E-mobility, the answer for a clean urban energy ecosystem

Hugo Niesing, Carlos Varela Martín

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Abstract

E-vehicles can enhance the energy transition by integrating the storage capacity in a smart electricity network. The project 'Amsterdam Vehicle 2 Grid' demonstrates how e-mobility, renewable energy, domestic electricity usage, the electricity grid and intelligence enforce each other in the nearby smart energy future.

Resourcefully manages a V2G in the Amsterdam vehicle2Grid project, where a household increased the self-sufficiency from 26 to 58% on a yearly basis. Normally 74% of the consumed electricity is injected in the grid and extracted. With the storage in the electric vehicle (EV) the consumption of local produced energy has more than doubled. The results exclude system optimization and some system failures occurred. In March 2015 the first International Vehicle 2 Grid conference took place, focusing on large scale out-roll of EV's for sustainable mobility and city development. Finances and policies are required to make a real contribution to clean transport and clean energy for a clean city. Now, large scale projects need to demonstrate the possibilities in real life, long lasting and with sound business models.

1 A new interaction between vehicles and grid

The 20th century has witnessed two main different ways our society has processed energy. One is the electricity system, that we will call "the grid". Fueled by generation centrals and a distributed by an extensive network, it provides energy to virtually every household in the industrialized world. The second way to process energy is the "mobility" system, constituted by countless internal combustion vehicles all over the world. Both served us well in the past, but now both face challenges that call for deep restructuring.

The energy system is experiencing a transition from fossil fuels to renewable energies. The main causes are environmental reasons and the depletion of these fossil fuels. The proportion of renewables in the energy mix is still small, but all scenarios point to a dramatic increase on solar and wind energy over the next decades. In European cities, both solar energy generation and electric mobility is increasing fast. Clean energy generation and mobility are two essential components of smart and clean city development, especially when these are well integrated. Good part of the challenge this new system has, is keeping the reliance of the grid in the face of widespread generation by intermittent sources of energy, like sun or wind. The schematic figure 1 illustrates how a typical demand profile of electricity along the day is modified by the production on solar energy. Domestic electricity needs create two peaks of demand, both in the morning and during the evening. The differences of energy production and demand peaks can limit the integration of renewable energies in the system. Among the solutions suggested to this problem are making the consumption of energy more flexible over time (Demand Side Management) and the use of energy storage.

If the electricity grid is designed for fossil fuels generated energy, the mobility sector is even more. It is unclear if the oil peak has been already overpassed, but what is beyond discussion is that oil will exhaust, climate change needs strong action, a higher degree of energy independence is needed and we require alternatives. One of the most evident alternatives is the Electric Vehicle (EV), fed by batteries, charged through the grid [7]. All data point that in the future these vehicles will increase

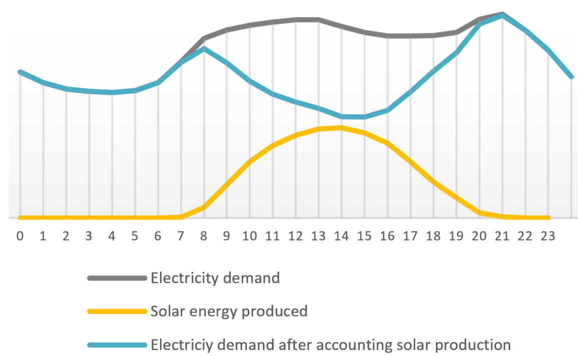


Figure 1: Demand of electricity and supply of solar energy

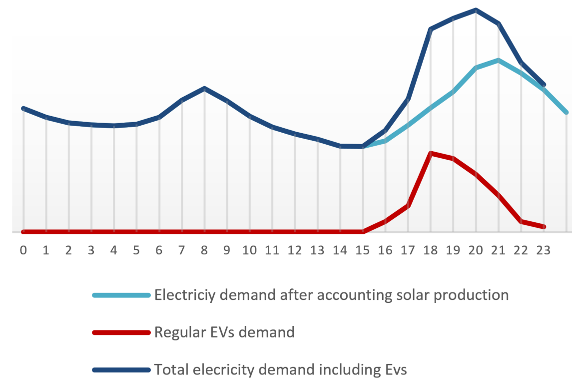


Figure 2: Charging electric cars during the evening worsens the evening demand peak

their market share, as the prices of the most expensive components (batteries) decrease.

With the popularization of EVs both grid and mobility systems will be joined... for the second time. Ironically, the future will look somehow like the start of the 20th century, when most of the vehicles sold were electric [9, 7]. This time however EVs will count with an additional advantage that did not exist hundred years ago: Information and Communication technologies. This will allow EVs not only to charge from the grid, but to take the electricity grid and other energy devices into account. Charging can be delayed or accelerated, intensitiy can vary depending on circumstances, the EV can feed energy into the grid when appropriate.

This bidirectional interaction between grid and mobility systems is not so much a gimmick as it is a need. If EVs feed themselves from the grid like is done from petrol stations, they risk to overload the electric system [2]. On a normal weekday people would charge their EVs in the evening, coming back from work. This increases the evening peak demand 2, with the danger of producing an electricity shortage or compromise power quality [2, 3]. The orthodox solution for this would be reinforcing the grid, to accommodate it to the increased demand of power; but grid reinforcement is a complicated and expensive work. Besides that this enforcement is only required during a small period of time, which makes the return on investment long. Could another kind of interaction between the grid and the electric mobility system be possible?

Resourcefully is committed to the achievement of this interaction; one in which grid and mobility work together, not against each other. This kind of relation, commonly called Vehicle to Grid (V2G), seeks to minimize the problems both systems suffer in the future. In a nutshell, V2G consists of charging the EVs when the grid experiment low demand of energy, and release it during the demand peaks. This is called grid flexibility, and does not only avoid the problem of overloading the grid, but also can improve the resilience of the grid.

The intermittency of renewable energies stresses one problem the grid already has; matching the generation of energy with the demand is a permanent task, and is not always is easy or cheap. Besides the baseload of power demand (the one that is expected to be covered all year around), the grid system requires energy plant that provide energy on demand; including some sources of energy that work only for the peak hours, only for few dozens of hour per year. Not to mention the increase difficulties keeping stable the voltage quality of the grid, also called ancillary services.

As seen, this conception of the energy system *reacts* to the demand matching the production of energy to it. Besides the use of batteries, a solution that has been proposed is the Demand Side Management, that is, adapting the energy is required to the production of energy. The concept of V2G blends both approaches, charging in the moments; an example of a profile of charging EV is illustrated in 3, showing how would it look to flatten the curve of power demand along the day. So far we have stressed the advantages of connecting EVs to the

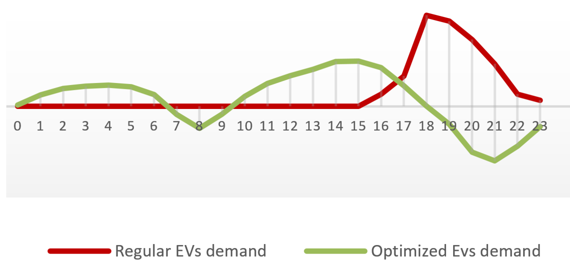


Figure 3: : Different charging profiles for electricity's demand charging EVs. The optimized version includes some "negative demand", meaning is providing energy to the grid.

grid, but there is no need of a large-scale project to see the benefits of integrating mobility in the energy system. As we will see in section 2, Vehicle to Home (V2H) concepts showcase much of the advantages predicted at larger scale. In any case, more EVs connected mean more energy storage, more demand response capacity and more grid resilience. This, in turn, translates into a higher capacity of the grid to accommodate renewable energies. EVs can contribute significantly in reducing both the dependence from fossil fuels and the ecological footprint of both city energy and mobility systems. Which is the ultimate objective we want to achieve.

2 Household integration: Resourcefully's living lab

The theoretical advantages of V2G require to be field tested in an small-scale showcase. For this, Resourcefully put in practice its own "living lab", combining a household energy system with an EV. The objective is clear: if the advantages of V2H are demonstrated, it will be much easier to widespread the technology at V2G level.

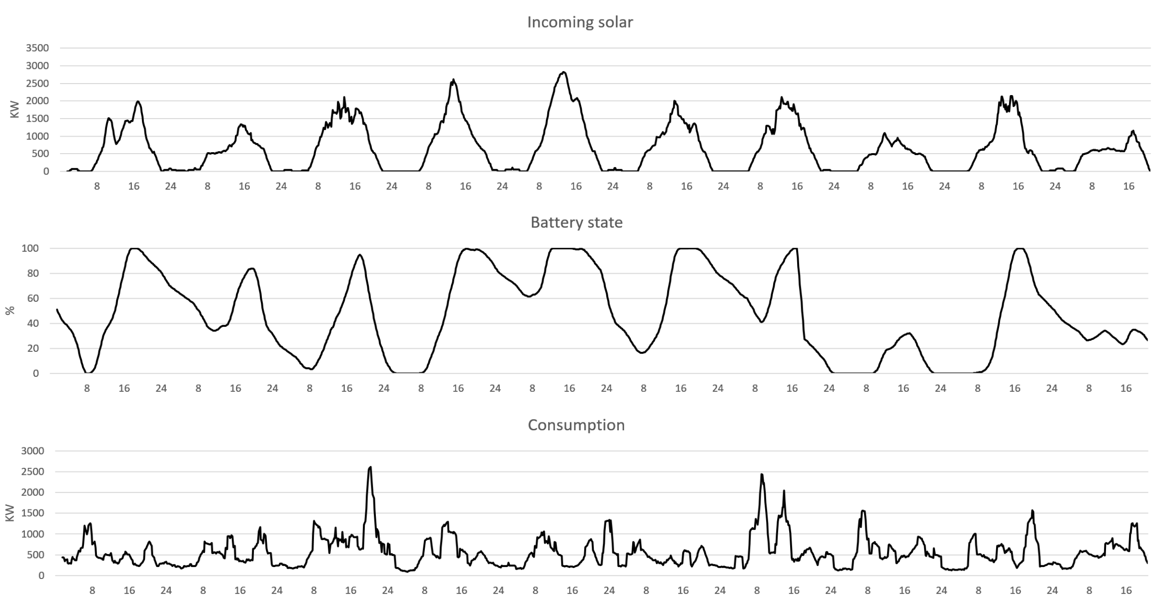
Resourcefully has undertaken an installation under the aegis of the Amsterdam vehicle2Grid project. The setting before the intervention was a houseboat with 30m2 of photovoltaic (PV) solar panels. These PV panels produce roughly enough energy as for supplying the average household consumption all year around, but in when production exceeded the demand this energy was poured into the grid and naturally the real, direct household consumption of electricity from PV panels was only a fraction of the energy consumed. Specifically, the electricity consumed by the household directly from PV panels was 26%; the rest was withdrawn from the grid. was self-sufficient at 26%. This means the PV panels could provide for 26% of the electricity consumed in the house. We can say then, that the house had a 26% of energy self-sufficiency. This represents at household scale the problem that face at large scale the grid system: it is impossible to match production of renewable energies with the consumption of energy, thus causing two problems: part of the energy produced is "lost", and there might be a shortage of supply when the energy is needed.

An obvious solution for this problem is the use of batteries. Resourcefully goes one step further and proposes using the batteries of the EVs for this purpose, because they offer a significant advantage: Meanwhile standalone batteries cover only one function, using batteries integrated in EVs cover a purpose both for the grid (acting as a battery) and for the mobility (fuel an usable vehicle). Given that cars stay parked 95% of the time, this dual use is one of the main advantages that V2G can offer.

3 Large scale implementation

In view of the good results obtained at household level, Resourcefully advocates for large scale implementation of equivalent projects. So far the experience has been performed with one household with a single electric vehicle, but what could it be possible to do with many households and many vehicles? Resourcefully believes that the inevitable differences in the production and consumption profiles of different users will complement each other; leading to percentages of self-sufficiency higher than the obtained at household level, increasing the grid flexibility and allowing for larger integration of renewable energies.

Scaling up the V2H concept to the V2G model means the inclusion of a new partner: the grid System Operator (SO). The function of SO is to keep the grid working at every moment, matching the production of electricity with the demand. As mentioned, the traditional way of doing this has been demanding variable production to energy produc-



ers. With sun shining at different times and wind blowing at different speeds this match will be increasingly difficult.

This is were V2G comes as a solution. The profiles provided in Figures 1-3 serve to illustrate how the SO can use EVs to meet energy demands in an scenario of variable renewable energy production, fulfilling both the functions of energy demand management and energy storage. No need to say, this schematic example is just an stylized case subject to a number of variations. This includes wind energy, much less predictable than the sun, that for sure shines only on the daytime. Here is when planning and management by part of SO is required; for instance, when the weather forecast predicts a windy night followed by a cloudy day it would be beneficial to maximize the charging of EVs during the night. To fulfill this function of regulation, there is no need for a complete migration to 100% EVs. To offset the variability of wind or sun it would only be needed 26% or 38% of vehicles running on battery, respectively [6].

In addition to flattening the curve of demand, batteries of EVs are useful for injecting into the grid large amounts of energy. The big advantage EVs have here is the speed of response; unlike other utility services, batteries can release energy on demand almost instantly [11], reducing enormously the need for back-up power ready to use. In addition, with widespread V2G implementation power output should not be a problem; according to Kempton [6], if just one fourth of the entire US light vehicle fleet were converted to EVs, it would rival in capacity of generation with the entire utility system. This means the SO should be able to exert easily high control over frequency regulation and peak demands of electricity at a cost much lower than today's standards. This last point is especially important because achieving stability in the grid, managing the demand peaks and assuring the quality of voltage, what is commonly named as ancillary service, is disproportionally expensive, accounting from 5% to 10% of the total grid cost [6].

All this capability of regulation also means that the grid does not need to be reinforced so much [2]. If the electricity supplied in moments of high demand is produced partially nearby the site of consumption, this means it is harder for the distribution network to overload. Less need of grid refurbishment is another side economic benefit of V2G implementation.

4 Actors: new roles for a new system

Merging grid and mobility systems is a change of paradigm, that naturally requires of a change in mentality for the three main actors involved in the energy system: the users, the SO and the public bodies. Each one of them can benefit from the new mindset, but also will require to adapt to it.

4.1 The user: benefited by the economic gains

As mentioned in the last section, V2G can provide important economic advantages. As a rule of thumb, the more sporadic and on-demand energy is required, the more expensive it is to produce. In a liberalized market, this means that there is an economic interest in not using these infrequent energy utilities, that actually derive most of their costs not from producing the energy in itself, but from being connected to the grid and being *able* to provide power on demand.

V2G can help in that, but precisely for the widespread of the technology it is also necessary that the end user will benefit from it.

In this context, White et al. [10] suggest that V2G can offer very significant economic advantages. Unlike other ancillary utilities, EVs connected to the grid would be ready to release energy at any moment without involved extra cost, which should give them an economic advantage. To be fair, this point of economic gains for end users is however not clear for all researchers. Quinn et al. [8] claim that the economic feasibility is highly place-dependent, and are required models accounting for the different variables involved. For instance, in places with high penetration of renewable or isolated areas with high ancillary costs, V2G would be especially appropriate and provide higher benefits for users.

I any case, it is clear the final user should be the receiver of these economic gains. This will encourage users to adopt EVs technology, which in turn will favor the creation of new infrastructure. This is also an objective for Resourcefully: lowering the barrier for EVs acceptance thanks to the implementation of V2G schemes. Tuttle and Baldick [9] compare the current situation with the "chicken and egg problem" : There is not enough infrastructure of Electric Vehicle Supply Equipment (charging points) because there are not enough EVs, and the last are not purchased because of the lack of charging points. This process is comparable to the situation of mobile networks some years ago: as more people purchased mobile phones, the network expanded and using a mobile phone became easier. Currently the mobile phones have overtaken the fixed ones. Will it happen something similar with the EVs, overtaking the internal combustion ones? We think that it is desirable, and that V2G projects can catalyze this process.

For the time the last users adopt the last technology, however, the economic advantages of grid regulation will not be so high. Kempton et al. [6] point out that there is only a certain amount of grid regulation need, and with the expansion of the EVs the prices paid for ancillary costs will drop.

4.2 System Operator: needs to coordinate with user

The V2G scheme poses significant behavioral challenges to the System Operator. The idea of mobile batteries able to regulate production and demand of energy is very different than managing only households that only act as energy consumers.

Due to this inherent complexity, some intermediate stages have been proposed to cover the gap between V2H and V2G. Liu at al. [7] believes that a possible option is creating a network of Vehicle-to-Neighbourhood, or a a network of Vehicle-to-Vehicle. This last option would consider all the connected vehicles in a district as an aggregated, in the way the energy given by one vehicle is used to charge another one rather than injecting it into the grid. The objective would be to have a single point of input and output of energy from the grid, which would be a more familiar situation for the SO. Another option is to establish this input and output point as a defined space; that is, considering stationary fleets or car parking as "batteries" the SO can make use of [6]. In any case, the business model behind these schemes would require the figure of the EV aggregator; how to exactly make work this actor in combination with the final user and SO is matter of reseach in the last years [1].

This relation between SO and end users will also increase in complexity because of the simple fact that the needs of both do not match quite well. The user wants to use the car and have the battery charged when needed, meanwhile the SO wants to count on the energy present in the battery. For the proper implementation of V2G, both needs should be fulfilled [8]. Kempton et al. [5] suggest several ways to solve this obstacle; perhaps the most realistic one is the "override system" approach, that is also used in the living lab from Amsterdam vehicle2Grid and Resourcefully.

This approach is based on the observation that vehicles in general are much more used for short range travels than long ones. In practice this means an EV will usually spend a small percentage of the battery before being connected again to the grid, but this is no reason to reduce the battery capacity of the EVs because they still should be suitable for long trips. Precisely the "range anxiety" is one of the main obstacles in the deployment of EVs [11, 4].

To meet in the best way the needs of users and SO, in the "override" approach the grid operator can routinely dispose of a relatively high percentage of the EV battery, in order to provide a high level of grid flexibility. However this percentage should be low enough so the user can make the daily commutes without worrying about the range of the car. Then, prior to a long travel that requires of all the battery capacity of the EV, the user could "override" the system for one day (or several days), so the SO will not have access to the battery for grid flexibility. Naturally, it is assumed the percentage of vehicles in "override" mode will be at any given moment low enough so it does not disrupt the grid flexibility functioning to the SO.

In short, both users and SOs will need to make behavioral adjustments to adapt to the V2G system; but the economic savings will hopefully offset these inconveniences.

4.3 Public bodies: need of a new legal framework

Talking about savings, the public sector should have high interest of V2G not only because of its potential economic gains, but also because of its environmental benefits. From a public point of view the monetary advantages should be considered as a nice side effect of the inclusion of more renewable energies into the grid, thus decreasing the carbon footprint of the energy system thanks to both clean energy utilities and electric vehicles.

The idea of V2H fits very well with a new paradigm of conceiving sustainable energy. In the case of internal combustion, the vehicle draws energy from fossil fuels, generated millions of years ago and perhaps brought to the closest petrol station from thousand of kilometers away. In comparison, the energy an EV consumes in the V2H scheme is produced instantly in the roof of the house, just meters away. This change in how to conceive the electricity system can bring forward multiple additional benefits. It can make end users more aware environmentally speaking, by putting them in contact with the energy produced by their own, and move forward the decentralization of energy production and consumption, in contrast with today's centralized production by large utilities.

To put in practice this vision, public bodies need to get involved, and not only using economic incentives or public subsidies, but more important establishing the right policy framework for it; a framework that does not exist right now, in part because inevitably policy regulations follow social and scientific development, and not the other way around.

In the specific case of the Netherlands, perhaps the main limitation today is the feed-in tariff for energy producers established by law. In former years this tariff had a very important function: by guaranteeing a fixed benefit rate for solar energy produced it became possible to encourage the widespread of renewable energies, lowering their costs thanks to economies of scale. However, this same feed-in tariff offers now little incentive for the implementation of V2G. The concept of EVs flattening the curve of demand lies upon the assumption of a liberalized energy market, where it is possible to apply the "buy cheap, sell expensive" principle: it is by storing energy cheaply produced and then selling more expensive in the moments of high demand how the end users can take economic advantage of the V2G scheme. Under this view, it is impressive how the feed-in tariffs have become obsolete so fast, passing in the space of few years from being an effective instrument in the promotion of renewable energies to hinder the further expansion of sustainable energy schemes.

Public bodies should take care on solving this issue, as well as being proactive and reducing the inevitable friction that will arise between the SOs and users. Another implication should be favoring the imminent intertwining between energy and mobility policies. For most of the municipalities, right now the mobility planning of the municipality is a very different matter than the planning of energy. In the case of mobility, there is the called the Urban Mobility Plan (SUMP).

For the integration of the energy system, we propose the institutionalization of a Urban Mobility and Energy Plan, or a SUMEP. A SUMEP would address not only the vehicles but from where these vehicles acquire energy. In a future with more EVs, this means managing the grid, predict how much flexibility is available for the grid operator and balance as necessary the renewable energies available in the area.

5 New business model: car sharing

So far we have only hinted the possibility of using private vehicles in households, in individual or collective way, so the SO can "share" the energy stored in the vehicles. From here it is easy to conceptualize a next step: sharing the vehicles themselves.

This possibility is framed within the called "shared economy", which motto is well synthesized on the saying of Harvard marketing professor Theodore Levitt: "People don't want to buy a quarter-inch drill. They want a quarter-inch hole." By the same principle, people do not want to buy a car, but the ability to move between destinations at will.

This solution, called "car sharing", propose to the potential users a relieve from the burden of owning a car and the number of costs associated (insurance, parking, maintenance, etc), moving then to a "pay as you travel" scheme. In practice this means people using a common fleet of cars, so they can dispense with the private one. This might seem counterintuitive; if the objective is using EVs for their battery capacity, why to encourage people to dispense with their private cars instead of encouraging them to buy a new, electric one?

The reason is, the production of EVs is still pollutant. Even when it runs on clean energies, the cleanest car is still the one not produced, so ultimately decreasing the total number of vehicles in streets has sense under the environmental point of view. In addition, as has been commented previously, if every person would dispense with their internal combustion vehicle and every EV shared would substitute three of them, then the capability for grid flexibility would still be high enough to manage a high share of renewable energies.

6 The use of information

As described, the implementation of a V2G scheme would require a high control over the information not only of the state of the grid, but about the state of the EVs' batteries. This would require a bidirectional system of Information and Communication Technologies (ICT) able, in addition, of requiring energy from the EVs' batteries on demand [7].

The ultimate objective of these ICT is allowing the utilization of renewable energies and a flexible, interactive (and very probably, decentralized) energy system. However, as with any technology able to compromise the privacy of the users, we should take some cautions. After all, should the SO be able to know when do we take our car, or where do we drive? These discussions add another layer of complexity to the technically intricate implications of ICT.

7 Final thoughts

It is time to take full advantage of the synergies between grid and mobility systems. In the second (and hopefully definitive) advent of EVs, it is a reductionist approach to focus on electric mobility without considering the advantages it can provide to the grid.

Resourcefully has gathered very promising results with its living lab, and literature support the idea of using EVs to regulate the grid. Now is the moment to think in a large-scale application of the V2G; a milestone that because of its novelty has unavoidable obstacles, but has numerous advantages: reducing the maintenance cost of the grid, offer overall economic savings and contribute for a decarbonized future.

The main obstacles are the lack of field test, the unusual nature of the proposal for potential actors involved, and a lack of legal framework. These are challenges that hopefully will be overcome with the right public support, and also choosing the right places to start the field test with. Probably the first jurisdictions to apply V2G will be the ones that require of grid improvements, have high ancillary costs and are committed to renewable energies and carbon reduction [6]. In the mid-term, we hope V2G to consolidate as a new paradigm for the achievement of a more sustainable future.

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