited to great extent in many sectors. In 2016, 65% primary energy of Iceland was generated by geothermal power, followed by 20% share of hydropower and 15% share of fossil fuels (mainly for

transport sector) (Government of Iceland, 2017). Additionally, the local renewable energy provided almost 100% of electricity with 73% share of hydropower and 27% share of geothermal power (Government of Iceland, 2017). Currently, Iceland does not produce any electricity using coal.

On the other hand, internal combustion engine vehicles (ICEVs) were privileged as the main transport mode, which results in a heavy reliance on the imported fossil fuel rather than the indigenous clean energy generated domestically. The car ownership is very high in Iceland. In 2014, there were 217,454 cars registered in Iceland (Statistics Iceland, 2016). Nine out of every ten people aged between 17 to 75 years old own a car (Collin-Lange and Benediktsson, 2013). The prevalence of car adoption can be primarily attributed to the country’s geography, history, the land use planning (Collin-Lange and Benediktsson, 2013), and non-existence of railway. If BEVs are widely adopted in Iceland, they can substantially boost the utilization of the domestic clean energy and reduce the consumption of imported fossil fuel in transport sector (Christensen *et al.*, 2012; Richardson, 2013; Lund *et al.*, 2015; Bauer *et al.*, 2015; Raugei *et al.*, 2018).

The interview results reinforce these statements (Table 2). 82.8% of respondents agreed that BEV adoption is beneficial to environment, including improving air quality, mitigating climate change, and reducing CO2 emission, which accelerates the achievement of Iceland’ 2050 GHG goal. 55.2% of respondents mentioned the major benefit of BEV adoption in energy security. One of the interviewees said that “For us, it’s a bit special, because all the fossil fuel we use have to be imported. It’s very wise to focus on BEVs.” Another stated that “If we were to put electric vehicles in every home, the people would enjoy our resources, and everybody would benefit from it”.

Table 2: Social benefits of BEV adoption on landscape level

Benefit type	Benefit factor	Illustrative quotes	N	Key reference
Environment	Environmentally friendly	You produce the electricity in an environmental friendly way and you use it on the cars on an environmental friendly way, completely environmental friendly.	24	Ma <i>et al.</i> , 2012; Hawkins <i>et al.</i> , 2013; Mazur <i>et al.</i> , 2015; Malmgren, 2016.
Energy	Energy security	For us, it’s a bit special, because all the fossil fuel we use we have to import it. It’s very wise to focus on BEV.	16	Jacobson, 2009; Sovacool, 2017; Shafiei <i>et al.</i> , 2019.
Health impact	Positive health impact	NA	NA	Ji <i>et al.</i> , 2012; Onat <i>et al.</i> , 2014.

N: number of respondents

Our findings buttress the existing literature. A large number of studies have demonstrated that BEV adoption is beneficial to the environment in terms of production, use, and end of life (Ma *et al.*, 2012; Malmgren, 2016). For example, Hawkins *et al.* (2012) who carried out a comparative environmental life cycle assessment of conventional and battery electric vehicles concluded that the life cycle GHG emissions of BEVs was less than that of conventional vehicles. Some studies indicated that promoting BEV adoption helps enhance energy security of the countries because BEVs are flexible to adapt to a variety of domestic renewable energy, such as wind power, solar power, biomass, geothermal energy, and hydroelectric power rather than only relying on imported fossil fuel (Jacobson, 2009; Sovacool, 2017; Shafiei *et al.*, 2019). The growing anxieties about the environment and energy security create opportunities for BEV development by exerting pressure to the existing regime.

A major concern associated with the usage of BEVs is the cleanliness of the electricity utilized to charge and recharge them. As mentioned above, clean energy generation techniques are widely used in Iceland and thus contribute positively to the image of environmental sustainability in public discussions about the diffusion of BEVs. On the other hand, the development of clean energy generation does not depend on the usage of BEVs. This unilateral complementarity relationship

suggests that the large-scale use of clean energy is beneficial to but does not necessarily result in the fast growth of BEVs, as in the case of Iceland. Moreover, as far as interaction stability is concerned, such complementarity is very reliable compared to the dependence of ICEVs on oil that has heavy reliance on importation and suffers from often unpredictable price fluctuations.

4.1.2 Regime level

Van Bree *et al.* (2010) suggested that the car-based regime comprises several components: regulations and policies, road infrastructure and traffic system, maintenance and distribution network, production system and industry structure, markets and user practice, fuel infrastructure, automobile, culture and symbolic meaning. Among them, the following components were mentioned when we asked the interviewees about the social benefits of BEV adoption: markets and user practice, maintenance and distribution network, and road infrastructure and traffic system (Table 3).

Table 3: Social benefits of BEV adoption on regime level

Benefit type	Benefit factor	Illustrative quotes	N	Key references
Markets and user practices	Low operating cost	People don't realize the significant savings. For the car, when it gets to electricity, it saves 200 ISK on petrol.	7	Messagie <i>et al.</i> , 2013.
	Pleasant driving experience	NA	NA	Kurani <i>et al.</i> , 1996; Bühler <i>et al.</i> , 2014.
Maintenance and distribution networks	Less maintenance	In a combustion engine car, you have about more than thousand moving parts. There is almost no maintenance of BEVs.	2	Moons and De Pelsmacker, 2012; Egbue and Long, 2012.
Road infrastructure and traffic systems	Quieter operation	Linked to traffic, and then noise benefits.	2	Skippon and Garwood, 2011; Roscher <i>et al.</i> , 2012.

N: number of respondents

Regarding markets and user practices, the main benefit of BEV adoption identified by respondents was low fuel or operational cost. As Iceland has cheap electricity price, the interviewee who is a car dealer told the researcher that “People don't realize the significant savings. For the car, when it gets to electricity, it saves 200 ISK on petrol.” The low operation cost may offset cost pressures of BEV purchase. It is worth noting that the benefit of BEVs in offering pleasant driving experience that were reported widely in previous literatures was not mentioned by our interviewees. Kurani *et al.* (1996) and Bühler *et al.* (2014) stated that BEVs bring great driving pleasure due to their smooth power delivery and instant power when required compared to internal combustion engine vehicles (ICEVs).

Other social benefits of BEV adoption which are recognized by interviewees include less maintenance requirements and quieter operation. A respondent who is a car dealer stated that “In a combustion engine car, you have about more than thousand moving parts. There is almost no maintenance of BEVs.” Many studies supported this point (Moons and De Pelsmacker, 2012; Egbue and Long, 2012). In addition, the interviewees hold the same opinion as Skippon and Garwood (2011) and Roscher *et al.* (2012) that BEVs possess enormous advantages in reducing noise level.

4.1.3 Niche level

Table 4: Social benefits of BEV adoption on niche level

Benefit type	Benefit factor	Illustrative quotes	N	Key references
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Technology	Link with V2G	If it is a beneficial for the car, I would like to be a car owner. So, if it under control, I put my chargers, I paid the highest price, then take the electricity back at the lowest price.	2	Lund and Kempton, 2008; Sovacool and Hirsh, 2009; Sioshansi and Denholm, 2009; Loisel., 2014; Noel et al., 2019.
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N: number of respondents

Several studies have explored the social benefits of using BEVs in conjunction with Vehicle-to-Grid (V2G) technology (Falahi *et al.*, 2013; Sovacool *et al.*, 2019). These studies suggested that combination of BEV adoption with V2G technology could improve power quality (Sovacool and Hirsh, 2009), increase renewable energy utilization (Lund and Kempton, 2008), reduce CO₂, SO₂, NO_X and GHG emission (Sioshansi and Denholm, 2009), mitigate the effects of wind power uncertainties (Loisel *et al.*, 2014), reduce BEV running cost (Noel *et al.*, 2019), and lower peak load and smooth load curve (Taljegard *et al.*, 2019), which regarded V2G as a promising solution to enhance the environment and energy benefits of BEV adoption (see Table 4).

However, in this study, only two interviewees agreed that combination of BEV and V2G technology is able to bring some social benefits. One of the interviewees mentioned that “If it is beneficial for the car, I would like to be a car owner. So, if it is under control, I put my chargers, I pay the highest price, and then take the electricity back at the lowest price.” Although there exist some interviewees who were aware of the potential advantages of V2G, they still claimed that such benefits were negligible for Iceland. Some argued that “I don’t see an obvious connection today. Not really. Iceland is a relatively large producer of energy per capita. It’s an energy intensive producer, and 80% of the market goes to heavy industry and the common market is 20% and the homes are 5%, so it’s a relatively small part of the total production of the island that goes to homes and the businesses. Honestly, I don’t see how really this sort (V2G) of minor component is going to have an impact on the development of the Icelandic electricity grid. I just don’t see it. I’m probably wrong, but I just don’t see it.” Some claimed that “The electricity is cheap here. We don’t have a market that price fluctuates per minutes, per hour, as other European countries. So, it is getting users to use the energy in low demand time and use the price signal to control that. It is really not a possibility with the current set up, so users in Iceland would not think about that.”

There are two probable explanations of why many interviewees believed that the benefits of linked BEV adoption with V2G were trivial for Iceland. Firstly, the aluminium industry consumes nearly 80% of the total electricity, which operates day and night, leading to a roughly flat load curve in Iceland compared to most countries. In comparison, the residential sector only occupies 5% of the total electricity. Consequently, the overall load curve is not likely to be influenced by the uptake of BEVs (IEA, 2018). Secondly, as mentioned above, Iceland has a straightforward electricity billing system. Consumers pay a fixed rate per year for distribution services and a fixed energy consumption charged per kWh. As a result, people are not motivated to charge during off-peak time and sell the electricity back to the grid during peak time.

When out into the context of multi-mode interaction and inter-niche competition, V2G has strong dependence on BEVs but not vice versa. Hence, at first sight the lack of V2G does not constitute a barrier of BEVs development. On closer inspection, however, we notice that V2G is able to reshape the interaction modes between clean electricity generation and BEVs. With the introduction of V2G as a bridging technology, clean energy generation can benefit from BEVs, indicating that the complementary relationship between them becomes bilateral rather than unilateral. As a consequence, BEVs are not only an emerging technology in the transportation sector but also regarded as a niche

in energy sector, whereby the diffusion of BEVs can catalyse support from the social-technical system of clean electricity supply and distribution.

4.2 Social barriers of BEV adoption

4.2.1 Landscape level

On the landscape level, geography and cold weather restricted the BEV development, as thought by 58.6% of respondents (see Table 5). Due to the specific Icelandic Geography conditions, the winter time in Iceland lasts around five months from November to March. In winter, the average temperature in southerly lowlands of the island, such as in Reykjavik, tends to be around 0°C, while in the highlands it is around -10 °C. The lowest temperatures in the northern part of the island, such as in Akureyri, range from around -25 to -30 °C. One of the respondent explained that “If it is cold, below 0 °C for instance, it takes longer time to charge. And the distances they go down may be 20% or something. Also, you are using more heat and also defog more often, which accelerates the electricity consumption”. Other interviewees also shared the same concern. They stated that “Especially in the wintertime when it gets cold. Even the BEV sale companies are saying that you can drive 200 km, but then you get -10 °C and you can only drive 50 km or something like that. So that’s a very much throwback.” The previous research results also found that the cold weather has adverse effects on BEV performance and vehicle operation energy efficiency (Fetene *et al.*, 2017; Pelletier *et al.*, 2019)

Table 5: Social barriers of BEV adoption on landscape level

Barrier Type	Barrier factor	Illustrative quotes	N	Key references
Geography	Weather	Especially in the wintertime when it gets cold. Even the companies are saying that you can drive 200 km, but then you get -10 degrees and you can only drive 50 km or something like that. So that’s a very much throwback.	17	Fetene <i>et al.</i> , 2017; Pelletier <i>et al.</i> , 2019.

N: number of respondents

4.2.2 Regime level

The social barrier types on regime level which were mentioned most frequently by the interviewees in this study are concerned with markets and user practice, fuel infrastructure, road infrastructure and traffic system, production system and industry structure, and culture and symbol meaning (Table 6).

Policy

Policy intervention plays a critical role in sustainable transition. One of the main aspects of the MLP studies is the transition management which emphasises the role of policy and suggests that the distinct policy intervention is fundamental to turning unsustainable practices into sustainable ones. This is because it stimulates and nurtures new production-consumption modes in the following aspects: distributing fiscal and other incentives; providing Research and Development (R&D) supports; taking charge of infrastructure development; and formulating regulatory frameworks (Schot *et al.*, 1994; Kemp *et al.*, 1998; Hoogma *et al.*, 2002; Köhler *et al.*, 2019).

In our interview, many respondents (with 58.6% response rate) criticised that Iceland lacks effective policy incentives to stimulate the BEV adoption (Table 5). One of the interviewees who is a car dealer

complained that “We lack leadership, and proper incentivized authority to do the roll out. There isn’t enough business incentive for it to roll out in this current state. There has to be more incentive for the business to really push forward.” Another interviewee from energy sector complained that “The government is trying to put through the parliament an action plan to promote the BEV adoption. However, the action plan is almost doing nothing. It is just to use a very small amount of money every year to make people to investigate how they can build up charging stations and things like that. But it’s not sufficient. Absolutely not.” Some respondents also told the researchers that “It’s politically so hard to stimulate the BEV adoption. This is not a real long-term policy. We had difficulties in standards”. Unfortunately, Icelandic government has not set up an official BEV deployment target (IEA, 2018). The policy issues bring uncertainty and risks to consumers and thus negatively affect their attitude and intention towards BEVs (Lane and Potter, 2007; Dijk *et al.*, 2016; Langbroek *et al.*, 2016).

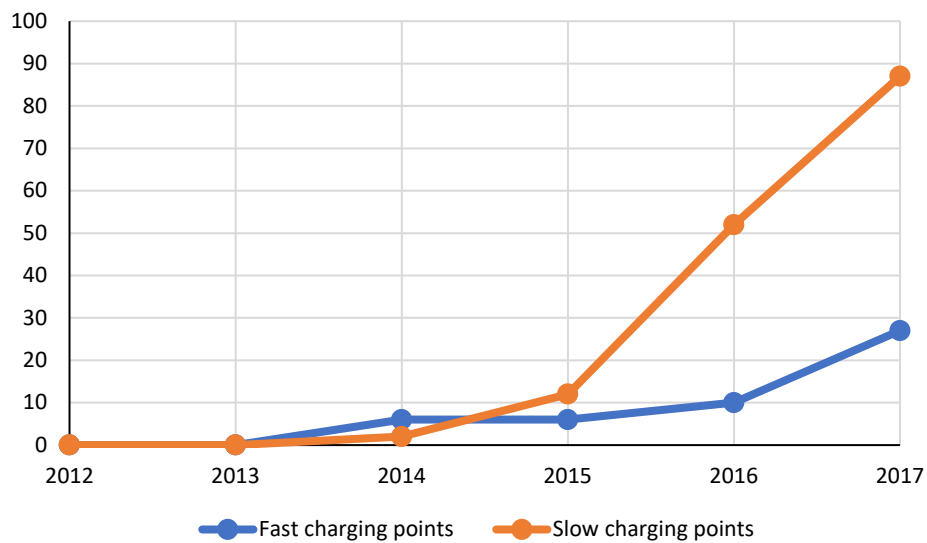
Markets and user practices

In terms of markets and user practice, nearly 70% of the respondents claimed that the high price constitutes the biggest barrier to wide adoption of BEVs. Although BEVs are exempted from the registration tax and VAT, respondents still complained that “the initial capital cost is too high”. Some respondents stated “BEVs are too expensive now. People are waiting until BEVs get cheaper.” This criticism is also consistent with previous studies, which claimed that price is the crucial purchase criteria for BEVs (Schuitema *et al.*, 2013; Bockarjova and Steg, 2014) and the high cost of BEVs diminishes the interests in BEVs (Burgess *et al.*, 2013; Fontainhas *et al.*, 2016; Sovacool *et al.*, 2019).

More than half of the interviewees hold the opinion that many people in Iceland are still not familiar with BEVs. The BEV as a technological innovation did not receive much attention from the Icelandic citizens. The interviewees stated that “People do not know much of BEVs”. Not surprisingly, it affects the attitudes towards BEVs and the purchase decision. The research finding was supported by Wood and Moreau (2006) who reported that consumer expectation of a technological innovation plays a key role in adoption of innovations and has an important influence on the purchase decisions. Some studies which explored the barriers of BEV adoption reinforced this research finding (Neubauer and Wood, 2014; Rezvani *et al.*, 2015; Sovacool *et al.*, 2019). For example, Egbue and Long (2012) explored the consumer attitudes and perceptions of BEV adoption, and drew the conclusion that the lack of knowledge of BEVs was a major barrier for the acceptance of BEVs.

Fuel Infrastructure

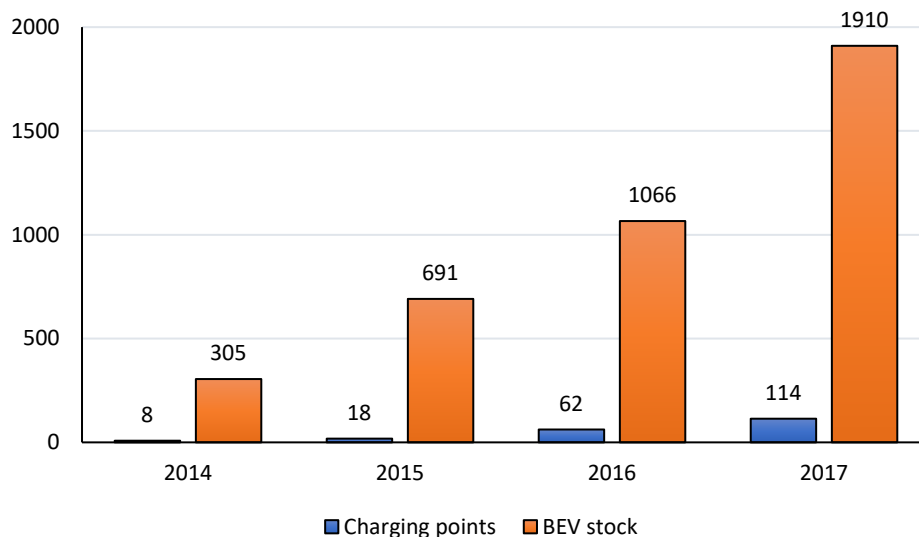
With regard to the fuel infrastructure component, the shortage of charging points is regarded as the main social barriers to BEV adoption in Iceland. The importance of charging points has been highlighted in many studies, which emphasised that establishing easily accessible charging infrastructure extends the travel range of BEVs, reduces range anxiety, and consequently accelerates the adoption of BEVs (Carley *et al.*, 2013; Jensen *et al.*, 2013; Steinhilber *et al.*, 2013; Newman *et al.*, 2014). Nonetheless, there were no publicly accessible charging points in Iceland before 2014. In 2016, there were twenty charging points built in Reykjavik and four charging points in Akureyri. Approximately 60% of respondent agreed that lack of charging points would remarkably diminish consumers’ interests in BEVs. Some suggested that “If we have more charging stations, people will buy more and more electric cars.” Some claimed that “Government should put charging station around the country.” The shortage of charging points severely hinders the wide acceptance of BEVs.



Source: IEA (2018)

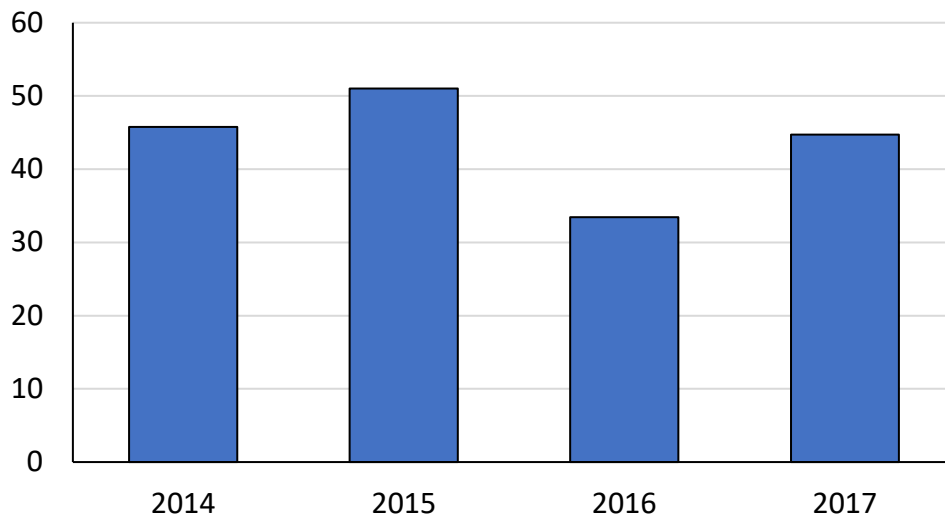
Figure 3: Number of fast charging points and slow charging points in Iceland from 2012 to 2017

From 2017, Iceland government started to increase the investment in building charging points. By the end of 2017, 114 charging points were constructed in Iceland with 27 fast charging points and 87 slow charging points (Fig. 3), which doubled BEV sales to 1910 in 2017 from 1099 in 2016. Fig. 4 shows the number of charging points and BEV stock in Iceland, which indicates that the BEV stock grows with the increase of charging points. However, the ratio of vehicles to charging point is still very low in Iceland with one charge point for 45 vehicles (Fig. 5), so more charging points are urgently needed to pursuit the BEVs' widespread market penetration and diffusion.



Source: IEA (2018)

Figure 4: Charging points and BEV stock in Iceland from 2014 to 2017



Source: IEA (2018)

Figure 5: Number of electric vehicles per charging point from 2014 to 2017

The availability of charging stations and BEVs have a mutual dependence and benefit each other (symbiosis). Such bilateral interaction modes may lead to bootstrapping bottlenecks due to a synchronous growth requirement. In this case, the intense coordination of different actors and policy interventions are crucial to solve the classic chicken or egg dilemma: build charging infrastructure to attract BEV users, or push BEV diffusion to incentivize charging? However, compared to the interdependence between petrol stations and ICEVs, the intensity of dependence of BEVs on charging stations is relatively weaker, since the BEVs can be charged at home where the existing electricity grid can be used.

Road infrastructure and traffic system

According to our interview results, the main social barrier related to the road infrastructure and traffic system is the road condition, which is largely attributed to low population density, widespread urban centre around Reykjavik, and complex topographic features in Iceland. Iceland has a population of 338, 349 and an area of 103,000 km² (Statistics Iceland, 2017). 99% of the inhabitants live in the urban areas, and the Capital Region has 65% of the total population with an area of 200 km² (Statistics Iceland, 2017). Another major town, Akureyri, is located in the northern Iceland. The inhabited areas are on the coastline, mainly in the southwest, whereas the central highland is cold and filled with sands, mountains, and lava fields, which shapes the specific road systems in Iceland. Nearly half of the respondents claimed that “The road is good in Reykjavik. If you go 200 km more north, you start to see the road getting narrower and narrower. They use pavement instead of asphalt in the roads. They use cheaper construction materials on the roads and therefore make the lines for the car to follow missing”. Others stated that “We have very good roads in this area here (Reykjavik), and here maybe (Akureyri), but in the rest of the country the roads are not very good. They are not good at all.”

The poor road condition hampers the adoption of BEVs in two ways. Firstly, the BEVs have to be equipped with durable tires, effective vehicle motion controls, and robust brake to guarantee the vehicle stability and reliability in the events of driving emergency, such as heavy braking, obstacle avoidance, and wheel slip (Sakai *et al.*, 1999; Fujimoto *et al.*, 2004; Tabbache *et al.*, 2011; Geamanu

et al., 2011; Nam *et al.*, 2012). Secondly, the low-quality road condition and traffic cognition increases the energy consumption and operation cost of BEVs (Shankar and Marco, 2013).

Table 6: Social barriers of BEV adoption on regime level

Barrier Type	Barrier factor	Illustrative quotes	N	Key references
Policy	Lack of policy incentives	We lack leadership, and proper incentivized authority to do the roll out. There isn't enough business incentive for it to roll out in this current state. There has to be more incentive for the business to really push forward.	10	Mazur <i>et al.</i> , 2015; Dijk <i>et al.</i> , 2016; Figenbaum, 2017.
	Policy uncertainty	It's politically so hard to stimulate the BEV adoption. This is not a real long-term policy. We had difficulties in standards.	7	Lane and Potter, 2007; Langbroek <i>et al.</i> , 2016.
Markets and User Practices	Price	The BEVs are too expensive now. The initial capital cost is too high. People are waiting until BEVs get cheaper.	20	Burgess <i>et al.</i> , 2013; Schuitema <i>et al.</i> , 2013; Bockarjova and Steg, 2014; Fontainhas <i>et al.</i> , 2016; Sovacool <i>et al.</i> , 2019.
	Lack of knowledge	People do not know much about BEVs. People see the BEVs as plastic toys.	18	Egbue and Long, 2012; Neubauer and Wood, 2014; Rezvani <i>et al.</i> , 2015; Sovacool <i>et al.</i> , 2019.
Fuel infrastructure	Lack of charging stations	If we have more charging stations, people will buy more and more electric cars. Government should put charging station around the country.	17	Carley <i>et al.</i> , 2013; Jensen <i>et al.</i> , 2013; Steinhilber <i>et al.</i> , 2013; Newman <i>et al.</i> , 2014.
Road infrastructure and traffic systems	Poor road conditions	We have very good roads in this area here, and here maybe, but the rest of the country the roads they are not very good. They are not good at all.	14	Sakai <i>et al.</i> , 1999; Fujimoto <i>et al.</i> , 2004; Tabbache <i>et al.</i> , 2011; Geamanu <i>et al.</i> , 2011; Nam <i>et al.</i> , 2012; Shankar and Marco, 2013.
Production system and industry structure	Lack of BEV model choices	Iceland has no power on manufacture. Iceland doesn't produce vehicles, so we are really dependent on the car manufacture, in other car producing countries.	13	Mazur <i>et al.</i> , 2015; Lang and Mohnen, 2019.
Culture and symbolic meaning	Automobility culture	We are so used to having 4 by 4 cars. Is it a 4x4 types of BEVs? Only few of the electric cars. People feel safer in a 4x4. Sometimes, the town is a bit hilly. You know, you have the slopes, the cars can slide and all that. So, people feel safer.	3	Urry, 2007; Wells and Xenias, 2015; Sovacool and Axsen, 2018.

N: number of respondents

Production system and industry structure

Regarding production systems and industry structure, a main barrier is insufficient BEV model types. Without domestic automobile industry, Iceland can only import cars and is not able to tailor the BEV models to satisfy the Icelandic citizens' needs. One of the interviewees who is from Icelandic Transport Authority explained that "Iceland has no power on manufacture. Iceland doesn't produce vehicles, so we are really dependent on the car manufactures in other car producing countries."

Another barrier against BEV adoption is relevant to car dealers and car rental companies in Iceland, a barrier deemed common across the Nordic region (Zarazua *et al.* 2018). In the recent years, BEVs in Iceland are expanding their share of the market gradually, but Iceland offers the fewest model choices among the Nordic countries (IEA, 2018). Nowadays, car buyers in Iceland suffered from supply delays and limited model availability. For example, the 2017 model of the Nissan Leaf was not available. The Hyundai Ionic arrived later compared to other markets (IEA, 2018). The interview

results further confirmed the shortage of BEV supply and limited model choices. One interviewee who is a car dealer stated that “The car dealers, importers of the cars such as BMW, Nissan, Volkswagen, didn’t really want electric cars on the road. They didn’t. There really wasn’t any interest. We had to be the first ones to import the Leaf, the Renault, the Kia, everything.”

Adding to momentum against BEVs in Iceland, rental cars account for 9% of the total car stock (Icelandic Transport Authority, 2017), but the car rental companies were not interested in BEVs, either. The respondents told the researchers that “The car rentals are not buying a lot of electricity cars, because the tourists don’t want to take it. When you come to Iceland and rent a car, you want to drive up around the country. And then this electricity car is not working. So that’s a problem.” As a result, the car buyers in Iceland have to resort to second-hand electric car markets in other countries (IEA, 2018), or not buy BEVs.

Culture and symbol meaning

According to the respondents, Icelandic citizens have strong preference for “4 × 4” cars, which forms the resistance of accepting other vehicle models in the aspect of mobility culture and use habit. One respondent stated that “We are so used to having 4 by 4 cars. Is it a 4 by 4 type of BEVs? Only few of the electric cars.” Another respondent clarified that “People feel safer in a 4 × 4. Sometimes, the town is a bit hilly. You know, you have the slopes. The cars can slide and all that. So, people feel safer.” This strong preference may be linked with Icelandic special geography features, weather, population distribution, and road infrastructure.

4.2.3 Niche level

On the niche level, the main resistance against BEV adoption arises from the technology development level of BEVs. The range anxiety is one of the most-frequently-mentioned social barriers to BEV adoption with 70% response rate (Table 7). One of the respondents said that “Range is probably going to be the heaviest barrier. We live in a big country and we need to have a car that we can drive around the country with our family, and that’s not possible yet. You can only use it here (Reykjavik), in the local area.” Another interviewee stated that “People have range anxiety. They buy a car. They always look at the meter and say that you have these Km left, because you cannot just go to gas station and fill up. It has to charge and takes time. So, people do not feel secure for that.” The research finding was in agreement with many studies which concluded that range anxiety is an important factor to cause resistance to BEVs (Skippon and Garwood, 2011; Franke *et al.*, 2012; Jensen *et al.*, 2013; Noel *et al.*, 2019).

Table 7: Social barriers of BEV adoption on niche level

Barrier Type	Barrier factor	Illustrative quotes	N	Key References
Technology	Range anxiety	Range is probably going to be the heaviest barrier. We live in a big country and we need to have a car that we can drive around the country with our family, and that’s not possible yet. You can only use it here, in the local area.	19	Skippon and Garwood, 2011; Franke <i>et al.</i> , 2012; Jensen <i>et al.</i> , 2013; Noel <i>et al.</i> , 2019.
	Battery performance and durability	People are afraid that the batteries will not last long enough and very costly to get new ones.	14	Daziano and Chiew, 2012; Graham-Rowe <i>et al.</i> , 2012; Bonges <i>et al.</i> , 2016; She <i>et al.</i> , 2017.

N: number of respondents

In addition, 50% of the respondents expressed deep concern about batteries in many respects. They responded that “People are afraid that the batteries will not last long enough and it is also very costly to get new ones.” One interviewee who is from safety and security department was worried about the battery safety issues, saying that “Lithium is quite a dangerous stuff. If you have accident in a lithium car, it is quite difficult to get out. If it contacts water here, it sparks immediately. Probably heard about the iPhone or Samsung 7 where the batteries are exploded.” Furthermore, interviewees mentioned the long charging time of the battery, claiming that “You are not traveling fast, because you have to wait for hours and it will take you 6 or 8 hours to charge. That is a problem. BEVs cannot fill like diesel.” Many studies suggested that battery leads to one of the biggest concern of BEV acceptance, because the battery is the key component influencing the performance, safety, reliability, range, and price of BEVs (Graham-Rowe *et al.*, 2012; Bonges *et al.*, 2016.). The resulting anxiety of battery life, battery safety, and battery charging time are listed in the top three concerns which is the main technological barrier to the expansion of BEV adoption (Daziano and Chiew, 2012; She *et al.*, 2017).

Even though batteries remain a central technology in the electronics sector, batteries are the upstream technology in the value chain of BEVs and constitute unilateral complementarity in the transportation system. The intensity of the dependence is strong since batteries determine the performance and cost of BEVs to a great extent. Such interaction modes tend to result in the “complementarity bottleneck” if the battery technology is not fully developed or not compatible with a broad range of electric vehicles.

4.3 Suggestions on accelerating the BEV transition in Iceland

Table 8: Policy suggestions for accelerating the BEV transition in Iceland

Regime level	Suggested Actions	Suggested Actors	Illustrative quotes	N
Tax policy	Tax and duties reduction.	Central government.	Keeping the price low, keeping the taxes on BEVs low.	14
Phase out fossil fuels	Increase the price of gasoline cars and fossil fuel.	Central government.	The government should put high taxes on gasoline cars, really high. The key is fuel prices are so low at the moment. I think if the fuel prices rise in next coming years, we will have more electrical cars on the roads.	4
Take charge of infrastructure development	Build new charging points for BEVs	Central government, local government public sectors, private sectors.	The governments have to make the infrastructure for charging the cars better. I think that it has to do with the municipalities. It is not only the central government, but also local government to make access to charging better.	12
Change user norms and preferences	Demonstrations and test fleets	Local government, private sectors.	The municipality for example just bought a e-Golf, just to show the example. Explain how you use the BEV, get people on board.	7
Reforming car markets	Import more BEV models	Central government, local government, private sectors.	I am very optimistic for Iceland. We only need more types and cheaper BEVs.	3
Niche level				
Nurture new production-consumption modes	Introduce new business model	Local government, public sectors, private sectors.	They could have some type of buyback programs that the government of course could do and probably should do.	3

N: number of respondents

In this section, the interviewees' suggestions on accelerating BEV transition are discussed to overcome the social barriers of BEV adoption in Icelandic context (see Table 8). On the regime level, five suggestions are proposed:

- (1) Firstly, the interviewees suggested the government to propose the tax exemption policy specific to BEVs, which is crucial to reduce the price gap between BEVs and ICEVs. A respondent said that "Keeping the price low, keeping the taxes on BEVs low".
- (2) (2) Some interviewees advised the government to raise the import duties on both ICEVs and fossil fuel, saying that "The government should put high taxes on gasoline cars, really high"; and "The key is fuel prices are so low at the moment. I think if the fuel prices rise in next coming years, we will have more electrical cars on the roads."
- (3) The third suggestion is to accelerate infrastructure development, especially, to build new charging points to improve the fuel infrastructure. The actors involved in include central government, local government, public sectors, and private sectors. The interviewees suggested that "The governments have to make the infrastructure for charging the cars better. I think that it has to do with the municipalities. It is not only the central government, but also local government to make access to charging better. Energy companies and oil companies should build the charging points, too". With more charging points in the future, the range anxiety could be alleviated, and the interviewees will be more likely to adopt BEVs as they said that "More money and more support in investing in the infrastructure and places where you can charge your BEVs will help expand BEVs around Iceland."
- (4) User norms and cognition of BEVs can be reshaped via demonstrations and test fleets. The actors should be local government and private sectors. There are several ways to enhance the public knowledge of BEVs and eliminate the bias of BEVs. For example, the local government and companies may increase procurement of BEVs as demonstration. What's more, the government should release some stimulation policies to encourage car rental companies to offer more BEV model types.
- (5) The car market should be reformed by importing more BEV models. The actors include central government, local government and private sectors. As discussed in 4.2.2, BEV models are very limited in the Icelandic market. Some interviewees suggested that the government put forward incentive policies to encourage the car dealers to import BEVs with longer range which match the Icelandic citizens' vehicle preference and automobile culture. One interviewee stated that "I am very optimistic for Iceland. We only need more types and cheaper BEVs."

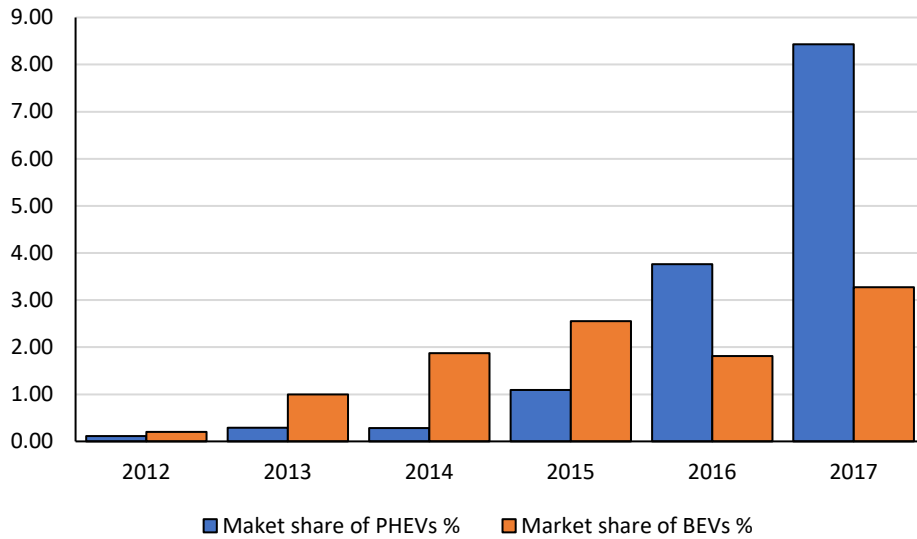
On the niche level, interviewees expected the local government, public sectors, and private sectors to nurture new production-consumption model by introducing new business models. The interviewees gave the suggestions that "They could have some type of buyback programs that the government of course could do and probably should do." They explained that the buyback programs could turn over the existing vehicle stock, which reduces the number of old gasoline cars and increases the ownership of BEVs.

Some of the suggestions have been turned into actions now. For example, recently, the Icelandic state and public utilities decided to construct 200 new BEV charging stations to Iceland by 2020 (STAFF, 2017). Both fast charging stations and regular charging stations will be added to major urban areas

and the most popular tourist destinations. The fast charging stations have already started to be installed at Geysir geothermal area. Blue Lagoon will shorten the full charging time of one car to less than 30 minutes.

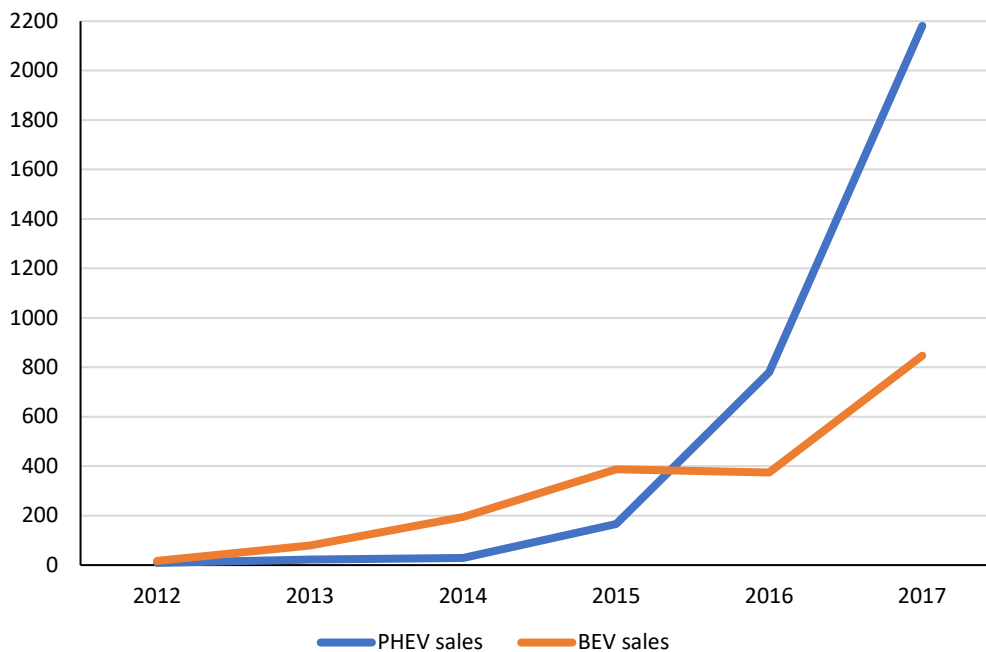
5. The competition and co-evolution of BEVs and PHEVs

The interaction between BEVs and PHEVs is one important driver of the social-technical transition of sustainable mobility in Iceland. In the material dimension, BEVs and PHEVs are competing each other, not only for the upstream resources such as the electricity and infrastructure but also the downstream market and applications. As shown in Fig. 6 and Fig. 7, although both PHEVs and BEVs were increasing in past years, the number and market share of the PHEVs was growing faster and exceeded the BEVs in 2016. In 2017, the market share of PHEVs is four times more than that of BEVs, implying that the features of PHEV better match consumer preference and user habit, for example, large off-road capacity.



Source: IEA (2018)

Figure 6: Market share (%) of PHEVs and BEVs in Iceland from 2012 to 2017



Source: EAFO (2018), IEA (2018)

Figure 7: PHEV and BEV sales in Iceland from 2012 to 2017

Nonetheless, PHEV and BEVs are not fully competitors. They can be complementary to each other (symbiosis). They both attempt to fulfil the same societal function in transportation sector, that is, to provide a sustainable mobility option with lower emission than ICEVs. More importantly, they share the brand or concept of “electric vehicles” and benefit from the same policy support mechanisms. For example, In Iceland, an average ICEV will be charged a registration tax at the rate of 15% and a value-added tax (VAT) at the rate of 24%. Cars emitting less than 80g CO₂/km have been exempted from the registration tax since 2010 (IEA, 2018) and the VAT. In addition, cars with less than 121g CO₂/km emission are exempted from the annual circulation tax about ISK 4 200 (roughly €30), a minor incentive to be sure but one that recurs every year. The CO₂ emissions (g/km) of a Volkswagen e-Golf (BEV) and Volkswagen Golf GTE (PHEV) are zero and 36 g CO₂/km, respectively. Therefore, they both benefit from the registration tax and VAT exemption policy. Furthermore, both BEVs and PHEVs have two hours free parking in the city centre of Reykjavik and Akureyri in Iceland (Bilastaedasjodur, 2017).

In terms of interaction dynamism, both technologies are currently in the early stages of development compared to incumbent technologies (ICEVs). The current registration tax and VAT exemption policy for low-emission cars are only in effect to 2020, so electricity vehicle users, car renters, vendors, and other advocates may have motivation to join force to have a favourable policy that is longer term. However, as BEVs mature, their common interest may weaken and competition will come into play rather than alignment.

Indeed, the modes of interaction between BEVs and PHEVs might even be more complicated after other technologies are involved simultaneously. Firstly, a salient advantage of PHEVs over BEVs is that PHEVs can parasitise on ICEVs due to their overlap in terms of some upstream elements such as oil, reliance on (known) petrol stations, and more conventional drivetrains. On the other hand, there are similar parasitism relationship between BEVs and PHEVs because BEVs can benefit from

PHEVs by sharing core elements including clean energy generation, batteries, policy, and learning processes. As a consequence, PHEVs will likely act as a bridging technology between BEVs and ICEVs, and change their interaction modes from competition to parasitism.

Secondly, batteries are complementary to BEVs and PHEVs, but with different intensities. For BEVs, batteries are critical components without no substitute while for PHEVs batteries are beneficial but not necessary at the same scope or intensity of usage. At the early years of technology development, the advancement of batteries will stimulate the growth of both BEVs and PHEVs. When the batteries mature to a satisfactory level, however, BEVs may retain much more momentum so that the PHEVs are hindered. Hence, the interaction mode between batteries and PHEVs are not stable and may shift from complementarity to amensalism.

Thirdly, the introduction of V2G, BEVs and PHEVs are not only interacting within the transportation sector, but also complementing and competing against each other in energy sector because of the potential use of the batteries as storage technology. Therefore, the evolution and the selection of the two technologies have large dependence on the both transportation and energy and electricity systems. In the transportation sector, PHEVs have historically outperformed BEVs in Iceland due to perceived advantages in driving range and reliability. Nonetheless, BEVs seem to be more preferable from the perspective of energy or electricity suppliers because of their larger capacity batteries. With the slow maturing of V2G, the position of BEVs in the energy sector could become further strengthened (Noel *et al.*, 2019; Després *et al.*, 2017) and the support of energy sector will exert more considerable influence.

Interestingly, the ongoing PHEV and BEV transition in Iceland meets the criteria for affecting all four types of complementarities suggested by Markard and Hoffmann (2016). *Technological complementarities* arise if other technologies positively affect the focal technology. Technological complementarities occur, for example, PV power plants and batteries, or natural gas vehicles and filling stations. Here, in our case we see the obvious technical coupling of automobiles with batteries as well as distributed generation at the residential scale as V2G emerges in practice. *Organizational complementarities* occur if particular types of organizational assets, competences or services positively affect the focal technology. Here, our case reveals the potential future intersection of business models focused on electricity supply or peak demand but also grid services and transmission operation as well as mobility as a service and developments in business models for charging as well as ridesharing. *Institutional complementarities* occur if specific institutional structures positively affect the focal technology. Here we can see a convergence of institutional support, and common narratives, backing PHEVs, BEVs and V2G in Iceland for reasons of energy security and resilience (government agencies and politicians), but also jobs and growth (industry), decarbonisation (environmental groups and some government agencies), and affordability (consumer groups) (Sovacool *et al.*, 2019). *Infrastructure complementarities* occur if there are generic elements that generate positive effects for a broad range of technologies, including the focal technology. Here we see the connection of electric utility power supply, independent power supply as well as renewable energy provision, car dealers, franchises, and service stations installing charging infrastructure (Zarazua, 2019; Zarazua *et al.*, 2020).

6. Potential BEV transition pathways in Iceland

In order to investigate how viable the BEVs are as a solution to promote or even converge low-carbon renewable sources in Iceland, we provide analysis from the perspective of the typology of transition pathways. Based on different forms of interactions between the landscape, regimes, and niches, Geels and Schot (2007) identified the following types of transition pathways:

- Reproduction (P0): Without the impact of external landscape pressure, the regime remains stable and the technological innovation is hidden or confined to shallow niches.
- Transformation (P1): The landscape imposes moderate pressure on regime but the innovation in the niche is not sufficiently developed. In response to the pressure, the existing regime makes adjustments by incorporating some new technologies from the niche.
- De-alignment and re-alignment (P2): The large and sudden pressure from the landscape destabilizes the existing regime. At the same time, multiple innovations emerge in niche form. After a period of competition between different niche technologies (what we term here “inter-niche competition”), the one which becomes dominant breaks out of the niche.
- Technological substitution (P3): Sudden and disruptive change occurs in the landscape at a moment when the novelty in niche is fully developed. Then the existing regime is replaced by its niche.
- Reconfiguration (P4): Similar to the transformation pathway, the landscape pressure is moderate and the niche’s novelty is not fully developed. The main difference with transformation pathway is that the initial adoption of innovation from niches trigger a sequence of further adjustments in regime and eventually leads to reconfiguration of the basic architecture of the regime.

When applied to our case study, in the landscape level, the abundant renewable power and low electricity prices in Iceland provide ideal conditions for BEV development. Meanwhile, the heavy dependence on imported fossil fuel in transport sector has aroused wide concern. Most of the respondents in our interview stressed that BEV can bring significant social benefits of environmental friendliness and energy security. Thus, the landscape put pressure on the established regime and created opening for BEVs to break out of niches. Nevertheless, compared to the sudden or “avalanche” change that is commonly found in technological substitution pathway (P3), the magnitude of current landscape pressure is still moderate and growing slowly, due to the lack of effective policy stimulation. The requirement of policy interventions in different contexts is highlighted to steer a radical innovations transition (Smith *et al.*, 2005; Smith, 2007; Genus and Coles, 2008). The different types of national policy changes on the landscape level affect actors on the regime level and niche level, which forms and shapes different transition pathways of BEV adoption in Iceland. However, it is not easy for the policy makers to determine which sustainable mobility technology to support, so the current policy incentives do not differentiate between BEVs and other low-emission vehicles. For example, both BEV and PHEV are exempted from the VAT tax and benefit from two hours free parking in the city centre of Reykjavik and Akureyri in Iceland (Bilastaedasjodur, 2017).

Although some efforts have been made, the existing regime elements are still unfavourable to BEVs, such as shortage of charging points, poor road conditions, and insufficiency of BEV models. The

regime actors, including the consumers, car renters, and car dealers, are not active in BEV adoption, as uncovered in our interview. The linkage of the regime elements and the co-ordination of the regime actors laid the stable foundation for the established regime, which poses great challenges to the diffusion of novel mobility technologies. For instance, the car renters and dealers are not keen on holding a variety of BEV models, so many consumers may not buy BEVs due to lack of model choices, which in turn reduces the wiliness of car dealer and car renters to import more BEVs. Such chicken-egg problems can only be overcome with the coevolution of multiple levels. On the other hand, some tension and internal destabilization also appears, creating the “windows of opportunities” for BEVs. For example, the public has realized the enormous advantages of BEVs over ICEVs in increasing renewable energy utilization, reducing fossil fuel consumption, and low operation cost. Additionally, without the domestic car industries, an important regime actor in the mobility regime in many other countries, Iceland has more flexibilities to transit to new mobility technology smoothly.

On the niche level, the BEV technologies have shown great potential but have not matured to a satisfactory level. In our interview, the respondents expressed concerns about batteries, and argued that BEVs mismatch their preference and use habit. Our interview also reveals that the current niche is also affected by landscape. A notable finding is that the advantage of V2G that was regarded in other countries as a pace-setting technology of reducing cost of using BEVs is thought to be negligible in Iceland. This can be ascribed to the influence of landscape elements in Iceland, such as plentiful renewable energy, low electricity price, and fixed electricity rate. Furthermore, BEVs also face the competition with PHEVs, whose sales have exceeded BEVs in 2016. The complex interaction modes of BEVs and PHEVs have significant influence on the technology diffusion. On account of the technology level and the influence of the landscape, BEVs are still stuck in the niche despite a “tension” in regime has appeared.

In summary, the current mobility regime in Iceland is dynamically stable but perpetually subject to the moderate pressure of the landscape and to the perturbation of internal tensions caused by evolving niches. BEVs have not (yet) fully developed and are competing with PHEVs. Hence, we infer that if an appropriate policy can be put forward and BEV technology makes great advances, then BEVs are likely to break through the transition barrier by following the de-alignment and re-alignment pathway (P2). Otherwise, the PHEVs, which serve as an “add-on” technology and form some sort of symbiosis with conventional vehicles, may hold the potential to diffuse into the current regime and trigger the reconfiguration of the established regime (P4). We also find that the evolution of BEVs and PHEVs rely on the technologies not only within the transportation sector but also in other social-technical systems, for instance the energy sector, the electricity sector, and the electronics sector, due to their intense interaction with multiple battery types and configurations.

7. Conclusion

This paper investigated the transition process of BEVs, PHEVs, and to a degree V2G applications in Iceland, by drawing on 29 qualitative interviews with experts in various areas. By applying the Multi-Level Perspective (MLP) framework, the socio-technical benefits and barriers were identified and discussed across the landscape level, regime level, and niche level, respectively. The interaction and competition of BEVs with other technologies, in particular PHEVs, was examined within the conceptual framework of multi-mode interaction as well as insights from transitions studies about technological, organizational, institutional, and infrastructural complementarities. The potential transition pathway of sustainable mobility in Iceland was furthermore analysed with the social-technical transition theory based on the MLP.

The most frequently mentioned social benefits of BEV adoption were environment friendliness and energy security. These two benefits are particularly important to Iceland since its renewable energy is plentiful but the transport sector heavily relies on imported fossil fuels. The barriers which hamper the transition of BEVs such as range or charging availability were not only associated with technology but also the integration of various societal elements, making them to a degree “societally embedded” (Kanger *et al.*, 2019). The coordination of the regime actors constitutes a lock-in mechanism of stabilizing the established regime of automobility. Thus, the government or industry needs to play a key role in stimulating the future pace and directionality of a BEV transition. To do so, any effective policy or strategic interventions should be introduced across the landscape, regime, and niche levels, an admittedly arduous task.

Moreover, to “loosen up” the linkage of the current regime elements, our study identifies numerous policy options and strategies, such as improving charging infrastructures, changing user norms and preferences, reforming car markets and marketing strategies (especially among dealers and rental car companies), and nurturing new production-consumption modes. We conclude that while a sustainable mobility transition in Iceland is ongoing, the transition process may follow either a de-alignment and re-alignment pathway (P2) or a reconfiguration pathway (P4). Which pathway it takes will depend not only on the types of policy interventions, but also the future improvement of multiple technologies and their interaction modes, that is, it will be shaped strongly by inter-niche competition. **Nevertheless**, that electric mobility pathways can thrive in climates as remote, harsh, and cold as Iceland is telling, even if they remain conditioned on selection pressures across regimes and landscapes extending well beyond the country.

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Appendix A. Institutions interviewed for the study

Atvinnuvega- og nýsköpunarráðuneytið (Ministry of Industries and Innovation)

Bílgreinasambandið (BSG, Automotive Association)

BL Ltd. (Car dealer)

EFLA verkfræðistofa (EFLA Engineering Company)
 Félag íslenskra bifreiðaeigenda (The Icelandic Automobility Association)
 HEKLA (Car Rental Company)
 Holdur Car Rental Iceland
 HS ORKA (HS Energy)
 Íslensk NýOrka (Icelandic New Energy Ltd)
 Landsnet (Transmission system operator of Icelandic high-voltage power grid)
 Landsvirkjun (National Power Company of Iceland)
 LOTA Consulting (safety and security)
 Metan Ltd.
 Northern Lights Energy
 ON Power
 Orkustofnun (National Energy Authority)
 Rarik (Iceland State Electricity)
 Samgönguráðuneytið (Icelandic Transport Authority)
 SORPA árangur umhverfismalum (Waste Environmental Performance)
 The Nordic Council of Ministers (Iceland)
 Umhverfis- og auðlindaráðuneytið (Ministry for the Environment and Natural Resources)
 Umhverfis- og mannvirkjaráð (Environment and Construction Department of Akureyri)
 University of Akureyri
 University of Iceland
 Veitur Utilities PLC
 VISTORKA (Green funnel-energy from the kitchen)
 Volcanic Capital

Appendix B. Codes used for thematic analysis of semi-structured interviews

Overarching themes	Higher-order categories	Cluster codes
Social benefits	Environmentally friendly	Environmentally friendly
		Climate change
		CO2 emission reduction
		Greenhouse gas reduction
		Improve air quality
		Less air pollution
	Energy security	Energy security
		Fuel consumption reduction
		Do not import fuel
	Low operating cost	Significant savings
		Cheap energy
		Cheap electricity

		Saves on petrol
	Pleasant driving experience	NA
	Positive health impacts	NA
	Less maintenance	No maintenance of BEVs
	Quieter operation	Noise benefits
	V2G	I get some money It is beneficial for the car
Social barriers	Lack of policy incentives	Need more incentives
		Lack of leadership
		Not enough of incentives
	Policy Uncertainty	No long-term policy
		Difficulties in standards
		It is politically so hard
	Weather	Cold
		Bad weather
		Snow
		Weather is terrible
	Price	Too expensive
		It is driven by the price
		The initial capital cost is high
		The whole upfront cost problem
	Lack of knowledge	People do not know much about EVs
		People are a little bit afraid of the EVs
		It need to proof the technology is working
		How EV has worked out
	Lack of charging stations	Need more charging points
		No charging points
		Government should put charging stations
		Need charging stations around the country
	Poor road conditions	Roads get narrow
		Rocks on roads
		The roads are not very good
	Lack of BEV model choices	Iceland has no power on manufacture
		Dealers do not choose EVs
		Car rentals are not buying EVs
	Automobility culture	People invest heavily in fossil fuel solutions
		We are so used to having an 4x4
		Feel more safe in a 4x4
	Range anxiety	Range is the heaviest barrier
We need drive around the country		
It can only use in the local area		
We need more, longer range		
The distance		
Our daughter lives in Akureyri, it is not able to drive there by one charge		
The range is not acceptable		
Driving range		
Battery performance and durability	People are afraid of the battery	
	Battery will not last long enough	
	Very costly to get new battery	
	Lithium is quit dangerous	
	Batteries are exploded	
		Price incentive schemes

Suggestions on accelerating BEV transition	Incentives	Tax reduction
		Reduce taxes
		No import tax for EVs
		Lower import tariffs
		Duties reduction
	Phase out fossil fuels	Increase the price of gasoline cars
		Increase the price of fossil fuel
		Put high taxes on gasoline cars
	Take charge of infrastructure development	Build new charging points for BEVs
		Build up infrastructure for EV
		Need more charging stations
		Better roads
		Rapid chargers all around the country
	Change user norms and preferences	Demonstrations
		Have green company cars
		Government buys EVs
		Explain how to use EVs
		Have test fleets
		Show on the TV
		Education
Reforming car markets	Import more BEV models	
	Car rentals buy more BEVs	
	Government creates the demand	
Nurture new production-consumption modes	Introduce new business model	
	Buyback programme	