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PUBLIC POLICY FOR ELECTRIC VEHICLES AND FOR VEHICLE TO GRIDPOWER*

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1. WHY POLICY TOWARD EV AND V2G?

All market failures are combined to hinder the development of the Electric Vehicle (EV) industry. EV and Vehicle to Grid (V2G) activities are pledged by absence of provision of public good, by difficult positive and negative

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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 some governments to develop EV policies to overcome these market failures after multiple try and errors in this industry in the 60th, 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 NO_x and CO₂ emissions and thus helping to stabilize climate, providing domestic supply of transport fuel, thus increasing energy security, energy independence and reducing the impact of oil price fluctuations. Even without a proactive public policy toward EVs diffusion, Policy-makers also need to plan ahead into the era of EVs, to prepare for future problems and opportunities related to the electric power system facing with new decentralized storage opportunity.

For example, large fractions of EVs could overload electric generation (regionally) or electric distribution systems (locally). One of the goals of the nation governance structures is to anticipate the needed evolution of the natural monopoly electrical network in a proactive way when needed (Rious, Perez and Glachant, 2011). In a more innovative way, 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). These services are complex and involve diverse actors from different 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 Marrero *et al.*, 2014; 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, the health costs of car pollution and the economic impact of various greenhouse gas emissions are diffuse and site specific. The problem is that the proposed tax amount must be a judgment call based on a range of damage estimates with neither non-clear economic evaluation nor methodology (Owen, 2004 for a survey on this question). Second, a high level of tax is likely to be problematic in terms of public/political/social acceptability in times of hard budget constraint. 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 diffusion 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. However two problems here may arise: First is the well-know logical problem of public action creating a distortion in the market willing to manage an externality issue. It is clearly not a first best solution to combine two bad signals (externality and distortion to correct it) to create an efficient one (Owen, 2004). In this respect, an operational solution has been to apply a try and error process in the definition of the distortion introduced to promote EV diffusion.

The second possible problem is the social burden of the public support designed. For any policies involving expenditures (see Table 1, below) government has also to control the cost of 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 (July, 2014), 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.

According to the existing literature (Perdiguero and Jiménez, 2012; Leurent and Windisch, 2011) and to the analysis of the main successful EV public policies program developed in Norway (Haugneland, 2014), we will assume that proactive policy intervention should take place in a coordinated set of dimension to be efficient: here we propose three dimensions that to us seem complementary and necessary to foster the development of an EV industry.

The paper is structured as follow: Section 2 will present the first type of intervention namely the direct action toward the cost of acquisition of the EV. In this respect, EVs are nowadays characterized by relatively high initial capital cost per car, but very low running costs. This characteristics can made EVs financially unattractive compared with traditional fuel cars using classical evaluation techniques based upon the lifetime of the asset called "Total Cost of Ownership". Section 3 will deal with 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 ability to reliably supply electricity. Uncoordinated development due to standards wars, often leads to the waste of private resources (winner take all situation). Section 4 will discuss the evolution of the grid rules, regulations and remunerations traditionally paid to 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 also offer peak load shaving capabilities. Last section will conclude.

2. POLICIES FOR ELECTRIC VEHICLE DIFFUSION: FROM DIRECT SUBSIDIES TO MORE COORDINATED ACTIONS

In this section, we will start by a comparison of petrol drive train and electric cars in terms of costs. Then we follow by a review of the existing subsidies schemes and their economic impacts. We end this section by a presentation of the Norwegian public policy regarding coordinated public action in favor of EVs.

2.1. Relative cost of electric and petrol drive trains

Today, the acquisition of an EV at a price between 19-45,000 €, with a 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 strong enough to create a large market at today's prices (Hidrué *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 is projected to drop by 50% over the next 7 years (Galves, 2011), battery costs may not be a long-term cost barrier to introduction.

However, the limited driving range of EVs, combined with slow charging, are their main drawbacks. 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 Cycle¹ (NEDC). In practice, actual range achieved depends hea-

¹ The New European Driving Cycle (NEDC) is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars (excluding light trucks and commercial vehicles). It is also referred to as MVEG cycle (Motor Vehicle Emissions Group). The NEDC aims to represent the typical usage of a car in Europe. It consists of four repeated ECE-15 urban driving cycles (UDC) and one Extra-Urban driving cycle (EUDC).

vily on weather conditions (especially temperature) and on an EU driving cycle type, as shown in Table 1.

Table 1. Typical maximal driving distance for a 22 kWh battery electric vehicle (source: CAE 2011)

Typical maximal driving distance 22 kWh BEV	
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 this short range is the smaller specific energy of batteries (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 presented in Table 2 might be advertised as “150 km range, less in winter” or might be advertised as “range of 100 km to 150 km range”.

Before discussing policies designed to address the cost of EV batteries, we shall 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 gasoline vehicle, but this is likely to shift as EV component production becomes more cost-effective with mass production. Also, maintenance costs are considerably lower on an EV, but that is not quantified nor certified at the time of purchase and we do not include it here. But taking these simplifications, we can compare the cost of the EV battery and electricity cost, versus gasoline fuel cost, to get a quantitative comparison of the incremental cost of EVs over gasoline vehicles.

First a comparison must be made between internal combustion vehicles (ICV) and battery electric vehicles (BEV) for characteristics such as motor power, weight, tank capacity, range, weight/power ratio (table 2). As electric vehicles are mainly small urban cars, we have compared the Peugeot ion and Renault Zoe with two ICVs Peugeot 208, with either gasoline or

diesel engine. Moreover we have considered ICV consumptions given by automakers for urban trips.

Table 2. Comparison of ICV and BEV characteristics

	Peugeot ion	Renault Zoe	Peugeot 208 1,0L Vti 68HP	Peugeot 208 1,4L HDi 68HP
Energy source	Li-ion	Li-ion	Gasoline	Diesel
Motor power (kW)	47	65	50	50
Tank capacity (l)			50	50
ICV Consumption (l/100km) urban driving cycle			5,2	4,4
NEDC range (km) (moderate climate)	150	200		
Consumption (Wh/km)	107	110	510	466
Tank capacity (kWh)	16	22	492,5	530
Curb weight (kg)	1065	1430	975	1050
Ratio weight/power (kW/kg)	0,044	0,045	0,051	0,048
Energy conversion factors:				
Gasoline → 9,8 kWh/l				
Diesel → 10,6 kWh/l				

Sources: companies' data.

Table 2 shows that all these vehicles are designed with a similar weight/power ratio. In this example the Peugeot cars have similar motor power and curb weight. Energy consumption per kilometer is much lower for BEV because an electric motor has a higher efficiency (90%-95%) than an internal combustion engine (25-30% for the optimal operating point). These energy consumptions are rather optimistic as it is well known that they are difficult to reach under normal driving conditions. Then, the following values are therefore used to calculate these costs: we assume a BEV efficiency of 175 Wh/km (280 Wh/mile) (Pearre *et al.*, 2013), and a gasoline ICV efficiency of 6 l/100 km (39 MPG).

Typical driver will use their car 200 to 300 days per year, and will charge the battery every day whatever the daily Depth of Discharge (DoD). For automotive applications, a battery must be replaced when its capacity has dropped to 80% of its original capacity. According to batteries data-sheets, the battery lifespan decreases with DoD from 10 000 cycles to 1 500 cycles for DoD in the range 20% to 95% (Peterson, 2010). Nevertheless,

measurements made on battery cells by Peterson (2010) have shown that more cycles are required. Due to the lack of large test cases, the issue of battery aging remains an open question. Finally we consider that each battery has up to one cycle per day, and a ten year life-time expectancy in agreement with a stated Li-ion battery cycle life, 1000 - 3000 cycles [UBS2013].

From Gross (2011) we assume the projected battery costs² 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). The battery management system is considered to represent an additional cost of 40%.

For cost comparisons, we assume urban vehicles (Peugeot iOn and 208) travel 10 000 km (6,000 miles) per year. Each year's travel has battery wear and fuel purchase costs. For a 16 kWh battery, assuming a 10 year life, each year's proportional yearly cost is respectively 1 120 €, 818 € and 470 €. Fuel for 10 000 km in a year is 5 880 kWh (600 l) for the ICV, and 1 750 kWh for BEV. We use an electricity price of 0.1€/kWh (average retail for France and the US, lower than much of the EU but perhaps appropriate for off-peak rates), and a gasoline price of 1.5€/l (EU average).

In table 3, the cost is first compared as a nominal euro yearly cost, equivalent to a 0% discount rate, on the third to last row. On the second to last row, we also calculate total present cost, using a discount rate equal to 20% of the fuel cost difference between gasoline and electricity. Such a high discount rate is appropriate for consumer purchases, and also consistent with Hidrue *et al.* (2010) finding that five years of gasoline cost are factored into consumers' willingness to pay for an electric vehicle. The last row gives the same results, but for a 22 kWh battery.

These results show that, at a 0% discount rate a BEV with a 16kWh will make sense very soon, and it already makes sense with the 20% discount rate. Of course, for a 22 kWh battery, it will take several more years. Such results depend on the distance driven per year. As the energy cost is much lower for BEV, the more you drive, the faster the battery cost is recovered. Thus, at 0% discount rate the breaking points in 2012 for a 16 kWh and 22 kWh batteries are respectively 11 000 km and 15 000 km per year.

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

Table 3. Comparison of fuel + storage cost for EV and thermal vehicles (assumptions in text)

	IC Vehicle Peugeot 208 1,0L Vti 68HP	Battery EV Peugeot iOn		
	Gasoline	2012 battery costs (projection made in 2009)	2012 battery costs (actual)	2020 battery costs (projection)
Distance (km/year)	10000	10000	10000	10000
Energy cost, gasoline or electricity (€/kWh)	0,15	0,1	0,1	0,1
EV consumption (Wh/km)		175	175	175
ICE consumption (l/100km)	6			
Energy cost (c€/km)	9	1,75	1,75	1,75
Battery cost (€/kWh)		500	365	210
16kWh battery cost (€)		8000	5840	3360
Tank cost or BMS cost (€)	75	3200	2336	1344
Yearly storage (battery and BMS) degradation over 10 years life €/year	0	1120	818	470
Fuel (kWh/year)	5880	1750	1750	1750
Fuel cost (€/year)	900	175	175	175
Ten years total cost (fuel & storage)	9000	12950	9926	6454
Total net present cost for EV with a 16 kWh bat- tery (capital cost + 20% consumer discount rate on fuel cost difference)		11500	8476	5004
Total net present cost for EV with a 22 kWh bat- tery (capital cost + 20% consumer discount rate on fuel cost difference)		15700	11542	6768

Sources: author's calculation based on company data.

In 2012, and assuming a consumer discount rate of 20%, the EV with a 22 kWh battery has a net present cost that is 6 700 euros higher than an ICV – 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. As shown in the table 3, the subsidy may not need to remain static, as the differential cost is forecast to drop. These changing subsidy levels required, and the sustainability of the subsidies, are addressed in the next section.

2.2. Sustainability of EV purchase subsidies

Several developed countries have introduced 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 number of OECD countries³ in Table 4. In some federal countries like the US (Knittel, 2012), additional help may 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 gasoline vehicles, is twofold: they provide environmental and fuel saving benefits of replacing gasoline 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 fee-bate 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 year⁴. Since 2013 the French system has been modified to a decrease at 6300 € and the last debate to date (July 2014) is to increase it to 10 000 € if it combined with the destruction of an old polluting diesel car.

3 The new French government raised the bonus in July 2012 to 7000 €.

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

Table 4. Public subsidies for EV purchase in example developed countries

Subsidies toward EV purchasing in 2012			
Amsterdam	15 000 €	Norway	0 € but 25% VAT rebate
Australia	0	Ontario	8500 CAD
Belgium	8 990 €	Portugal	5 000 €
China	60000 Yuan	Romania	5 000 €
Denmark	29 300 €	Spain	6 000 €
France	7 000 €	Taiwan	300\$
Germany	0 €	UK	5000£
India	1 100 000 Rs	USA	7500\$
Ireland	5 000 €		

Sources: http://www.evscroll.com/Electric_Car_Subsidy.html

Two questions should be raised here: first is the rational calculus beyond the level of the financial help and its stability through time. The 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 the year 2020 will be 7 million plug-in vehicles (IEA 2011, see figure 1).

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

Sources: IEA (2011)

Our first remark is linked to the total cost of achieving the national goals set by governments. 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 subsidies. A cost control mechanism is needed. It 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 a \$7,500 tax credit granted to the purchaser, and for each manufacturer it is phased out in steps over six months once the manufacturer reaches a total of 200,000 qualifying vehicles (US Dept of Energy, 2012).

We consider 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). We believe that in order to frame the market the subsidies should be tailored to provide a clear, sustainable and predictable future to the EV industry over 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 the UK in the 60th and 70th).

Our second remark is driven by the two last years of public policy toward EV and their results in terms of private sales. In the following figure, we have collected data about EV sales in different countries. This data collection is not easy to collect owing the lack of clear international database, so we have collected raw data from different sources in the following figure.

Matching public policy incentives and private sales is not an easy task. Even if governments want customers to buy EVs and they set for them some direct monetary incentives (see table 4) and sometimes indirect advantages (see table 6), real private decisions about buying EVs are below expectations. Arguments to justify this gap are multiple. Some derive from the comparison between the relative performance of EVs and internal combustion vehicles (ICVs (see table 5). As the two products are not strictly equivalent in terms of performances, only a small fraction of the consumers have chosen the EVs to replace their internal combustion vehicles even if public policy support reduces the acquisition cost of the EVs.

Figure 2. EV Sales in 5 leading countries in 2012 and 2014 **Table 5.** Comparison of relative performance of EVs and ICCs

	EVs	ICVs
Price per new car	Minimum 23k€	Minimum 7500€
Driving range	150 km	400 km-600km
Time to refuel	From 30min to 6hours	6min
Life time	Unknown for the battery pack	Years
CO ₂ emissions	o emission while running; Some according to the energy mix while charging	From 90 g to 250g/km
Noise pollution inside and outside the car	Very low	Function of the technology
Energy cost for 100 km	1€to 2€/100 km	4-15 liters/100km * price per liter
Ancillary services provided to the grid	Positive contribution if managed efficiently (see next section)	None

In the following section we will see how Norwegian public policy have succeeded in setting a more dynamic EVs environment by combining direct and indirect incentives in favor of EV adoption.

2.3. The Norwegian EV success story

For many national and international observers, Norway is the leading country in terms of EVs adoption by private households. In July 2014 there were over 33,000 electric cars registered in Norway in a population of 5 million. This makes Norway the world leader for the adoption of electric cars.

Figure 3. Registered cars in Norway in July 2014

Sources: Grønnbil (2014) http://www.gronnbil.no/statistikk/?lang=en_US

According to Haugneland (2014) the benefits for electric car owners in Norway include monetary and non-monetary elements defined and adjusted over the last 20 years. For this author, the Norwegian EV success story is explained by the combination of different and complementary elements to make EVs attractive to private users: first in a national perspective is the fact that no purchase taxes (extremely high for ordinary cars) are applied to EVs. In the same vein, EVs have been granted an exemption from 25% VAT on purchase. They have also no charges on toll roads to paid. In terms of local public policies, EVs enjoy a free municipal car parks access and have free access to bus lanes in rush hours to facilitate their

mobility. In addition, to alleviate the range anxiety problem and to sustain this large fleet of private EVs, there are registered 1,200 charging stations with 5,500 charging points⁵.

The sum of the direct and indirect benefits provided by the Norwegian public authorities at the national and local levels make the electric car competitive with traditional cars. Because of high purchase taxes on traditional cars, the electric cars are only marginally more expensive than a comparable gasoline car. The price difference in Norway is much more favorable to EVs than in many other countries. As electricity in Norway is cheap (0.11 Euro/kWh) and gasoline expensive (1.9 Euro/liter), the result is that the running cost for electric vehicles is cheap compared to traditional cars. The combination of these benefits compensate for the limited range and uncertain price on the second hand market for electric cars. Figure 4 shows the efficiency of the Norwegian public policy to make the comparable EV car cheaper than its ICC version.

Figure 4. Total Cost of Ownership comparison

Sources: <http://www.avem.fr/actualite-voiture-electrique-une-etude-confirme-le-role-des-politiques-fiscales-5009.html>

⁵ Sources: gronnbil (2014) <http://www.gronnbil.no/ladepunkter>, in July 2014.

Lastly to manage the “stop and go of public policy” problem, the Norwegian parliament guarantees the purchase incentives until 2018 or until Norway reach 50,000 zero emission cars on Norwegian roads.

If we try now to compare the Norwegian system VAT free incentive to the French fee bate one, we will argue that both systems create distortions in the EV market. The Norwegian VAT free system creates an incentive to buy large and expensive EV cars (Tesla, Leaf, WV and BMW) whereas the French one is favoring the rather small and accessible EVs (Zoé, Kangoo, Leaf and Bluecar). According to level of this fee bate, the threshold of equal incentive between the two schemes (Q) moves down and up as described in table 6.

Table 6. Comparing French feebate and Norwegian VAT at 25%

Feebate level in 2012	Feebate level in 2013-2014	Feebate level in 2015
$7\,000\text{€} < Q^{*0,25}$	$6\,300\text{€} < Q^{*0,25}$	$10\,000\text{€} < Q^{*0,25}$
$Q = 28\,000\text{€}$	$Q = 25\,200\text{€}$	$Q = 40\,000\text{€}$

In the following section, we will deal with the question of policies toward charging stations.

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 mentioned above, the battery in a typical EV will provide less range than a typical gasoline vehicles. The 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. To add on this, policies toward EVSE try to solve the EV chicken and egg conundrum. In fact, as EVs are not yet massively deployed, a large EVSE infrastructure is not necessary and it is not deployed, but, due to range anxiety, high battery cost and low distance issues, it is necessary to have a large EVSE to allow the massive deployment of EVs...

3.1. EVSE types, costs, and charging functionality

Table 8 defines several types of EVSEs. The cost of the AC units is generally about 1 000 to 2000 € equipment cost, but cost jumps to the DC units at 10 000 to 20 000 €. The installation costs vary greatly but given sufficient building electrical capacity, installation may range from under 500 € for units of less than 6 kW to 2 000 € for 20 – 30 kW, and to 3 000 – 4 000 € for 50 kW⁶.

The main difference between AC and DC charger is that the latter has an AC-DC converter built in to the EVSE: then the battery is fed through protective circuits by the EVSE. Although DC EVSE suppliers argue that this is the least expensive⁷, their 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 converter 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 scaled 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 cost of DC charging units suggests they will not prevail in the marketplace without continuing awarding of large subsidies.

6 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 entities with diverse installation experience. Also see OVE (2011).

7 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 8. EVSE power capacity and charging duration for a 22 kWh battery

EVSE capacity		Charging duration at 80% of the battery capacities ⁸
(1j) 230 V – 16 A	3,7 kW	~ 5 hours
(3j) 400 V – 16 A	11 kW	~ 2 hours
(1j) 230 V – 32 A	7,4 kW	~ 3 hours
(3j) 400 V – 32 A	22 kW	~ 1 hour
(3j) 400 V – 63 A	43 kW	~ 30 min
(DC) 500 V – 100 A	50 kW	~ 20 min

Most EV industries players agree that both slow and fast charging speeds⁹ 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 car parks, 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 charging lasting less than one 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 costs), and may be useful for increased flexibility or greater potential for V2G services, as described below.

8 Going for more than 80% is complex for two reasons: for heat generation when charging and for dynamic constraints inside the battery.

9 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.

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

States with early EV programs, such as California or Norway, 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 shopping centers, they may add up to a large number and often the commercial location may be an incentive to attract wealthy EV drivers during free charging time. 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 (2011) 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 places¹⁰.

Finally, in our view EVSE policies should allow:

- Reducing size thus cost of batteries
- Plan for en-route locations for EVSE to serve longer trips not served by home or workplace charging, and as the Norwegian experiment clearly shows, a safety net of fast-charging stations around the main driving routes is a key issue.

¹⁰ The last figure announced by the French government in July 2014 is to have now 7 millions EVSE for 2030, but without any details concerning the implementation of this new policy goal. <http://www.automobile-propre.com/2014/06/18/transition-energetique-10-000-e-bonus-les-voitures-electriques-7-millions-points-recharge/>

- Reducing EVSE costs to increase their en-route number, and reduce accordingly range anxiety
- Encouraging fast and very fast AC charging

One alternative for funding EVSE, would be to levy 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 charging¹¹. A third option would be a small fee on gasoline 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 making trips longer than battery range.

4. POLICY FOR GRID SERVICES FROM EV

Electric power systems security depends 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) must be respected to prevent risks of over current or tripping. The first characteristic requires flexible generation to match 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

¹¹ 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.

storage¹². Storage has the dual advantage of economically handling over-generation, not just under-generation, and is also 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 a 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 possible markets.

4.1. Frequency control

Transmission System Operators (TSOs) are the responsible organization that purpose is to ensure at all time the frequency constraint in a given geographical zone. For frequency control, *Regulation up* is used when sources are providing power to the 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 a 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

¹² These 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 et al., 2012).

may describe different services and remuneration profiles. For an introduction to this diversity of services remuneration for regulated markets, see Rebours *et al.* (2007). As an illustration, PJM¹³ and ENTSO-E¹⁴ frequency control organizations are compared in table 9.

Table 9. Frequency control terms and markets at two TSO organizations

Power system	second	Second-minute	10-15min	
PJM	Frequency response	Operating reserve		
		Frequency regulation	Primary reserve (spinning and quick start, 10min)	Secondary reserve
RTE	Primary control (primary reserve)	Secondary control (secondary reserve)	Tertiary control	
			Fast reserve (15min)	Supplementary reserve (30min)

Sources: Rebours *et al.* (2007)

More specific descriptions of how these different control schemes and markets work can be found in PJM and ENTSO-E documentation¹⁵. Suffice is to say here that EVs with batteries are potentially appropriate for all the services in Table 8, in the 30 minute and under requirement¹⁶.

¹³ PJM Interconnection LLC (PJM) is a Regional Transmission Organization (RTO) in the United States. It is part of the Eastern Interconnection grid operating an electric transmission system serving all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

¹⁴ The European Network of Transmission System Operators for Electricity (ENTSO-E) is an association of Europe's transmission system operators (TSOs) for electricity. It is a successor of ETSO, the association of European transmission system operators founded in 1999 in response to the emergence of the internal electricity market within the European Union.

¹⁵ PJM, and ENTSO-E (2012 a & b) for last update of theses issues.

¹⁶ The open issue is the impact on the battery ageing, even if batteries life span may be more than thousands of cycles.

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 per 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; over 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).

Table 10. Frequency control remunerations

Sources	Analyzed region	Participated market	Net Profit €/Month/Vehicle	Regulation power
Kempton and Tomic, 2005	USA	Regulation up and down	112-165	10-15 kW
Tomic and Kempton, 2007	USA, Four different control areas	Regulation up and down	4.3 – 43 (Think City) 6 – 64 (Toyota RAV4)	6.6 kW
Andresson et al., 2010	Germany	Control energy market	30 – 80 (Germany, coal fired power plants)	3.5 kW
Codani et al., 2014a	France	Regulation up and down	2 – 45	3kW, 7kW, 23kW, 43kW

As calculated via the formulas of Kempton and Tomić (2005a), a car with 18 kW of bidirectional capability, available 20 hours/week, could earn 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. Some other studies provide revenues for ancillary services for VtoG services as summarized in table 10.

Potential policies to further this revenue stream for EVs include making TSO not irrationally biased against distributed storage resources and to allow more market mechanisms to give the real value of the services provided by the different actors.

4.3. Definition of the Optimal TSO rules toward VtoG and implementation in the EU

According to Codani *et al.* (2014b) the optimal implementation of the TSO rules can be expected as displayed in table 11 by an international comparison of six existing rules framing the institutional arrangement toward VtoG services.

Based on these international best- worst existing practices, authors have collected, they define an ideal TSO for VtoG services in which almost no barriers to the building of EV coalitions exist. Conversely they also define the opposite, the worst possible institutional organization toward VtoG remuneration. Therefore in the best scenario, EVs are aggregated and participate into electricity reserve markets in a fair way. In opposition in the worst scenario, EVs services are not paid and deliver to the electricity grid. In order to guide actual EU policies toward better rules for VtoG, authors have finally analyzed ENTSO-E proposal at the EU level and find some weak points in the project driven by ENTSO-E. For instance, the rules defining the minimum side of aggregation of EVs (R1) and the possible bonus for extra-flexibility (R6) are not addressed in ENTSO-E's proposal and some additional efforts are expected to reach the optimal TSO goal.

Surprisingly some rules are not addressed within the network codes because they are left at the discretion of each TSO. We can see that there is a good correlation between the ENTSO-E guidelines and the ideal TSO. It seems that the network codes are paving the way to the implementation of a complete Demand Side Response framework suitable for all new controllable loads. The rules of this ideal TSO would encourage the formation of EV coalitions, no matter neither their sizes nor their geographical expansions. All TSO services would be remunerated in a fair and just manner.

Table 11. Comparison of TSOs rules to manage VtoG services

TSO Rule	Best Organization	Worst Organization	ENTSO-E proposal
R.1. Minimum Size of the fleet capacity for EVs aggregation	100kW	10MW	Not addressed
R.2. Interoperability among multiple and local Distribution System Operators ¹⁷	Possible	Impossible	Not clearly defined, but TSOs and DSOs should make all endeavors and cooperate in order to ease the participation
R.3 Aggregation rule and payment precision	Telemetry	Financial	Status of aggregator defined. Telemetry aggregation considered up to 1.5MW
R.4 Nature of the payment received for the resource	Market based	Regulated	Market based
R.5 Consistency of the payment	All ancillary services should be paid	Incomplete payment scheme	All ancillary services should be paid
R.6 Bonus for extra flexibility provided by BEVs	Set at the efficient level	No existing	Not addressed

Sources: Codani et al. (2014)

5. CONCLUSION

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. To conclude, we have proposed three-dimensions of public policies toward EV and V2G – purchase subsidies, EVSE strategic development and removing barriers to the market for grid-services from EVs. In this paper, we have investigated current barriers to widespread EV deployment, reviewed the state of art of public policies toward these problems and proposed some remedies for each of the identified problems. We advocate integrated public

¹⁷ More than 900 are existing in Germany and 215 in France (100 ERDF + 115 non nationalized local distribution companies).

action to address these problems beyond the classical subsidy schemes for EVs. As the topic challenging, we invite further studies and analysis with the goal of making a robust frame for policies to develop, at last after multiple tries, the promise of an EV industry.

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