Comparison of innovation policies for electric vehicle business ecosystems

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Comparison of Innovation Policies for Electric Vehicle Business Ecosystems

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***Abstract*— Shift away from fossil fuel-based transportation is challenging countries to develop strategies for electric vehicle deployment. The transition offers countries also strategic opportunities in growing markets. Policy incentives are commonly used to help sustainability enhancing technologies to succeed in their journey from labs to markets. Electric vehicles are not standalone but require an ecosystem of related products, services and infrastructure and cannot be considered only from the transportation sector point of view. This paper compares electric vehicle innovation policies in four Nordic countries. The results show how different positions in the electric vehicle ecosystem these countries have chosen and how their choices reflect their economies.**

***Index Terms*—Electric vehicle, innovation policy, business ecosystems**

I. INTRODUCTION

The global trend of decarbonizing transportation has lead to rapid diffusion of electric vehicles (EVs). Transition from internal combustion engines to battery EVs is changing the value chains in transportation and electricity industries. It is necessary to consider EVs not only from the transportation sector point of view, but also to analyze the required enablers for EV integration to the power grid so that their integration is done resource efficiently. Transition connects with digitalization, urbanization and other megatrends that are changing the way especially young people think about mobility and different solutions like car sharing and mobility as a service (MaaS) are diffusing.

Innovation policy is defined in [1] to "comprise all combined actions that are taken by public organizations that influence innovation processes". Governments balance between different policy objectives and approaches. For instance, EV policies are framed by environmental policies that are set more globally through the Paris agreement and EU directives. Yet, innovation policies are country-specific and can have economic, environmental or social objectives. The international aspect is important because systemic changes, like diffusion of EVs, require complementarities from many different sectors and technologies that many countries cannot provide by themselves. Especially small countries make strategic decisions on specialization while the transition happens. Literature on technological innovation system (TIS) framework has been criticized for not including cross-country interdependences and differentiation enough [2]. Several previous works [3]–[5] have pointed out the differences between national EV policies, but there is lack of studies that look at the roles counties are taking as a part of an international EV business ecosystem.

The aim of this paper is to fill this gap by exploring the innovation policy instrument options for EV technologies in different phases of their development, and by comparing the innovation policy mixes of EV technologies in four Nordic countries. The paper is structured as follows: in the second chapter, we introduce the theories and policy categorizations related to technological transitions. In the third chapter, we review EV related technologies and their development levels. In fourth and fifth chapters, we look at the results and discuss them from the theoretical perspective.

II. THEORETICAL BACKGROUND

A. *Socio-technical transitions*

The ongoing energy and transportation transitions are often referred to as sustainability transitions. Socio-technical multilevel perspective (MLP) [6] is one way to comprehend the sustainability transitions taking place on many levels of the society. In the socio-technical system, macro level, i.e. the landscape, refers to a broad scale of global trends, politics, international arrangements and actions. Micro level on the other hand hosts new emerging innovation systems that are referred to as niches. TIS research focuses on understanding the niches as the motors of change in the industries [7]. Between the macro and micro level is the meso level where regimes consisting of industries, institutions and incumbent actors hope to maintain their status quo and direct access to resources. Industry transitions take time as transformations in the regimes occur slowly, in most cases stretching over decades, and require sufficient push from both the landscape and the niches to break the path dependencies that restrict the adoption of new technologies and business models.

B. *New product development (NPD) phases*

Product development process is typically divided into several phases starting with an idea generation and ending with commercial rollout of the new product or service. A commonly used NPD model, the stage-gate model [8] includes pre-NPD, R&D, demonstration and commercialization stages. The pre-NPD phase ends with a decision to either allocate resources and start the R&D phase or to kill the project. Most projects end up in the "valley of death" [9] due to absence of resources for further development. At the end of the R&D stage the product or service is released to testing and demonstration that can take place with external stakeholders e.g. lead users and partners. Finally, the product or service is rolled-out commercially and its diffusion begins.

EV sales are growing, but the EVs still face several barriers and lack broad scale consumer acceptance. Some of the main challenges for EV diffusion include: high purchase price (compared to ICE vehicles), portfolio of choices, charging infrastructure, limited driving range, concerns over battery life and uncertainty of resale markets. It is widely recognized that policy support is important for environmental innovations [10] as investment decisions are required while there is still a high level of uncertainty on the returns.

C. *Policies and policy instruments*

Policies that support the development and the diffusion of electric mobility come from multiple straits of policy, for example, taxation policy, energy and climate policy, transportation policy and industrial policy. Policy mechanisms can be categorized as command-and-control, economic and soft instruments [11]. The command-and-control policies are mandates, laws or regulations such as intellectual property rights. The economic incentives are efficient boosting diffusion through lowering the investment threshold in new technologies through e.g. R&D subsidies, support for venture and seed capital, tax exemptions, purchase subsidies or grants. Furthermore, the soft instruments include information and education campaigns that improve public awareness and acceptance of new technology. They include also voluntary approaches on standardization, codes of conduct and public-private partnerships.

Innovation policies can be also divided into technology-push and demand-pull instruments. These polices are targeted at the different stages of development. Technology-push policies can directly lower the threshold to invest in R&D and the demand-pull policies can prepare and develop the market for the new technologies [12]. Technology-push instruments, such as R&D subsidies, can be used to ensure that there are sufficient resources for developing relevant products, services and infrastructure. On the demand-pull side, subsidies for demonstrations can help testing and validation of new concepts. Similarly, policy support focusing on economic incentives for diffusion is essential in the commercialization stage. In the case of EVs, different technologies and concepts are in different phases of their maturity. Thus, a balanced policy approach consisting of both the technology-push and demand-pull policies covering different stages is needed in order to ensure that the e-mobility as a system is supported effectively [1].

D. *Business ecosystem perspective on innovation policy*

Recent literature on innovation policies highlights systemic nature of technological changes meaning that such changes happen on different system levels. Business ecosystem approach is a common, yet also criticized, approach to study systemic changes [13]. They can be defined in multiple ways. For example, Moore [14] defines business ecosystem as: "an economic community supported by a foundation of interacting organizations and individuals." Innovation ecosystems can be considered as national innovation systems in which innovations are brought to market as collective effort by different stakeholders that find synergies from working together [15]. Another relevant type of business ecosystem is the digital ecosystem, in which the digital platforms combine the economy (business ecosystem) and the digital representation of economy (digital ecosystem) [16].

EVs offer a suitable example of a complex ecosystem of actors, products, services and infrastructure. EV business ecosystem involves multiple stakeholders involved in developing products, infrastructure and technologies such as the vehicles, their batteries, charging infrastructure and solutions, data analytics, and applications and services. Each of them has a role in the ecosystem and missing one of them may produce a bottleneck for its technological evolution as a whole [17]. Also, seizing value creation opportunities opens other new opportunities [18]. When EVs are considered as part of the broader energy system as flexible energy resources, the number of relevant stakeholders, technologies and infrastructure expands to smart grid technologies, like smart homes, smart meters and monitoring technologies.

III. EV BUSINESS ECOSYSTEM TECHNOLOGIES

A. *Electric vehicles*

The amount and variety of different EV (full EVs and plug-in hybrid EVs) models on the market have grown hugely in recent years. Almost all car manufacturers have launched different kinds of EVs on the market. The global proportional (e.g. in percentages) increase in EV sales has been very high for many years and the cumulative sales of EVs between 2010–2016 was about 2 million units [19]. This kind of development seems to be continuing, although there are still many barriers ahead of the wide scale EV adoption. One of the most important is the high purchasing price of the EV, at least without any subsidies.

B. *Battery technology*

Battery technology progresses mostly as an evolution and not revolution. The volume of battery technology related research is significant, but most of the innovations are such that they are not mature enough to be commercialized in many years. The latest "revolution" in secondary (rechargeable) battery technology was made in 1991 when Sony brought lithium-ion (Li-ion) batteries to the market. Today, Li-ion technology is the choice of almost all EV manufacturers in the world, and with a very high probability, this technology stays as the dominant choice also in the near future. Slight improvements in Li-ion battery technology are expected to happen every year in terms of energy content or input/output power per mass or volume (Wh/kg, Wh/l, W/kg, W/l), lifetime, safety and production costs.

C. *Smart meters and home energy management systems*

Measuring flows of electrical energy, but also carrying out intentional changes in the energy flows is a very important part of future smart electricity grids. When network customer participates to different flexibility markets with her/his (controllable) loads, electricity production and energy storages (like EVs), different market actors have to have a good knowledge on the consumption. The measurement and control actions can be made with different pieces of technology in the customer sites. In addition to energy flow measurement, some smart meters can also carry out some load control actions with a help of two-way communication system.

Home energy management systems (HEMS) are partly a competitor for smart meters in a sense that also HEMS measure energy flows, but the focus of HEMS is typically in controlling and managing the local energy resources at the customer site. It seems that in many cases, lack of standardization and insufficient market rules are an obstacle for active market participation of small electricity consumers. However, there is a growing number of HEMS producers in the market, and the field is constantly developing.

D. *ICT-based services*

Different ICT applications, including smart meters and HEMS, but also GPS tracking and smartphone data, play a key role in value creation in e-mobility. Processed information include locations of charging stations, EVs being parked, required parking times, delay-tolerant reservations with traffic information, arrival times and energy prices. These are used for smart charging and vehicle-to-grid (V2G) systems, billing, route planners and charger sharing. These systems are increasingly used also for renewable energy (RE) storing and secondary energy market services [20]. These services have great influence in EV integration to the energy system and their role increases as the regulation develops and EVs and fast charging diffuse. ICT-based services are further developed in fleet management and mobility services like MaaS.

E. *Smart charging, V2G and V2H*

There are basically three ways to use EVs to support the electrical energy system: “smart charging” (EV as a controllable load in a demand response scheme), EV energy storage as a domestic back-up power (Vehicle-to-home – V2H) and EV energy storage as a power source for the public power system (V2G). Most of the pilot projects, like [21], are realized in practice using the DC charging interface of the EV. This means, that in order to run V2H or V2G applications, an expensive DC charging/discharging station is needed. Another approach is to the include energy storage network connection equipment in the car, but this would require remarkable paradigm shift from the EV manufacturers. In power system related EV applications, the development is needed in many areas like EV network interface technology, service models etc., and in all of these areas, continuous development is made.

IV. EV INNOVATION POLICY FRAMEWORK

A. *Method and data*

The innovation policy mixes are studied through a comparative case study. The Nordic countries Finland, Sweden, Denmark and Norway were chosen as case countries for several reasons. On one hand, they have many things in common, e.g. by forming a common energy market. On the other hand, they have different energy mixes and transportation policies. Even though all of them are highly developed societies, their industries and economies are built in different ways. Denmark is small and service-oriented economy that lies between Nordic and German energy markets. Finland is sparsely populated small open economy, which is dependent on its exporting industries like ICT and forestry. Sweden has traditional industrial actors like Volvo and Scania who act also in EV field. It has relatively non-carbon electricity mix based on nuclear and RE. Norway has been a frontrunner in EV adoption for a longer time and has nearly 100% RE-based electricity mix, which has supported electrification of heating and metal industries.

Norwegian research projects were sought from Research Council’s database [22], Finnish projects from Business Finland’s database [23], Swedish projects from VINNOVA’s database [24] and Danish from enegiforskning.dk’s database [25]. Databanks include variety or projects and for that reason, the criteria for picking R&D projects were relation to EV technologies and budgets of over one million euros. Search worlds used were “electric vehicle” and the local translation for it.

B. *Results*

Results (see Table 1) show that the countries have similarities but also differences in their EV policies. They are heading towards the same direction as smart grid technologies are being adopted in the whole region. EU regulation has a large role in harmonizing the policies and Norway follows many of the directives, as it is part of the EEA and the Nordic energy market. Sweden and Finland are the frontrunners in smart meter adoption and now Norway and Denmark are adopting them too. On the other hand, Denmark is the only one that has adopted a central data hub for energy data management but others are currently planning or building theirs. All countries have public procurement projects with different successes. Extensive list of procurements under way would require city-level consultation, which was not done.

Differences exist on many levels. On the demand side, Denmark has very high electricity prices, of which it actually offers reductions for EV charging. High share of fixed costs in the electricity price is hindering also dynamic pricing contracts. Norway stands out for its strong EV adoption, usage and charging infrastructure incentives. Finland has developed the furthest its demand response regulation and is testing V2G technology. V2G is developed the furthest in Denmark, which also emphasizes smart grid related research especially in the EU context. Finland has invested in its battery manufacturing R&D and aims to operate in the whole battery value chain. Sweden has emphasis in electrification of trucks and electric roads but also car controls and safety.

V. DICUSSION AND CONCLUSIONS

The usual categorization of technology-push and demand-pull instruments can be applied to EV policies (see Figure 1). The technology-push policies used for less mature technologies like V2G are more related to issues of the energy system itself. Demand-pull policies creating the markets are answers to customers' issues like costs and range anxiety. There should be a balance between these policies and recognition that customers are more interested in personal rather than system's benefits. Norway's policy can be seen as merely environmental than industrial policy. Despite its strong demand-pull policies, it has not specialized in a certain part of the ecosystem. Its energy mix and relatively strong grid have reduced the urgency for complementary solutions and technologies. Finland aims to increase exports in EV business to 2 billion by 2020 and to be the "leading operator" and "game changer" in global intelligent energy systems [26]. It has good market conditions but further demand-pull policies could sharpen its role in service provision since now its policies are concentrated on first NPD phases. Sweden aims to become fossil fuel independent in transportation and currently it has policy mix covering the whole NPD process [27]. Its policy is steered by electrification of heavy transport, which will continue its efforts in trucks' charging solutions. Denmark's activity in smart grid projects and standardization can be partly explained by its role in wind energy and as a bridge from Nordic and central-European markets. Although it has clear strategy to enhance grid integration of EVs through V2G and other smart solutions, it has lacked steady policies on the market level.

In general, countries want to support domestic industries instead of foreign ones [5]. This can be interpreted as a

TABLE 1. EV INNOVATION POLICIES IN THE NORDIC COUNTRIES

		Denmark	**Finland**	**Norway**	**Sweden**
Energy Market	*Aggregation w/o balance resp.*[28]	In discussion. FCR-D piloted in Parker project.	Business models being piloted. Possible in FCR-D	No role for independent aggregators.	Role of Balance Service Provider to be introduced.
	Retail kWh price [29]	0,305 €/kWh; 67% is taxes and levies.	0,158 €/kWh; residential kW-tariff introduced	0,164 €/kWh; kW-tariff planned for 2019	0,194 €/kWh; kW-tariff if fuse is > 80A
	Reading Interval. EC proposed 15min	1 h, 15 min in new ones	1 h, 5-15 min resolution expected	1 h, 15 min supported	1 h, 15 min in new ones
Infra	*Public funding for fast / slow chargers* [4]	- Tax exemptions, cheaper charging - Many fast charger EU projects.	- € 4,8 m for 2017-19 for smart charging, half for fast chargers. - €10m for 2011-15.	- € 2,1m for housing associations in 2018 - ~€7m for fast chargers on highway €10m in 2010-14	- €8,8m for home chargers annually in 2018-20 - 50% Klimatklivet aids on fast charger
	Fast charger deployment [30]	468 fast chargers; 350 kW planned	-241 fast chargers	- 2058 fast chargers	-2370 fast chargers
	SG projects and investments (% for e-mob) 2004→[31]	- 50 R&D, 131 demo projects - €270m (~10 %)	- 24 R&D, 31 demo projects - €100m (~12 %)	- 22 R&D, 64 demo projects - €110m (~10 %)	- 37 R&D, 53 demo projects - €170m (~6 %)
Data	*Databub*	Centralised (ready)	Centralised (2020)	Centralised (2019)	Centralised (Q4 2020)
	Smart meter rollout	by 2020	100 %	by 2019 (10)	100% 2nd round starting
Services	*V2G projects (public funding)*	- Edison (€6,5 m), - Nikola (€2 m), - Parker (€2,0 m) - ACES (€0,75 m) [25]	-V2G charging point in Suvilahti. (my SMARTLife EU project)	- Demo planned (Evenstad)	
Product	*Deployment target*[4]	No official target.	250 000 EVs by 2030.	All new cars, vans and busses ZEVs by 2025.	No official target.
	EV subsidies [4]	Tax reductions, reduced charging costs.	Rebate, tax reductions, scrapping bonus.	VAT, registration and ownership tax reductions. Free tolls and ferries.	Tax reductions, subsidies, company car reductions.
	Public procurement targets [30]	85% of government vehicles ZEVs by 2015. Only e-busses in Copenhagen by 2031	33% of busses electric by 2025 in Helsinki.	85% of government vehicles zero emission by 2015.	Gov. vehicles environmentally friendly. 20% subsidy for e-busses.
	BEV -buses [32]	2	16	18	24
	BEVs+PHEV in total Market -% [30]	9 436 + 1 429 = 10 865 BEV 0,2%, PHEV 0,3 %	1 357 + 5 601= 6 958 BEV 0,3%, PHEV 3,7 %	119 978 + 63 786 = 183764 BEV 22,3%, PHEV 19,7 %	12 739 + 40 366 = 53 105 BEV 1,0%, PHEV 6,2 %
Technology	*EV related R&D projects*	- Batnostic, 2016-18 ; battery life span research - ReLiable, 2012-16 - Lithium air batteries	- EVE; 2011-15, Winter operability, IT, electric busses and machinery - Green Mining, 2011-16 - Batteries from Finland; 2018 →	- DOVRE 2017-2019 and other projects on combining silicon in lithium ion batteries - Cineldi, 2016-24 Smart grids and EV grid integration	- FFI program [33] - Electric road pilots in Gävle and Stockholm - GreenChargeSydost 2011-15 - DriveSweden, 2015→; Batteries, EV controls, safety, software, trucks

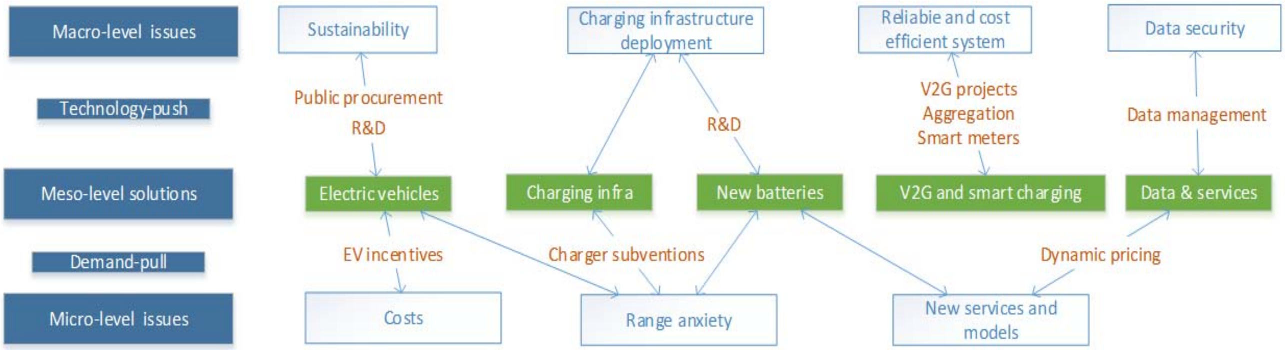

Figure 1. Innovation policies influencing macro and micro level issues in the EV business ecosystem

challenge or opportunity. Sweden, Denmark and Finland have had challenges in creating a clear strategy and vision for their EV policies. In Norway, the strategic path has been easier to create, which can be explained by low opposition by incumbents. Scania and Volvo have had an influence on Sweden's policies and biofuels as an alternative fuel in Finland. In general, governments of the Nordic countries have been courageous in supporting systemic innovations like V2G, battery swapping, electric roads and MaaS services. Partly this is because of the incumbents but also for desire for being the early mover and Doing, Using and Interacting (DUI) – innovation policy mode. All of these solutions are still in very early phase and achieving the dominant design cannot be reached without demonstrations. Even though the demonstrations do not lead to wider deployments, the solutions may provide answers for pilots in other contexts. As a whole, the Nordic area forms a comprehensive ecosystem in e-mobility with expertise on EVs, batteries, trucks, smart grid solutions and services and relatively good market structures to implement these technologies. There are further opportunities for co-operation between the countries, which will be enabled by harmonizing regulatory frameworks.

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