The Electric Vehicles Ecosystem Model: Construct, Analysis and Identification of Key Challenges

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This paper builds a conceptual model of electric vehicles' (EV) ecosystem and value chain build-up. Based on the literature, the research distinguishes the most critical challenges that are on the way of mobility systems' electrification. Consumers still have some questions that call for answers before they are ready to adopt EVs. With regard to technical aspects, some challenges are coming from vehicles, charging infrastructure, battery technology, and standardization. The use of battery in EVs will bring in additional environmental challenges, coming from the battery life cycle for used battery, the manufacturing, and from some materials used and treated in the manufacturing process. The policy aspects include mostly taxation strategies. For most part, established market conditions are still lacking and there are a number of unresolved challenges on both supply and demand side of the EV market.

Key Words: electric vehicles, ecosystem, mobility, policy, environment
JEL Classification: L22, L62, O18, Q01, R41

Introduction and Scope

A vast number of studies on electric vehicles (EVs) have been issued up to date and the reasons for this are obvious, as the movement towards electrification of mobility is gaining strength as part of greening the transportation systems. This paper introduces a conceptual model of the EV ecosystem – the relevant stakeholders and actors – and identifies the key challenges of EV market penetration. EVs have potential to change the nature of the whole vehicle manufacturing business and the ecosystem around current fuel-powered vehicles (cf. Petrie 2012). EVs use one or more electric motors as their power sources either directly powered from external power station, or powered by an on-board electrical generator. EVs include plug-in electric cars, hybrid electric cars, hydrogen vehicles, electric trains, electric lorries, and electric motorcycles/scooters.

Many countries are considering what electrification of their mobility system in fact means. Furthermore, these countries are not completely aware of their current industrial structure and how EV industry will complement the existing industry architecture. EV industry needs an ecosystem that is able to deliver necessary technologies, services and processes that facilitate EVs to penetrate the market. The ecosystem consists of both public and private actors, but the ex-ante presumption is that private actors are more dominant in the making of EV ecosystem works. Tax and energy policies are not the least of these issues, but are consciously framed outside the analysis. In addition, trade policy issues remain visible in the background context.

The policy of the European Union has been to promote electrification of the mobility system, although the related directive on the promotion of clean and energy-efficient road transport vehicles leaves much room for member states to apply (European Commission 2009). A particular emphasis is put on public procurement of vehicles, which puts weight on public transport vehicles, e. g. buses or some other vehicle fleets in public service. On taxation or other promoting measures, the directive speaks only little, and stays only on promotional level. If the policies are to be efficient, specific and targeted measures need to be taken in order to make EVs more lucrative for both consumers and producers.

This paper draws from the existing body of literature some of the key challenges on the way of electric mobility. The structuring of the challenges summarizes existing research and points out whether the challenges are mainly arising from the market, policy or business, or whether they have more of a technical or societal (environmental) nature. Literature base and systems modelling are used as research approaches to main research questions that are stated as follows:

1. What are the key challenges of EVs' wider acceptance by the market and consumers and how these challenges can be categorized?

2. What is the current electric vehicle ecosystem (or cluster) looking like and how do the main challenges relate to the ecosystem?
3. Can we identify prospective development paths that would pave the way for EVs and speed up the electrification of the mobility system?

In order to answer the above research questions, the study focuses on the ecosystem level view that comprises set of companies or industries with their functions, roles, and dynamics. Firm level analysis is excluded as it would require higher resolution focus on firms' business models. The research process was divided into four steps:

1. Reviewing and clustering of the literature and disaggregating the clustered themes into major challenges regarding EV markets based on the researchers' perception derived from the literature.
2. Identification of relevant actors and stakeholders and constructing a generic EV ecosystem description.
3. Reflecting the major (but disaggregated) challenges against generic electric vehicles ecosystem (EVE) and 'mapping' the challenges in the EVE architecture.
4. Concluding and presenting some of the relevant steps to overcome the identified and mapped challenges.

Methodologically, reviewing of the literature and extracting the relevant key challenges that are on the way of mobility systems' electrification and building visual representative models can be regarded as heuristic modelling of the phenomenon (EV ecosystem), i. e. problem solving or increasing the understanding of the problem (Frigg and Hartmann 2012). The tree-like hierarchy of challenges built around clusters (i. e. themes) are a logical continuation of this method. The devising of the ecosystem description is constructive research by nature. We construct the ecosystem model in order to scale-down complex reality. In some countries, the ecosystem model finds empirical objects that correspond to the elements of the construct, but in some countries, the ecosystems are undeveloped or unconscious of the needed actions to be taken. Thus the research process consists of exploratory part (literature review) and constructive parts, which are partly heuristic (modelling of ecosystem and challenges) and partly empirical (ecosystem description and analytics).

The authors gathered literature on EV from year 2009 onwards. The catch was about 50 articles altogether published in peer-reviewed journals or other well-established references, from which the authors selected the prominent ones. The key selection criteria were (i) good quality journals, (ii) preference for holistic rather than focused theme and/or approach, (iii) exclusion of explicitly vehicle technology-focused material.

After the initial phase of the literature review, the source material was clustered in four main categories of research: (1) consumer aspirations and preferences, (2) EV policy deployment, (3) business models in EV ecosystem, (4) environmental issues associated with EVs. After reviewing the references, the authors mapped conceptually the key challenges that seem to be posing on wide-scale deployment and market penetration of EVs. For the ecosystem description, a typical systems analysis and system modelling was adopted. One can refer to 'a model,' 'architecture' or 'a design,' but in essence, the result is a visual illustration of the EV ecosystem stakeholders and how they build the value chain for EV market. We call this the EVE (Electric Vehicles Ecosystem) model. The model is also a morphological approach in order to give shape and structure to a complex socio-technical system (Ritchey 2002).

The work was performed as part of Finland's EVs national test site programme that comprises several small-scale test sites in different parts of the country (see http://www.tekes.fi).

Literature Brief

WHAT ARE (BUSINESS) ECOSYSTEMS?

Business ecosystems address business opportunities that require a diverse set of capabilities to meet customer needs that are beyond the capability of any single company (Carbone 2009). Compared to a single company, a business ecosystem can invest more resources and tolerate higher risk through cost sharing, integrate broader set of diversified capabilities and develop broader set of products (Iansiti and Levien 2004). Business ecosystems work for incorporating the next round of innovations by (Moore 1993) bringing synergies of different companies and public actors together towards a common innovation. The ecosystem perspective emphasises actors' co-evolving relationships and dynamic nature of business networks (Hearn and Pace 2006). There is a shared fate of the involved actors and need to understand organization's own role in the ecosystem. The most relevant and strong actors or stakeholders could have three alternative roles within the ecosystems: *a keystone* who improves overall health of the ecosystem, *a classic dominator* who leaves little opportunity for emergence of a meaningful ecosystem, or *a value dominator* who captures most value for itself leaving a starved and unstable ecosystem around it (Iansiti and Levien 2004). Actors' competitive and cooperative interactions advance the ecosystem coming up with new offerings and satisfying customer needs (Moore 1993). Thus, actors in a co-evolutionary relationship activate selective pressure towards others and influence consequently each other's evolution (Corallo 2007). In an ideal ecosystem, actors share resources, knowledge and technologies across the ecosystem providing basis for holistic value creation via the ecosystem (Hearn and Pace 2006). Each organisation adds its distinct aspects of offering to the value generated by the ecosystem and share the total value created by the ecosystem (Camarinha-Matos et al. 2009). Productivity of the ecosystems can be measured by networks' ability to consistently lower costs and launch new products.

In emerging ecosystems, such as the EV ecosystem, central companies typically focus on working together with essential stakeholders, such as lead customers, key suppliers and channels, to: (1) define new customer value propositions based on innovation; (2) determine how to deliver and implement the customer value propositions; and (3) design business that serves the potential market (Moore 1993). EV ecosystem has been competing against fuel-powered vehicle ecosystem for a while without significant global success, and most likely much due to the dominance of key stakeholder, i. e. the vehicle manufacturing industry. For other stakeholders, the market and negotiation power is significantly lower. Thus, the EV ecosystem is not yet providing good enough business cases for the most of the customers and, consequently, cannot capitalize its market potential (e. g. Petrie 2012). The grand challenge of the EV ecosystem in this competition is to change this status quo by creating compelling customer value propositions, which, by itself, facilitate the emergence and growth of thriving global business ecosystem. At next, challenges related to EV ecosystem performance are studied based on the literature to facilitate the EV ecosystem description and analysis.

SELECTED EVS STUDIES AND IDENTIFIED CHALLENGES

A number of studies on consumer views of EVs will cover several aspects i. e. consumer willingness to pay, attitude and behaviour, awareness, and preferences that seem to be crucial to push EVs into the market. Hidrue et al.(2011), Skippon and Garwood (2011), Axsen, Kurani and Burke (2010), Lieven et al. (2011), Zhang, Yu and Zou (2011), and Zulkarnain et al. (2012) have taken part in some studies in term of consumer aspirations and preferences of the EV.

Hidrue et al. (2011) point out that in the US the consumers are concerned with EVs' driving range and vehicles' availability because of the needed charging time. In addition, the consumers seem to be uncertain on the potential fuel savings, which is one of the obvious arguments for EVs. Without subsidies, the battery costs are also considered too high. The same concerns were expressed by the consumers in the UK: driving range, cost savings and charging options (Skippon and Garwood 2011). Axsen, Kurani and Burke (2010) particularly raise the question on battery technology's maturity and whether that meets the consumers' expectations – their results point out these expectations will not be met in the near future at least. In Germany, a study by Lieven et al (2011) concluded that about 5% of the potential consumers would be ready to choose EV as their primary car. Hence, the total volume of the market was not that significant, as the 5% share would be divided by several manufacturers. However, it must be noted that these figures might quickly change over short period. In China, the consumers' awareness of EV options is still limited, as reported by Zhang, Yu and Zou (2011). This indicates that the emerging markets might not be ready for larger scale EV penetration, in particular if the market potential for conventional vehicles is still far from unsaturated and the level of motorization still low. Zulkarnain et al. (2012) point out that the EV industry is in its infancy, but possesses great potential according to market surveys and business intelligence reports. The test sites are already emerging around the globe. Once the market penetration starts to take place seriously, the early actors are in the best competitive position, if they have been able to successfully pilot their own concepts.

Perujo and Ciuffo (2010), Kang and Recker (2009), Camus, Fariau and Esteves (2011), Schill (2011), Hong et al. (2012) and Crist (2012) have studied EV policy needs and options. The charging of EVs will not have any significant effect on annual energy consumption according to Perujo and Ciuffo (2010), but the daily and hourly electricity demand in turn might require some regulation or at least demand-based pricing in order to even out demand peaks. Camus, Farias and Esteves (2011) reached about the same conclusion regarding on-peak and off-peak pricing, as well as did Schill (2011). Peak-time demand will reduce the consumer surplus of EVs from purely economic point of view, either through pricing or increased need of supply capacity. Both, Perujo and Ciuffo (2010) and Camus, Farias and Esteves (2011) point out positive impacts on CO_2 emissions. Despite of possible reduced economic gains due to sharper peak-time demand of electricity and/or demand-based pricing, the public subsidies can still pay-off from the societal perspective. Hong et al (2012) claimed that in South-Korea with 1 trillion won government subsidy to services for grid-to-vehicle would result in almost 2 trillion won of social welfares and additional 2 trillion increased profits for service operators' profits. In their analyses, they included in social welfare: (i) expansion of charging infrastructure, (ii) increase in peak time electricity sales, (iii) fuel cost savings. The last mentioned was actually the most explicit benefit from the macroeconomic viewpoint (as Korea is an importer of oil). They also included externalities (CO, CO_2 and NO_x) but did not price them. The most efficient way of maximizing the social welfare was tax incentives. Crist (2012) analyses the differences between BEVs and internal combustion engine (ICE) vehicles and finds out that under the French tax regime and subsidy system the government revenues over the life cycle of the vehicles are not very far from each other but still favouring ICEs over BEVs. Furthermore, the comparison result is highly dependable on how and where the initial electricity is produced.

Recent studies on EV industry and business are presented by Kley, Lerch and Dallinger (2011), San Roman et al. (2011), and Andersen, Mathews and Rask (2009). Kley, Lerch and Dallinger (2011) identified three sub-ecosystems or components for the EV ecosystem and devised an approximate descriptive model for the ecosystem. San Roman et al (2011) identified two roles or functions in the ecosystem that were needed for efficient market structure, whereas Andersen, Mathews and Rask (2009) showed that EVs could be used as distributed electricity storages when not in use. This in term would call for intelligent electricity grid. The scarcity of this literature is obvious but understandable as so many technical issues remain to be solved and regulated. The ecosystem in itself starts to be visible, even if some new roles or functions could be needed in the future.

Browne, Allen and Leonardi (2011), Thomas (2012), Zackrisson, Avellán and Orlenius (2010), and Lucas, Silva and Neto (2012) have conducted their own research regarding to environmental issues of the EV. At the same when EVs have great potential to reduce CO_2 emissions (Browne, Allen and Leonardi 2011, Thomas 2012), Lucas, Silva and Neto (2012) suggest that EV energy supply infrastructures are more energy consuming than those of conventional vehicles,' when looking at the whole life cycle of infrastructures. Furthermore, the batteries' life cycle analysis is still somewhat open, but more than 50% of the batteries' carbon footprint

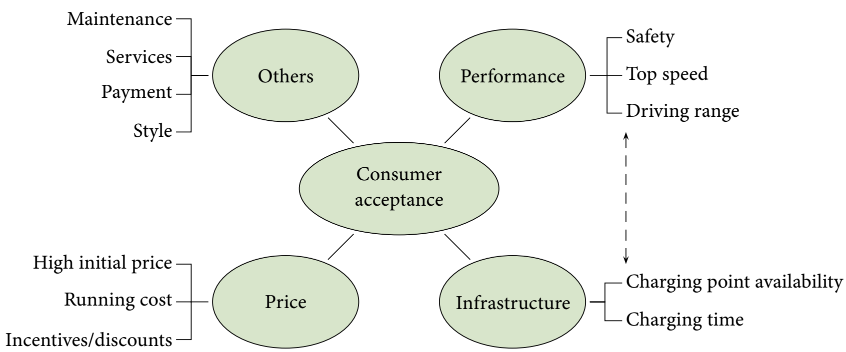

FIGURE 1 Consumer Acceptance Challenges

is generated by their manufacturing (Zackrisson, Avellán and Orlenius 2010). The recycling issues have not been yet thoroughly addressed.

The summary of reviewed literature on EVs is presented in table 1.

Building the Hierarchy of the Challenges

CONSUMER ACCEPTANCE

In this early stage of EVs development, consumer acceptance is one of critical aspects that need to be paid attention. A number of consumer surveys show a promising market for EVs when there is a group of people, called EVs adopters, who have willingness to buy EVs as next generation vehicles. However, some challenges coming from the consumer perspectives are still present. Consumers still have some questions that call for answers before they are ready to adopt EVs. These questions relate to the price, performance, and infrastructure, among others (figure 1).

As to price aspects, the high initial price to buy an electric vehicle still becomes one of the major inhibitors. This is mainly caused by high battery costs – 48% of total price (MEC Intelligence 2011). Moreover, the running cost for the EVs are still uncharted. Incentives provided by governments have been brought forth in several countries, for instances in EU environmental zones (e. g. London, Berlin and Stockholm) that offer attractive incentives for EV drivers such as: free public parking, allowed to use bus lanes, no road taxes and free ferry transport. However, some studies indicated that the government incentives' impact on the adoption of EVs is still relatively low (e. g. Diamond 2009 and Jenn, Azevedo and Ferreira 2013).

Other challenges are coming from EVs' performance, i. e. safety issue,

TABLE 1 Summary of Reviewed Literature on EVS

Consumer and market views to EVS	WTP for EV and their attributes: (1) Driving range, charging time and fuel cost saving; (2) Significantly drop battery cost is required to attain competitive market without subsidy.	Hidrue et al. (2011)	Stated preference, choice experiment, internet based survey
	Responses to battery electric vehicles (BEV): UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. (1) Would consider BEV as a main car if it has 150 miles range and as a second car for 100 miles range; (2) Willing to buy BEV over conventional vehicle for equivalent 3 years running cost saving; (3) Prefer credit/debit card and electricity bill as payment.	Skippon and Garwood (2011)	Direct experience, questionnaire, vignette exercise
	Who will buy electric cars (Germany case study): 5% of total buyer will choose EV as their main car.	Lieven et al. (2011)	Stated preference, online survey
	Market potential is still projected to be significant, but the real growth has not yet taken place; test sites are active around the globe.	Zulkarnain et al. (2012)	Review of market surveys, business intelligence reports and test sites
	Battery technology is not meeting the consumers' expectations concerning the costs, power, longevity and safety.	Axsen, Kurani and Burke (2010)	Consumer survey, analysis on battery technology
	Analysing public awareness and acceptance of alternative fuel vehicles (EV) in China. (1) Factors influencing consumers' purchase willingness: purchase time and purchase price; (2) Limited acquaintance of EVS in China- different influences on consumer behaviour.	Zhang, Yu and Zou (2011)	Questionnaire
EV policy deployment and impacts	Impact of EVS recharging activities on the electric supply system in Milan for 2030 time horizon: (1) In the future, with high market penetration the impact on annual energy consumption will quite negligible; (2) For daily electric power request, appropriate regulation is needed (e. g. smart grid)	Perujo and Ciuffo (2010)	Forecasting and simulation

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TABLE 1 *Continued from the previous page*

	Potential energy profile impact on PHEVs deployment in the US: (1) Circuit upgrades bring faster charging time and less charging time difference between PHEV20 and PHEV60; (2) Home charging and public charging benefits to serve travel distance and mileage conversion to electricity.	Kang and Recker (2009)	Activity-based modelling, simulation
	Impact EVs penetration on load profiles, electricity prices, and emission for scenario 2020 in Portugal: (1) Electricity prices of 20 cents/kWh for high hydro production and peak hours scenario with 2 million EVs, and energy costs of 5.6 cents/kWh for low hydro production and off-peak hour scenario; (2) Up to 10% CO_2 emission reduction are obtained.	Camus, Farias and Esteves (2011)	Simulation
	The effects on price, welfare, and electricity generation: (1) Uncontrolled vehicle recharging could increase evening peak loads and prices; (2) Arbitrage capability of unused battery will smooth electricity price and increase consumer surplus; 3) Increased utilization of generating technologies because of controlled loading of EVs.	Schill (2011)	Game theoretic model
	Comparison of BEVs and ICEs show no great differences in government total revenues when analysed under French tax regime; the life-cycle emissions between BEV and ICE are slightly in favour of BEVs.	Crist (2012)	Socio-economic cost analysis
	Ex-ante evaluation of profitability and government's subsidy policy on V2G system in Korea: (1) The maximum profit for a V2G service provider will be 1.27 trillion Korean won/year with an annual subscription fee of 0.65 million Korean won; (2) The government subsidy of 1 trillion Korean won, given annually, will increase social welfare by 1.94 trillion won and also boost the profit of vehicle-to-grid service provider to 1.98 trillion won.	Hong, Jeong and Lee (2012)	Conjoint analysis and simulation

Business models and regulatory framework	A new business model for electric cars – a holistic approach. Three components were considered: the vehicle including the battery, infrastructure and system services	Kley, Lerch and Dallinger (2011)	Morphological box
	Regulatory framework and business models for charging plug-in EVs: (1) Two new agents: EV charging manager, and EV aggregator were introduced; (2) Main charging modes: home charging, public street, dedicated charging stations; (3) V2G services regulatory framework was also presented.	San Roman et al. (2011)	Constructive approach
	Overview of Electric Recharge Grid Operator (ERGO) business models – intelligent charging grids for EVs: ERGO business models could solve problems of power grid utilization and fluctuating supply, and CO_2 emissions problem, by transforming EVs into distributed storage devices for electricity.	Andersen, Mathews and Rask (2009)	Exploratory
Environmental issues related to EVs	Evaluating the use of an urban consolidation centre and EVs in Central London: (1) Total distance travelled decreases by 20%; (2) CO_2 emissions reduction of 54%.	Browne, Allen and Leonardi (2011)	Trial evaluation
	How green are EVs? At most 25% GHG reduction and less than 67% oil consumption reduction resulted in replacing all vehicles with BEVs or PHEVs.	Thomas (2012)	Argonne National Laboratory GREET model
	Life cycle assessment of Lithium-ion batteries for PHEVs: (1) Energy use in battery manufacturing dominate the global warming impacts (>50%), followed by electronics (30%) and cathode (10%); (2) There will be decreasing production phase environmental impacts due to improvement of recent battery technology.	Zackrisson, Avellán and Orlenius (2010)	ISO 14044 environmental management & the International Environmental Product Declaration EPD® system
	Life cycle analysis of energy supply infrastructure for conventional and EVs: EV supply infrastructures (construction, maintenance, decommissioning) are seen to be more carbon and energetic intensive than conventional vehicles' energy supply infrastructures.	Lucas, Silva and Neto (2012)	Global warming potential and cumulative energy demand calculation; Monte Carlo

top speed limitation, and the driving range. The latter one still becomes key challenge for many consumers especially for those who need long range mobility (see e. g. Franke and Krems 2013). Besides the battery performance, the availability of charging infrastructure is somewhat associated with the driving range performance. If there were more charging points available, this would extend the driving range. Other aspects also exist, such as the top speed limitation and safety issue. However, the challenges do not end here. Long charging time is still considered as the matter by consumers.

Other aspects related to user experience, method of payment (mainly charging), style of vehicle (e. g. design, existentialism) and maintenance services (accessibility, quality, etc.) are likely found too, but these are not on the top list, at least yet.

TECHNICAL ASPECTS: INFRASTRUCTURES

With regard to technical aspects, some challenges are coming from vehicles, charging infrastructure, battery technology, and standardization (figure 2). Vehicles' challenges are in the designing of EVs to meet the consumers' requirements properly. The design deals with the performance, style, etc. that calls for new types of industry value chains compared to the old automotive industry structure. Several new cooperation contexts are needed, e. g. between OEM and battery manufacturers or charging manufacturers, to deliver their products and services. Besides, the impact of EV deployments to the electricity consumption has also been a concern of the stakeholders, i. e. how to manage the distribution of power, especially in peak hour period. Smart grid/intelligent solutions are currently believed to be one of the answers to this challenge. Vehicle-to-Grid (V2G) technologies have been also in development focus, for the same reasons. V2G technologies are enabling EVs to communicate with the smart grid to either delivering electricity into the grid or to throttle back their charging rate.

According to most experts, even if there are challenges concerning infrastructure, the most profound problem or bottle neck for EVs is the battery. This is mostly because of the battery costs. Production costs of electric vehicle today are about 2.5 times higher than of one with combustion engine (Koskue and Talka 2010). Several battery technology challenges must be solved, such as reduction in weight, volume, charging times, dependence on operating temperature, and the use and treatment of toxic components. The latter will pose an issue when disposing the

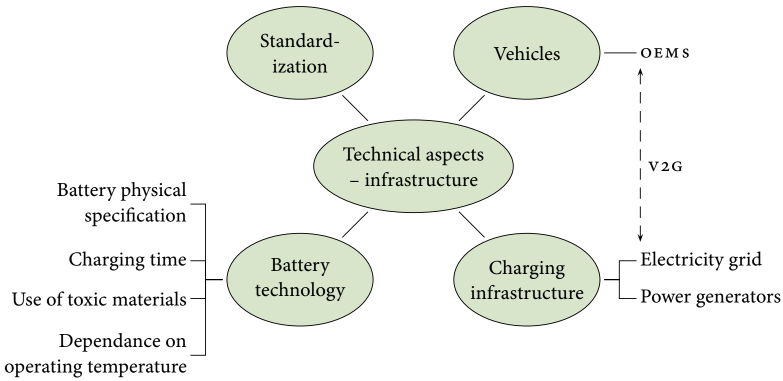

FIGURE 2 Technical Challenges

batteries. The disposal system needs to be established and financed in the end.

Standardization and regulation issues are also imperative. Standards and technical norms have to be created to ensure that the vehicles can be easily connected to the power network in order to recharge the energy storage system. The goal should be of course global standards in order to avoid technological islands to achieve economies of scale. For the EU, these questions are of relevance in order to avoid a fragmented pattern of locally competing and incompatible solutions.

ENVIRONMENTAL CHALLENGES AND POLICY/ REGULATORY ISSUES

Electric vehicles (EVs) are believed to be more environmentally accepted than conventional vehicles and they could reduce the fuel oil dependency. The latter is seen partly as a climate change challenge but also as a trade policy issue. However, a closer examination will bring in other critical questions to be answered, e. g. concerning the battery and power supply infrastructure (figure 3). Environmental aspects are, as said, tightly associated with tax policies and other incentives for wider adoption of EVs. Carbon based taxes have been introduced in many countries across the globe.

The use of battery in EVs will bring in additional environmental challenges, coming from the battery life cycle for used battery, the manufacturing, and from some materials used and treated in the manufacturing process. The disposal system for used batteries needs to be established and financed in the end. Moreover, power supply infrastructure has also

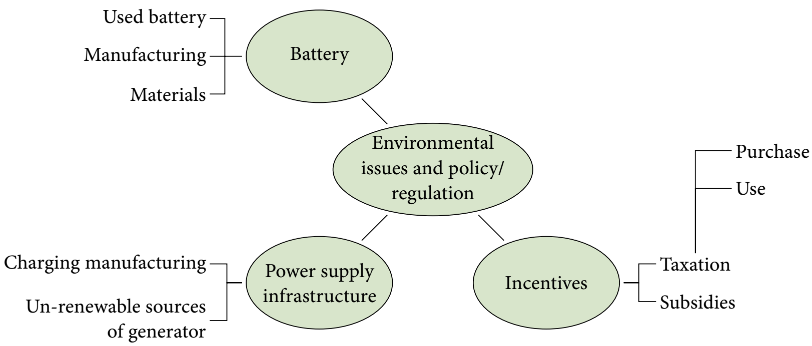

FIGURE 3 Environmental Challenges

potential environmental problems that might be caused by the increasing use of un-renewable sources of electricity generation. If renewable sources for production are used, the problem is solved, however. The last probable challenge is coming from manufacturing of charging infrastructure, though this issue still needs further investigation.

Electric Vehicles Ecosystem (EVE) Model

EV STAKEHOLDERS IDENTIFICATION

Giannoutakis and Li (2011) conducted a stakeholder analysis for Intelligent Transport Systems (ITS). They identified government and policy makers, funding bodies, transport group and organizations, ITS designer and manufacturers, automobile suppliers, key shareholders, energy sector, environmentalists, local authorities and users. This list was applied to large extent to map relevant EVs stakeholders. The EVs ecosystem (EVE) model is constructed by mapping the EVs stakeholders within the ecosystem and defining the relationship among the actors (figure 4). The EVE model includes the following main players:

- EVs end users: the key consumers who use EVs for their mobility. They comprise consumers, corporate customers, and public sector. Customer acceptance challenges apply for the EVs end users and determine the critical success factor for EVs deployment.
- Power utilities and infrastructures (PUI): the EVs-enabler facilities, i. e. charging points, power network providers, electricity producers, fuel suppliers (for hybrid-type of EVs), including their upstream value chain actors.

- EVS manufacturers (EVM): the key motor in EVE that contains EVS manufacturers (OEM), EVS suppliers, component suppliers and their related services providers (e. g. mobility/telematics service providers and EVS rental service providers).
- Battery suppliers (BS): including battery manufacturers, component suppliers, and related R&D. Together with power utilities/infrastructures and EVS manufacturers, they deal with identified technical aspect challenges.
- Regulators and external actors (REA): Policy makers/regulators from any levels of governments, e. g. inter-governmental bodies, regional, member states, municipalities and local authorities; EVS-related industry association, academic research and development, and environmentalists as 'catalysts' for EVS policy deployment.
- EVS aggregators/integrators (EVAI): a system integrator that is proposed to be a key operator for the ecosystem. The integrator can be one of the existing players, an entirely new one or a combination of both (e. g. a joint venture). This new player was introduced by e. g. in San Roman et al. (2011). A real-world corresponding example of this actor was BetterPlace, which after implementing the first modern commercial deployment of the battery swapping model in Israel and Denmark, later filed bankruptcy in Israel (SmartGridToday 2013). The EVS aggregator/integrator is driven by regulators and integrating/coordinating the roles of the main actors in EVE.

The value chains of each main layer include the actors that have a stake in EVE. The value adding flows obviously represent product/service offerings, cash flows (the opposite direction), contractual relationships or some other type of interaction of relevance. This 'multilayer stakeholder mapping' not only shows the ecosystem but also the interactive links between ecosystem stakeholders and the value creation process of the ecosystem. Furthermore, the colouring of the map shows which of the stakeholders are in key position as cornerstones, classic dominators or value dominators. It is not always clear yet how these roles will be in the end and the casting could well change from country to country, or even locally.

EV ECOSYSTEM ANALYSIS

The identified key challenges of electro-mobility system are reflected in EVS ecosystem model (figure 4). The consumers' acceptance challenges

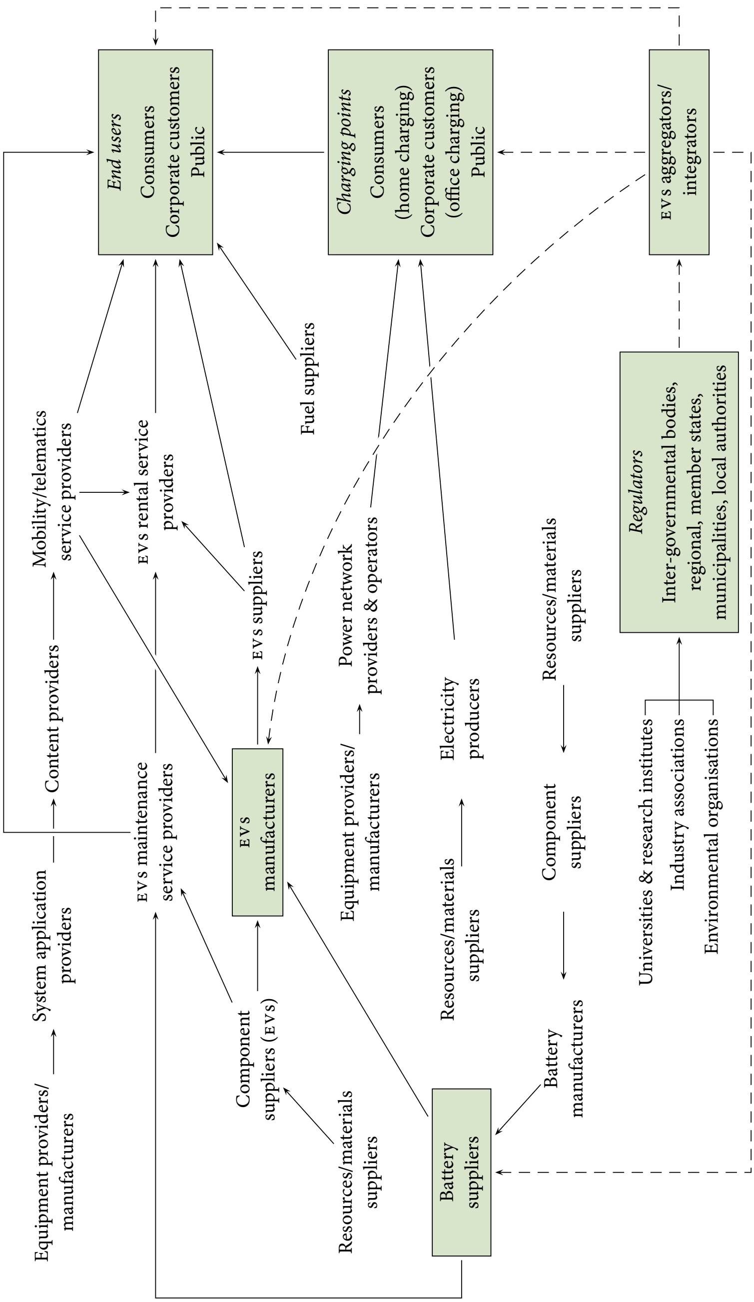

FIGURE 4 Electric Vehicles Ecosystem (EVE) Model (solid – current offerings/actors, dashed – future offerings/actors)

form perhaps the gravest obstacle from the demand side concerning EVs' market penetration. But this demand side challenge is not independent but intertwined with supply side impediments: price, performance, and infrastructure readiness and other related services are considered by the users prior the prospective purchase of an EV. The technical aspect challenges (supply-side as well) concern the EVs manufacturers' ability to meet some of the consumer demands, the battery producers' sustainable, durable and available (e. g. replacing) solutions. The electricity infrastructure providers are clearly in a decisive role as enablers of EVs market penetration and having the power to pull one critical obstacle from the way. How dominant exactly this position is, remains to be seen and depends on policies that pave the way over the critical period of time when demand of electricity for EVs does not yet solve the investment equation for the utilities and power infrastructure companies. All the aforementioned challenges are crucial, but their inter-dependencies will make both business and policy planning an exercise, where very careful pacing is called for. Technology immaturity is the main reason behind the high EVs price, whereas insufficient performance and infrastructure readiness are the factors that concern the customers. For long run, the environmental issues related to the manufacturing process of the vehicles, life-cycle treatment of batteries and the sources of energy need to be tackled as well. Failure to do so will undermine the arguments for EVs, not matter how sound they might appear from the surface. For example, the battery recycle problem and the rising use of fuel for generating electricity are believed to have the opposite effect on decarbonizing targets. The master driver for EVs seems to be the automotive industry, which is not a surprise. They have the cornerstone role without which the ecosystem shall not exist. Two other evident keen actors are the battery suppliers and energy utilities, particularly those who own their networks and not only the production facilities. Battery suppliers seem to fit to the role of value adding dominator, since their technology will to large extent dictate the fate of EVE, but their dominance potential – at least so far – looks restricted. They enter the ecosystem with their technology only unless they come up with innovative service ideas that enable radical expansion of the EVs market. The rest of the actors are undoubtedly contributors to EVE but their dominance potential is minimal.

Both the automotive sector and the utilities have a strategic expansion potential in the value network of EVs and they equally can have dominating roles. Both have prospects to lower customer acceptance challenges. Table 2 highlights the principle B2B dynamics between ecosystem's stakeholders.

It is obvious, that along with the EV manufacturing industry the regulators are in the key position. With the support of the two, the ecosystem can exist, and without it, the ecosystem will die, if emerged at all. The case of BetterPlace serves as a good example. A modern business case of EV aggregator/integrator that had been grown promisingly and believed in by many market analysts, considered as a great innovation on accelerating the EV market acceptance. However, it was the lack of support from the keystone actor in EV ecosystem, the vehicle manufacturers, that was believed to be as the main reason to the bankruptcy of BetterPlace. Apparently, only 950 cars fitted with Better Place's replaceable battery technology were sold since 2012 and the only carmaker to sign on with Better Place was Renault. According to some views (e. g. Lunden 2013), creating a breakthrough technology that relies on industrial-scale overhaul is capital intensive to start with, and further there is the question of critical mass for electric car technology. This could be regarded as a preliminary indication that strengthens our hypothesis – as well as the inevitable observation – on automotive industry's key role.

The integrators, whoever they could be, seem to have a good position to address the technical challenges by being in the centre of the stakeholder group that are facing them. Therefore, a proactive role from their side might have a good boosting effect on EVE's growth and flourishing in business sense. Nevertheless, if they are moving too early and the EV manufacturers are not ready for up-scaling EV business, the manufacturers can easily block these efforts. The more time passes and technologies mature, however, the lesser role the manufacturers could have. In time, the batteries' prices will be falling, more environmental taxes will likely be levied on transport that will favour the mobility system's electrification, and the infrastructures are developed to facilitate EVs on a larger scale. Therefore, and in our opinion, it is in the EV manufacturers' interest to move in fact rapidly towards electrification as they still have most of the strategic advantages on their side.

The new potential actor in the EV ecosystem is mobility services/digital information services provider. This actor provides in-vehicle system services for e. g. information of charging station location, charging status, and payment services for vehicle charging. These features will ease the EV drivers in operating their cars and increase customer convenience. This potential could expand the business ecosystem of EV since it will in-

TABLE 2 EVE Stakeholders' Relationship Matrix

	(1) EV manufacturers (EVM)	(2) Battery suppliers (BS)	(3) Power utilities & infrastructures (PUI)	(4) Regulators & external actors (REA)	(5)EV aggregator/integrator (EVAI)
(1)		EVM provide the main customer base	EVM provide significant new market segment and increased demand	EVM are a subject of regulation, yet with substantial negotiating power	EVM provide the main collaborator for prospective EVAI, but may also through their market power pursue the role of EVAI
(2)	BS provide key technology without which the ecosystem would not exist		BS provide potential new collaborators but also an alternative supply source which can mean competition as well in some situations	BS are a subject of regulation especially when considering the life cycle treatment of batteries	BS could be a valuable collaborator or the two roles could be integrated easily when battery rental business models are considered
(3)	PUI provide technical framework under which EVM must operate and that will frame the market conditions as well	PUI provide also here both the market and technical restrictions which will affect BS		PUI are a subject of regulation but with substantial negotiation power; however, the PUI are not the primary subject of REA	PUI provide also here both the market and technical restrictions which will affect EVAI
(4)	Provide guidelines, regulation and policy framework	Provide guidelines, regulation and policy framework	Provide guidelines, regulation and policy framework		Provide guidelines, regulation and policy framework
(5)	Build B2B contractual relationship with EVM or directly with consumers in the rental schemes; hence they might have either positive or negative impact on EVM and BS, depending on what the latters' strategy is		Build B2B contractual relationship regarding e. g. charging stations	EVAI are a subject of regulation, with no substantial negotiation power unless they are aligned with e. g. PUI; however, EVAI are not likely the primary subject of REA	

volve a number of industries – called ITS (Intelligent Transportation System) industry – that comprises equipment provider, content/application provider, and service provider (see Zulkarnain and Leviäkangas 2012). Furthermore, there are still some other relevant actors that might be considered as part of the EV ecosystem. They are battery recycling companies, vehicle testing services providers, used car dealers, telecommunication service providers, insurance companies and investment/finance institutions. The latter will play any important roles e. g. in the procurement and purchasing of new EVs, loan and leasing, and rental systems. However, to reduce the complexity of the EVE model, we decide to exclude them and their value chain on our existing model.

Conclusion and Policy Implications

The most important issues or challenges regarding the market penetration of the EVS are associated with infrastructure questions (the supply grid), maturity of technologies (EVS and their power sources) and consumer aspirations (mainly price). If one attempts to rank these in the order of necessary appearance, i. e. which of these must be solved first and which are then to follow; the likely vote goes to technology issues. Technologies must still mature to have the right price for EVS so that they provide a viable alternative to consumers. Public innovation policy in terms of research funding for technology developers, be they private or public, is essential. Through public research funding, the scale-up of technological leads is probably swifter. Once this challenge is overcome the demand is likely to boost and create need to develop the infrastructure fast. The latter mentioned will obviously be the next bottleneck.

It is hence the automotive industry that will have to take the necessary first steps, but obviously, government policies that support the development and maturing of these technologies will have a substantial relevance. Tax issues in addition to R&D support are one of the tools for governments. The governments of the countries where the automotive industry is strong have apparently the greatest motivation. In Europe, for example, Germany and France have a clear stake, even though the industries no longer are that tightly connected to particular member states. Globally taken, also US, Japan and South Korea must deal with the issues. Whereas some countries, like Finland, have adopted carbon and emissions based vehicle taxation system, it only brings the purchasing and operating costs of EVS to a more acceptable level, and indeed such policies can have a positive impact on emissions (OECD 2011; OECD 2013). In Finland for example, the Ministry of Transport and Communications lists climate change mitigation as one of its primary policy targets (Liikenne- ja viestintäministeriö 2013). Electrification of the mobility system obviously is one of the key policy action lines of such strategies. The Finnish tax regime for transport is already based on emissions and carbon footprint, but identified necessary additional measures include road user charges and varying means of favouring of low-emission technologies across the modes. However, deploying carbon based tax system also throughout the production chain could actually pose an additional challenge to EVs' market penetration.

Many energy utilities and grid companies are closely associated with public owners. These have the second largest stake in the new ecosystem. EVs penetration has a profound impact on these companies' cash flow projections, and they must be ready when the time comes for EVs to really enter the mobility market. Supporting their efforts to prepare the infrastructure for EVs could be one successful national and pan-national line of policy. The role of governments to stimulate the development of the charging infrastructure could take many forms: tax incentives, investment grants, etc.

Questions that are more general can be raised regarding the true life cycle sustainability of EVs considering both the energy consumption of the whole ecosystem and evident need to treat the used batteries appropriately. The first question is still somewhat unanswered but the first results from scientific references do not give a straight green light to EV ecosystems. The second question is yet to be solved and a part from technical issues, also financed. If the financing of battery disposal is rolled over to battery manufacturers, which is the first obvious option, the price of EVs (including the batteries) will be slightly higher and slow down the penetration. It might be also here where governments' policies can have an impact.

What is obvious from the literature that EVs in operation will significantly reduce carbon releases of road transport and therefore have a positive contribution to climate change mitigation. The whole ecosystem of EVs and life cycle of ecosystem components could, however, have an opposite effect.

The role of integrators is crucial but in the light of our analysis, it seems that new entrants adopting the integrator role may not be successful unless backed up by key stakeholders, and mainly by the vehicle manufacturers. In order to have some control over the market, the EV manufacturers are likely to pursue this integrator role themselves. The situation might change, however, if manufacturers are able to come up with a model that benefits them all. A jointly owned integrator is one of the obvious answers and it remains to be seen whether EV manufacturers are able to join their efforts to mould the ground of EV business in their favour.

The dynamics between the firms within the ecosystem calls for further analysis. Business model compatibility among ecosystem players is obviously a prerequisite to bring synergies and to pave the way towards a common market platform. Since business models are firm-specific as well as industry-specific, a higher resolution research must be conducted.

Hence, the overall picture remains unclear and it is difficult to see an easy solution to the deadlock of inter-depending challenges. What is clear for certain is that technological development should be supported further in order to remove some of the technical obstacles. The continuum of carbon-reducing policies is equally important, but these must have tangible embodiments affecting the prices of EVs and supply of working infrastructures.

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