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A Public Policy Strategies for Electric Vehicles and for Vehicle to Grid Power

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Abstract

Abstract: The paper aims is to define the possible efficient action of a public policy toward Electric Vehicles (EV) and Vehicle-to-Grid (V2G) development. We will start our paper by a discussion on the market failures appealing for a public intervention in the EV and V2G activities. We then address four main dimensions of a coordinated public policy toward the development of an EV industry: 1) mitigate the currently high purchase price; 2) define a standard for infrastructure equipment, 3) facilitate development of grid services businesses, which will both improve the electric system and make EVs more economically competitive, and 4) define and initiate R&D programs to advance key EV components that still require research and development for successful EV introduction. In this paper, we will investigate current barriers to widespread EV deployment, review the state of art of public policies toward these problems, then we propose some remedies for each of the identified problems and advocate integrated public action to address these problems.

Keywords: Electric Vehicles; Vehicle to Grid; Automotive public policy.

1- Why policy toward EV and V2G?

All market failures are combined to hinder the development of the EV industry; EV and V2G activities are pledged by absence of provision of public good, by difficult positive and negative externalities management, by a possible war standard between different companies in the early development of the industry and finally, by the presence of learning-by-doing dynamics. The presence of these multiple problems has driven governments to develop EV policies to overcome these market failures after multiple try and errors in this industry in the 70th and in the 90th (Kloess 2011). Society has multiple common interests in the success of EVs. They provide a partial solution to protecting collective public goods like local public health (via reduced urban air pollution), reducing CO2 emissions and thus helping to stabilize climate, providing domestic supply of transport fuel, thus increasing energy security and independence from oil price fluctuations.

We also need to plan ahead into the era of EVs, to prepare for future problems and opportunities related to the electric power system. For example, large fractions of EVs could overload electric generation (regionally) or electric distribution systems (locally). On the other hand, EV fleets could be managed to provide decentralized storage of electricity, benefiting management of the electric system and offering another revenue stream to EV drivers. The potential interactions between an electric vehicle fleet and the power grid often referred to as "Vehicle to grid power" or V2G (Kempton and Tomić 2005a, 2005b) are complex and involve diverse industries with different market and regulatory environments. This suggests that common action may be helpful in setting standards, regulatory frameworks, and common understandings of problems and potential solutions.

More broadly, as electric cars become a significant fraction of the fleet, and if they are implemented along with an intelligent vehicle-to-grid system, would lead the whole electricity system to undergo an important paradigm change. Up to now, the electricity system is considered as temporally constrained, because electricity cannot be stored economically, thus the amount of storage available is very limited. Operationally, the lack of storage requires that generation must strictly equal electrical demand, also called load, in real time and at all times. The need for matching generation and load becomes more challenging as variable generation (e.g. wind and solar power) increase to represent a larger fraction of the electric generation mix. Thus, large-scale EV introduction, or even just 10% EVs, along with the possibility of charging and discharging these cars in an intelligent way, will facilitate real-time management and greatly reduce the short-term need to precisely balance generation with load. A recent simulation of variable generation as 30%, 90%, and 99.9% of a regional transmission system shows that storage in EVs can make even 90% and more variable generation manageable (Budischak et al 2013, also see Lund and Kempton 2008).

Welfare economics suggest that an environmental tax reflecting the value of the marginal damage will provide incentives to achieve optimal levels of technology substitution and development of clean power transport equipment. However, adopting such tax is difficult for three main reasons: First, no firm consensus has yet been reached regarding the marginal damage of pollution and greenhouse gas emissions, so the proposed tax amount must be a judgment call based on a range of damage estimates. Second, a high level of tax is likely to be problematic in terms of public/political acceptability. Third, as any new technology, EV technologies meet classical entry barriers, yet eco-taxation may not be sufficient to overcome these barriers. From the public economics perspective, policy instruments designed to promote EV and V2G development can therefore be justified because the market under-supplies EV relative to the socially optimal one, due to the existence of such barriers. But for policies involving expenditures (see Table 1, below) government has also to control the cost of EV policies. If subsidies are greater than the cost to provide the service, there may be redistributive effects of EV developers' surplus, which would constitute a windfall gain for the industry. Given that EVs are still expensive, and that EV demand does not seem excessive as of this writing (end of 2012), and given that at least one study suggests that the US EV purchase subsidy is about right to bridge the gap between cost to produce and willingness to pay (Hidrue et al 2011), this may not currently be a problem. However, if subsidies go to manufacturers who do not lower prices, or if subsidies become more than needed to sustain an initial market, that would be an industry windfall paid directly by the taxpayers through higher taxes or reduction of other public activities. Some part of windfall gain could be reallocated in a socially efficient way, for example by further investment in R&D by developers, yet there is no guarantee that this will strictly happen. A legitimate concern for the public authority therefore is to ensure that the burden on taxpayers is efficiently set.

We believe that policy intervention should take place in more than one dimension: here we propose four dimensions that to us seem complementary and necessary to foster the development of an EV industry. We discuses these policies briefly here, and in more detail in the article itself.

The first type of intervention discussed here is the direct action toward the cost of acquisition of the EV. Today, the acquisition of a highway capable EV at a price between 35-45,000 €, with 35kWh battery and 150 km range is much more than the cost of the equivalent thermal car (Lemoine et al. 2008). The private consumers willingness to pay is enough for a small market, but not high enough to create a large market at today's prices (Hidrue, et al. 2011). Lithium-ion battery technology is currently the single largest contribution to higher EV vehicles prices. Since the cost of Lithium-ion vehicle-class batteries are projected to drop by 50% over the next 7 years (Galves 2011), battery cost may not be a long-term cost barrier but only a current barrier to introduction.

The second dimension of policy concerns the definition of EV technical standards, since these have an impact on charging strategies, which in turn affect both the car's usability for transport, and the electric distribution network's functionality to reliably supply electricity. Uncoordinated build out due to standards wars, often lead to waste of private resources (winner take all situation). This can be resolved if a common standard is developed that meet the multiple parties' requirements.

The third policy dimension is related to the evolution of the grid rules, regulations and remunerations that are traditionally paid to a power plant or centralized electricity storage facilities. EVs and decentralized batteries can be a great help for the real-time management of electric networks by providing electric services such as capacity guaranty, frequency regulation services, spinning reserves, storage to smooth variable generation, and in the long run may be peak load shaving capabilities. Finally, the fourth dimension of public policy is the management of R&D effort in the pre-commercial phase. We will treat these four dimensions in the following sections.

2- Policies for electric vehicle purchasing

2.1. Relative cost of electric and petrol drive trains

The limited driving range of EVs, combined with slow charging, are their main drawbacks. Market acceptability of today's EVs available also is reduced due to high purchase cost. Taking a tradeoff between battery cost, weight, and consumer need for minimum range, a typical full-function vehicle today might have a 150 km range, based on a 22 kWh lithium-ion battery. The range for 22 kWh can be calculated using the standard New European Driving Cycle (NEDC). In practice, actual range achieved depends heavily on weather conditions (especially temperature) and on driving cycle type – urban or extra urban, as shown in Table 1.

Table 1: Driving range evaluation for EV (source: CAE 2011)

Maximal distance trip for a 22 kWh battery	
NEDC cycle, temperate climate	160 km
NEDC cycle, winter (outside temperature -5°C)	97 km
Motorway cycle (speed 100 km/h), winter	92 km
Urban Cycle, winter	79 km

Such a short EV range is primarily due to a much higher cost per unit of energy storage than the storage cost of liquid fuels. A secondary reason for short range is a smaller specific energy (200 Wh/kg for Li-ion) than gasoline (around 12 kWh/kg), but the larger weight and size is easily managed in vehicles designed from the ground up as EV, such as the Tesla Model S with its 85 kWh battery option. A vehicle with test results like those of Table 2 might be advertised as "150 km range, less in winter" or might be advertised as "100 km to 150 km range", we call this a 150 km range, but we will use 125 km for cost calculations.

Before discussing policy to address the cost of EV batteries, we analyze the relative cost of EV and petrol vehicles. The cost of an EV without the battery is comparable to the cost of an entire gasoline vehicle. This is not exactly correct, today the cost of an EV even without the battery is more than the cost of a comparable petrol vehicle, but this is likely to shift as EV component production becomes more cost-effective with mass production. Also, maintenance is considerably lower cost on an EV, but that is not quantified nor certified at time of purchase and we do not include it here. But taking these simplifications, we can make a comparison of the EV battery and electricity cost, versus petrol fuel cost, to get a quantitative comparison of the incremental cost of EVs over petrol vehicles.

The following values are used to calculate these costs. We assume an EV efficiency of 175 Wh/km (280 Wh/mile) (Pearre et al 2013), or petrol efficiency of 5-7 l/100 km (39 MPG). We assume the mid range value of 2000 from the stated Li-ion battery cycle life,1000 - 3000 cycles. Although such a battery could theoretically last 260 000 km in our sample vehicle, well over 10 years in cycles, we think a safer assumption is a 10-year life. From Gross (2011) we take the projected battery costs[1] from a projection made in 2009 at 500 €/kWh ($650), actual 2012 battery costs at 365€/kWh ($475) and projected 2020 costs of 210€/kWh ($275).

For cost comparison, we assume 15 000 km (9,000 miles) of travel per year. Each year's travel has battery wear and fuel purchase costs. For a 22 kWh battery, assuming a 10 year life, each year's proportional yearly cost is 1 100 € for the 2009

[1] We should note that even the "2012 actual" price varies considerably as reported from auto manufacturers.

estimate, 803€ for 2012 or 462€ for 2020). Fuel for 15 000 km in a year is 900 l or 2 625 kWh. We use an electricity price of 0.1€/kWh (average retail for France and the US, lower than much of EU but perhaps appropriate for off-peak rates), and petrol price of 1.5€/l. (EU average)

The cost is first compared in nominal dollar yearly cost, equivalent to a 0% discount rate, on the second to last row. On the last row, we also calculate total present cost, using a 20% discount rate. Such a high discount rate is appropriate for consumer purchases, and also consistent with Hidrue et al's (2010) finding that five years of gasoline cost are factored into willingness to pay for an electric vehicle (for example, taking the electric cost, 263 €/year at 20% discount rate over 10 years is 1103 € net present cost).

The two ways to calculate yield different results. From a social perspective, an EV with a 22 kWh battery makes sense in 2012, that is, at a zero or low discount rate, it is less expensive on a life cycle cost basis. However, consumers have a higher discount rate (and/or borrow money to finance the vehicle at consumer rates). A high discount rate means that they count the initial battery cost at full cost, but they discount future payments on petrol (or equivalently, discount future savings on lower-cost electricity.) As a result, the car buyer's perspective may be that the net present cost of an EV is considerably above that of the thermal vehicle, and will not equalize until battery costs reach that projected for 2020.

Table 2. Comparison of fuel + storage cost for EV and thermal vehicles (assumptions in text)

	Thermal vehicle	Battery EV		
	Petrol	2012 battery costs (projection made in 2009)	2012 battery costs (actual)	2020 battery costs (projection)
Distance (km/year)	15000	15000	15000	15000
Electricity cost (€/kWh)		0,1	0,1	0,1
Petrol cost(€/l)	1,5			
EV autonomy for a 22kWh battery (km)		125	125	125
EV consumption (Wh/km)		175	175	175
ICE consumption (l/100km)	6			
Batterry cost (€/kWh)		500	365	210
22kWh battery cost (€)		11000	8030	4620
Tank cost (€)	75			
Yearly storage degradation over 10 years life €/year	0	1100	803	462
Fuel (l/year or kWh/year)	900	2625	2625	2625
Fuel cost €/year	1350	263	263	263
Yearly total cost (fuel & storage)	1350	1363	1066	725
Total net present cost (capital cost + 20% consumer discount rate on future costs)	6025	12172	9202	5792

Table 2 suggests that the current higher cost of EVs is temporary, as, even at a 20% discount rate, the batteries will decline to parity with fuel costs by 2020. In 2012, and assuming consumer discount rate of 20%, the EV has a net present cost 6 443 higher than petrol—surprisingly close to the purchase incentives of several OECD countries (see below), so the amount of purchase subsidy is sensible in relation to this analysis, for 2012 prices. An alternative analysis suggested by the table, would be to tie interest-free loans for battery purchase, which would put the stream of payments for battery on an equal basis with fuel payments. As shown by the table, the subsidy may not need to remain static, as the differential cost is forecast to drop. This changing subsidy level needed, and the sustainability of the subsidies, are addressed in the next section.

2.2. Sustainability of EV purchase subsidies

Several developed countries have funded directly tax-funded purchase subsidies to promote the local EV industry, often a direct payment, tax credit, or tax exemption to each electrical vehicle buyer. These are shown for a few OECD countries[2] in Table 3. In some federal countries like the US (Knittel 2012), additional help can be provided at the state level ($6 000 in tax credit in Colorado), and/or in some municipalities (up to $2 500 added to the Federal subsidy). The rationale of purchase subsidies, which reduce the above-analyzed buyer cost premium over petrol vehicles, is twofold: they provide environmental and fuel saving benefits of replacing petrol and diesel cars, and they stimulate the country's ability to produce new, high-technology and presumably future-oriented cars.

In some countries like France, government subsidy of EVs is funded through a feebate system ("bonus-malus") that rewards low CO2 emitting cars and fines higher-emitting cars in a self-financing system. Unlike a system trying to fund increasing EV sales from tax revenues, the self-financing French system is sustainable as long as the relative fees and the number of EV versus polluting vehicles are balanced in each year[3].

Table 3: Public subsidies for EV purchase in example developed countries.

Subsidies toward EV purchasing	
France	7 000 €
Germany	0 €
Spain	6 000 €
UK	5 000£
USA	7500$

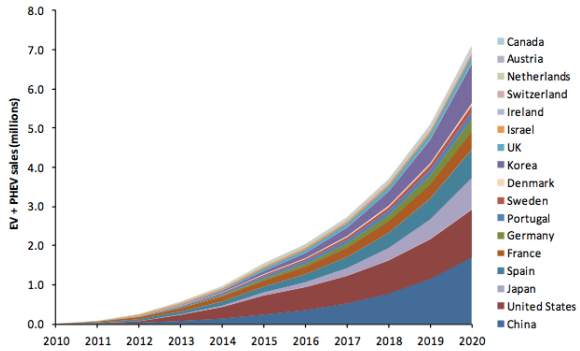
Two questions should be raised here: first is the rational calculus beyond the level of the financial help and its stability through time. Second question is the cost control criterion of any public policy. If we combine the stated objectives or goals of EV sales in different countries, the sum by year 2020

[2] The new French government raised the bonus in July 2012 to 7000€

[3] Penalty paid according to the CO2 emission * sold cars of that category > EV subsidy * numbers of EV for a year.

will be 7 million plug-in vehicles (IEA 2011, see figure 1) and the cost of the subsidy per vehicle, numbers are impressive!

Figure 1: National goals or projections for EV and Plug in Hybrids in 2020.



Sources: IEA (2011)

As a simple check, the total national cost of EV purchasing subsidies would be very high if these IEA figures were correct, for example, a country with a 5 000 €subsidy and achieving a goal of 1 million plug-ins per year by 2020 would be paying 5 billion € per year in purchase subsidy. A cost control mechanism is needed, and can be in total outlay, in time duration, or in total numbers of cars. For example, the US purchase subsidy is larger for vehicles with larger batteries, is capped at $7,500 tax credit to the purchaser, and for each manufacturer it is phased out in steps during six months after that manufacturer reaches a total of 200,000 qualifying vehicles (US Dept of Energy, 2012). We think that it will help the development of the EV market to have this type of *ex ante* safeguard both to limit taxpayer cost and to avoid subsequent reactions against growing subsidies (Finon and Perez 2007; Glachant and Perez 2011). In order to be efficient, we suggest that subsidies should be tailored to provide a clear, sustainable and predictable future to the EV industry in the next five to eight years. Economic history teaches that badly calibrated public interventions may be challenged by citizens (nuclear in Japan or Germany), by other industrial actors (Solar or Wind energy subsidies are today challenged by classical electricity generators and fuel suppliers) or by a change in the governing party (industrial stop and go policies in UK in the 60th and 70th).

3. Policies for charging stations

As important as the EV itself, widespread EV adoption will also require public access to Electric Vehicle Supply Equipment (EVSE, also called charging stations). For the reasons itemized above, the battery in a typical EV will provide less range than typical petrol vehicles. Availability of EVSE for en route charging can, to some extent substitute for a larger and more expensive battery. However, en route charging is impractical if charging rates are slow or if access is unavailable, out of the way, or cumbersome.

3.1. EVSE types, costs, and charging functionality

Table 4 defines several types of EVSEs. The cost of the AC units is generally about 1 000 to 2 000 € equipment cost, but cost jumps to the DC units at 10 000 to 20 000 €. The installation costs vary greatly by the local electrical system, but given sufficient building electrical capacity, installation may be under 500€ for units less than 6 kW to 2 000 € for 20 – 30 kW, and to 3 000 - 4 000 € for 50 kW[4]

The main difference between AC and DC charger is that the latter has an AC-DC converter in the EVSE then the battery is fed through protective circuits by the EVSE. Although DC EVSE suppliers argue this is the least expensive[5], that calculation assumes that a separate charger would be added on-board the car. Rather, the most economical approach is to use the on-board motor drive for AC to DC conversion during charging as several OEMs are already doing in production or prototype units (e.g. Renault, BMW, Daimler, AC Propulsion). Presently, all manufacturers have some way of accepting AC charging, adding DC requires an additional connector and on-board circuits for DC protection. The charging levels shown in Table 4 are interesting because even the highest (50 kW) are already accomplished by the on-board motor drive circuits, the latter being already dimensioned for the electrical motor (e.g. 150 kW for the Mini-E, 80 kW for the Nissan Leaf and 47 kW for the Peugeot iOn).

There is a surprising amount of confusion about the relative costs of these approaches within both the EV and EVSE industries. Although a wider recognition of the cost-effectiveness of using the motor drive for charging would be helpful, the much higher costs of DC charging units suggests they will not prevail in the marketplace without continuing large subsidies.

[4] Approximate figures based on co-author Kempton's experience designing EVSEs, bidding installations at diverse buildings and parking areas in the US, and discussions with several EU entitles with diverse installation experience. Also see OVE (2011).

[5] SGTE Power has sold these DC chargers since 1995. Their chargers use the CHAdeMO standard, and SGTE argues that this solution is the cheapest for the automakers because they don't have to integrate a charger inside the vehicle.

Table 4: EVSE power capacity and charging duration for a 22 kWh battery

EVSE capacity		Charging duration at 80% of the battery capacities
(1φ) 230 V – 16 A	3,7 kW	~ 5 hours
(3φ) 400 V – 16 A	11 kW	~ 2 hours
(1φ) 230 V – 32 A	7,4 kW	~ 3 hours
(3φ) 400 V – 32 A	22 kW	~ 1 hour
(3φ) 400 V – 63 A	43 kW	~ 30 min
(3φ) 480 V – 63 A	52 kW	~ 25 min
(DC) 500 V – 100 A	50 kW	~ 25 min

Most EV industries agree that both slow and fast charging speeds [6] are required because they correspond to different needs, which can be approximately divided into three functional levels:

- Slow charging (3-6 kW) is sufficient to be used at home or for dedicated parking, as vehicles are generally parked more than 5 hours;
- Medium power charging (11 or 22 kW) at shopping centers, as people spend at least one or two hours for shopping;
- Very fast charging (> 40 kW) for short stops during long trip or specific applications (taxi, high duty-cycle fleets), when less than an hour charging – even if only partial charging – is required.

Already-standardized EV charge connectors, IEC 62196-2 for all countries, and SEA J1772 for only US and Japan, define communications so that the charging rate is the maximum allowed by either the car or EVSE. Thus an EV or EVSE capable of higher power charging will not over-load the other. Thus, home or work charging at rates higher than the above suggestions do no harm (other than higher EVSE cost), and may be useful for increased flexibility or greater potential for V2G services, described below.

3.2. Deployment of EVSEs; policy choices, public or private investment

States with early EV programs, such as California, have generally funded both EVSE and electricity for charging at public expense. Indeed, by comparing the cost of EV subsidies with the cost of en route fast AC charging, it can be seen that the cost of subsidizing a single EV could equivalently be used to install a high-power AC EVSE in a public space en route and potentially serve thousands of EVs per year. Alternatively, for medium power units at locations such as at shopping centers, they may add up to a large number and often the commercial location may have incentive to attract drivers. Thus, there is an argument for private funding, possibly with some government incentive. We can see each of these alternatives in various national cases today (ABI Research 2011; CGDD 2011).

Many countries have defined objectives for EV and EVSE roll-out, which may be accompanied by a model of where EVSEs are likely to be located. For example, in France, the general commissariat for sustainable development plans 1.1 EVSE per EV for development up to 2020, and define main versus secondary EVSE locations, distinguishing between main (one EVSE per EV) and secondary (0.1 EVSE per EV) charging. Main charging places include residential private parking (0.6), workplace private parking (0.2), public parking (0.1), and street parking (0.1). By this definition, the EVSE investment for one million of EV is about 1.5 billion euros up to 2020, but less than 20% are in public places.

Finally, in our view EVSE policies should allow:

- Reducing size thus cost of batteries
- Planning for en route locations for EVSE to serve longer trips not served by home or workplace charging,
- Reducing EVSE costs to increase their en-route number, then less range anxiety
- Encouraging fast and very fast AC charging

One alternative for funding EVSE, would be taxes on electricity delivered by public EVSE. For example, consider the case of France, with potentially 20% of the charging done with public EVSE. Then 100000 vehicles driving 12000 km/year at 175 Wh/km would need 200 GWh of energy. Thus 40 GWh could be delivered by the public EVSE. With a 2.5c€/kWh taxes (about 25% of the regulated tariff) a revenue of one million euro would be available for EVSE installation and maintenance. A second approach would be if business models would allow investment and maintenance in EVSEs by private firms, which would in turn require payment for charging[7]. A third option would be a small fee on petrol and diesel fuel to be used for the initial rollout of EVSEs in public locations, like the current French vehicle purchase subsidy, this would be charging the polluting infrastructure in order to fund the replacement. Finally, there may be a role for transportation or other public entities to examine national roadways and travel data, in order to plan locations to install the EVSEs, in order to plan EVSEs where most needed by EV drivers taking trips longer than battery range.

4- Policy for grid services from EV

[6] Going for more than 80% extends the time required non-linearly for two reasons: for heat generation when charging and for dynamic constraints inside the battery.

[7] A fee of 0.5€/100km may not be enough for private EVSE investors and operators, so attractive business models would need to be found.

Electric power systems security lays on three fundamental characteristics: (i) generation and demand must be balanced in real time, keeping frequency close to its rated value, (ii) voltage levels must be kept inside a classical +/-5% range around the rated value, and (iii) maximum capacity of distribution equipment (transformers, lines, breakers) must be respected to prevent risks of overcurrent or tripping. The first characteristic requires flexible generation to adjust demand. Hydro or gas power plants are often used for this role. The current rapid increase in variable-generation renewable power sources is increasing the need for flexible generation or storage[8]. Storage has the dual advantages of economically handling over-generation, not just under-generation, and also is generally carbon-free.

The electric power networks and light vehicle fleet are exceptionally complementary as systems for managing energy and power. Economic and engineering studies show that EVs fleet may profitably provide power to the grid when they are parked and connected to an electrical outlet (Kempton & Tomić 2005a, 2005b). Since EVs are located on the low-voltage end of the electric system, they could also address local distribution constraints such as congestion or over/under voltage.

At the present time, some energy markets are more ready to accept EVs as a source. Due to the limited kWh size of EV batteries, they cannot economically provide power for long duration. For example, a 20 kWh battery with a 40 kW grid connection can provide 40 kW for 10 minutes for primary frequency correction; but to supply a 5-hour peak, no more than 2 kW would be prudent to minimize battery depletion. On this basis, the markets suitable for EV grid services are frequency regulation, spinning reserves and the capacity market. We examine frequency regulation as an example of these markets.

4.1 Frequency control

For frequency control, *Regulation up* is used when sources are providing power to grid, or when loads are reducing their demand. Conversely, *regulation down* allows sources to reduce power fed to the grid, or loads to increase their demand. Then EV that would participate to *regulation up* will discharge into the grid, and they will charge during *regulation down*. EVs can provide fast response (less than fifteen seconds, possibly within a second) for regulation purposes, faster than typical power plants now providing this service. Comparing frequency services in different power systems must be done very carefully because similar terms may describe different services and remuneration profiles. For an introduction to that diversity of services remuneration for regulated to market, see Rebours *et al (*2007). As an illustration, PJM and UCTE frequency control organizations are compared in table 5.

Table 5: Frequency control terms and markets at two TSO organizations

Power system	Second	Second-minute	15min	30min
PJM	Frequency response	Operating reserve		
		Frequency regulation	Primary reserve (spinning and quick start)	Secondary reserve
UCTE	Primary control (primary reserve)	Secondary control (secondary reserve)	Tertiary control	
			Fast reserve	Supplementary reserve

More specific descriptions of how these different control schemes and markets work can be found in PJM and UCTE documentation[9]. Suffice to say here that EVs with batteries are potentially appropriate for all the services in Table 5, at the 30 minute and under requirement[10].

4.2 Frequency reserve payment (FRP)

Analyzing the payment for these grid services is important for EV purposes because, if appropriately transferred to the EV owner (less transaction costs), it creates a reduction of the total cost of ownership of the car. Since markets and rules for these payments vary by TSO and national rules, we will present two TSOs with very different rules, the French regulated TSO pricing and the PJM market based. PJM frequency regulation payments fluctuate with markets; during the past 4 years, payments have fluctuated from roughly $15 to $30 per MW, per hour of availability (12€ to 23€). In France, it is a regulated tariff with two components:

(a) A capacity payment for availability, requiring ability to hold the requested value for 30 minutes:

- 8.04 €/MW for primary reserve
- 9.30 €/MW for secondary reserve

(b) An energy payment per kWh when power is produced. This is only for secondary control (9.30€/MWh).

As calculated via the formulas of Kempton and Tomić (2005a), a car with18 kW of bidirectional capability, available 20 hours/week, could earn

[8] Theses are the solution for managing the flexibility problem for the generation part; some studies also explore the possibility to provide flexibility from demand side (Rious & al. 2012).

[9] PJM,and ENTSO-E (2012 a & b) for last update of theses issues.

[10] The open issue is the impact on the battery ageing, even if batteries life span may be more than thousands of cycles.

approximately 2 300€ at a recent $20/MW-h PJM market price, and about half that at a French price of 8.50€ per MW-h. In either case, if the driver retained, say, 2/3 of the revenue, it would significantly improve the cost of ownership of the EV.

The advantages of the French system are in terms of simplicity and that a known future payment stream can better motivate an investment than a fluctuating market rate, whereas the regulated price faces the classical regulatory risks of capture, opportunism and discretion (Perez 2002, Glachant & Perez 2011).

Potential policies to further this revenue stream for EVs include making TSO markets more open to moderate-sized storage devices (e.g. setting the minimum threshold for market entry at 100 kW, as PJM has done, rather than 1-10 MW), providing a higher compensation for TSO resources that are more valuable because they can provide power more quickly, and re-evaluating TSO rules, now designed for centralized production (generation), to insure they are not irrationally biased against distributed storage resources. Further research on how to share the benefits of TSO payments between the aggregator and the car owner will be needed to explore the cost and benefits of the different possible scenarios.

5- Policy for EV key components research

A final type of policy is research targeted at primary component needs for the EV industry. We provide a few of multiple possible examples. For example, research and development is needed on at least 3 EV internal components: mobile Heat pumps for EV application; combined motor-drive and charger power electronics, Lithium-Ion batteries, and cooling systems for cars and batteries when charging at 43 kW.

Heat pumps are needed for EV passenger comfort. In a thermal car, waste heat is abundant and is used for passenger cabin heating. EVs are more efficient and have minimal waste heat; a heat pump in an EV makes the most efficient use of battery electricity.

The second R&D area, as noted, is integration of motor drive and charging electronics. Although each automaker will continue design its own motor drive, only a handful have yet mastered the integrated approach. Some common-funded research and analysis could be helpful in moving the industry toward this lower-cost solution. A third area is already well recognized and well-funded, but deserves mention. Battery R&D, from fundamental electrochemistry to electrode surface topology to battery pack designs--all aspects improving life and reducing cost of batteries are essential to making EVs more competitive as noted earlier. Our fourth example is cooling battery packs, needed both hot weather driving and fast charging. But how to support these different needed innovations efficiently at their different stage of maturity?

In our view, to identify the best-suited public support scheme to each development stage of any EV key components innovation, we suggest to explore this question thanks to the simplest model of innovation diffusion[11] following an S curve like in Foxon & al. (2005). Following them, innovation diffusion model has 5 stages: 1° invention, 2° the applied R&D phase, 3° the demonstration phase, 4° the pre-commercial diffusion and the 5° the commercial diffusion. Then logically, for an efficient support of needed technological innovations, the support schemes must be adapted to each of these stages according to his maturity level.

To conclude, we have proposed four-dimensions of public policies toward EV and V2G—purchase subsidies, EVSE strategic development, removing barriers to the market for grid-services from EVs, and targeted research and development on the needed components of the EV. The change from liquid fuel to electricity for most light vehicles is a fundamental change, yet essential to make, to do so successfully and at good speed will require multilevel coordinated action to overcome the hurdles. We invite further studies, comment, discussion, and analysis to challenge or augment each of the public policy dimensions proposed in this article, with the goal of making a robust frame for policies to develop, at last after multiple tries, the promise of an EV industry.

6. References

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[11] Further studies my be needed in the future to take into account other form of innovation diffusions like disruptive innovations (Christiansen (1997)) or even the no diffusion case in presence of path dependency issues (Liebowitz, & Margolis (1995), Garcia & Cantalone (2002), Der Panne and al. (2003).

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