Vehicle to Grid and Crisis Management

Potential of V2G for smart city power grids in Norway

Marius Rohde Johannessen
School of Business
University of South-Eastern Norway
Horten, Norway
email: marius.johannessen@usn.no

Lasse Berntzen
School of Business
University of South-Eastern Norway
Horten, Norway
email: lasse.berntzen@usn.no

Boban Vesin
School of Business
University of South-Eastern Norway
Horten, Norway
email: boban.vesin@usn.no

Qian Meng
School of Business
University of South-Eastern Norway
Horten, Norway
email: qian.meng@usn.no

Thomas Brekke
School of Business
University of South-Eastern Norway
Horten, Norway
email: thomas.brekke@usn.no

Inessa Laur
School of Business
University of South-Eastern Norway
Horten, Norway
email: inessa.laur@usn.no

***Abstract*— Researchers and practitioners alike have discussed Vehicle-to-Grid (V2G) technology for quite some time, and we have extensive coverage of the technology needed, as well as opportunities, challenges, algorithms, and business models. However, few studies have examined V2G from a crisis management perspective. This paper presents a review of the current V2G literature. It gives an overview of the possibilities for using electric cars as a backup power supply in case of emergencies, such as citywide power outages. We calculate the potential power available in a typical Norwegian mid-sized city and examine to what extent this can be part of crisis management in case of a massive power outage. We then review existing business model literature to analyze possible incentives for people to make their cars available for V2G. Finally, we conclude by pointing out several technical and social issues that need to be addressed for V2G to become a viable option and suggest vehicle-to-home (V2H) as the most likely scenario in the short to mid-term.**

Keywords-vehicle-to-grid; V2G; smart city; smart grid; electric vehicles.

I. INTRODUCTION

Vehicle-to-Grid (V2G) technology is the ability to reverse the flow of energy between Electric Vehicles (EVs) and the home/power grid so that EV batteries function as a backup power source for peak hours or power outages. V2G can also help balance renewable energy sources by feeding electricity to the grid when winds are calm or the sun is not shining. The charging interface initiative (Charin) estimates that V2G technologies are widely available around 2025 [1].

Many technical papers are describing V2G algorithms for optimizing grid and charging efficiency [2], optimal placement and planning of charging and charging locations taking supply challenges and demand into consideration [3], or cost-optimization for end-users [4]. There are even examples of modeling V2G capacity [5]. However, few papers combine this with a crisis management perspective. Thus, this paper focuses on the potential of vehicle-to-grid technology in the context of crisis management. As Norway has been the leading country in adopting electric vehicles, we use Norway as our example. We examine the potential of V2G to act as a backup power source for households in case of emergencies and present a scenario for potentially available energy in 2025 and 2030, based on the current EV fleet and predictions of future uptake. We have calculated the potential for the country as a whole and for a typical mid-sized Norwegian city of 80.000 inhabitants. However, few papers combine this with a crisis management perspective. Crisis management refers to handling a crisis, which in our case is a potential failure in the power grid and the use of energy stored in EV batteries as part of the solution.

The reason for only examining households is that critical functions such as hospitals already have backup systems such as generators in place. For these functions, the varying energy available from EV batteries would probably not meet the strict criteria for reliable backup (but could perhaps be of interest as a last resort if everything else fails).

The rest of the paper is structured as follows: Section II presents a literature review of V2G, including technical requirements, available algorithms, and the challenges, opportunities, and willingness of users to adopt the technology. Section III presents our research approach. Section IV presents our findings; Available energy on the national and mid-sized city level as a best-case scenario for summer and winter, and a more realistic scenario where assume less available energy. Finally, in Section V, we present our conclusions and possibilities for future research.

II. LITERATURE REVIEW

This section presents related research on the vehicle to grid definition and background, business case, challenges, opportunities, and crisis management.

A. Vehicle to grid definition and background

The power grid has little storage capability and needs to be carefully managed to handle fluctuating customer demand. Storage capacity is costly, except perhaps for hydropower, where energy is stored in dams. According to Kempton and Tomic, electric vehicles are already there, and the number is increasing. On average, cars are stationary 96 % of the time, making their stored energy potentially available for the power grid. The basic definition of V2G is simply the ability of vehicles to provide power to the grid when stationary [6].

There are different ways of connecting vehicles and the power grid. This paper is concerned with bi-directional V2G, where power can flow both ways, and EV batteries can aid in grid balancing and backup. This requires aggregator services, communication between DSO/TSO and homes, as well as smart meters and equipment for two-way transfer of energy between home and grid [7]. Other definitions include unidirectional V2G, where charging is determined based on variables such as available energy and the current prices of electricity. Unidirectional V2G requires less infrastructure and has considerable potential for overall energy-saving and load-balancing of the grid but does not allow for using batteries as a backup energy source [2]. Literature has also examined hybrid solutions, such as Vehicle-to-Home (V2H), where the EV battery is used as a backup power source for individual homes, and Vehicle-to-Vehicle (V2V), where cars can charge each others' batteries [8].

B. Business case, challenges, opportunities

The overall business case for all variants of V2G is the potential for significant cost savings due to energy saving and load balancing, which in turn requires less investment in peak capacity [8]. In Norway, for example, the challenge is not (yet) the availability of electricity but the fact that peak demand sometimes exceeds the grid's capacity to deliver.

As electricity moves to renewable sources such as wind and solar, the need for backup and balancing increases. Winds fluctuate, and the sun doesn't always shine when the need for electricity is greatest. So one scenario for V2G is to act as a backup to ensure the grid is balanced and operational, replacing polluting alternatives such as coal- or gas-driven power plants. Calculations indicate that V2G could stabilize half the US electricity grid with a low base capacity in the form of fixed batteries and 8-38% of the EV fleet providing reserves [6]. Høj, Juul, and Lindegard [9] claim that V2G technology offers the potential for new and profitable business models if they manage to balance and integrate intermittent renewable energy into the grid, reduction of peak load, charging optimization, and regulation of participating capacity. They, therefore, call for more research into the creation of such business models.

Almenning, Bjarghol, and Farahmand [10] have responded and examined the impact of grid tariffs on peak power demand. They found an 11% decrease in peak power use in a test neighborhood where peer-to-peer energy trading in local markets allowed for local energy exchange from solar and batteries. Economic incentives are also important for the large-scale acceptance of peer-to-peer "prosumerism", including willingness to participate in a V2G scheme [11].

In recent years, several studies have modeled the potential economic costs and benefits of V2G. Gough et al. applied a monte Carlo-based data-driven analysis of V2G in UK commercial buildings, where the car park was equipped with V2G capabilities. They found that the most significant potential was wholesale market trading involving peak and off-peak tariffs, with a potential income of around £8400 per vehicle over a 10-year investment period. Vehicle-to-home peak reduction generated less value. Short-term operating reserve (providing extra power at times of high demand) was not viable because battery degradation cost exceeds the savings. This factor is likely to change as battery prices drop [12]. Similarly, Ahmadian et al. [13] found battery degradation costs to exceed the potential income unless set up in a system for balancing wind power. Unidirectional V2G (smart charging) was found to be economical and with no impact on battery degradation.

Li and colleagues [14] found that battery costs might already have dropped enough for a short-term operating reserve to be profitable. They conducted a case study in Shanghai and found the total net profit of V2G to be positive, but with higher profit for power plants than EV users and negative profit for grid companies. Finally, Berglund et al. [15] found that effective use of battery storage could shave peak energy costs by as much as 13,9%, enough to cover the costs of battery storage facilities. This makes it even more likely that V2G could become profitable even when considering increased battery degradation.

There are also some challenges to V2G: A survey conducted in the Nordic countries regarding EV adoption and willingness to be included in V2G capacities showed that only two of the four countries (Norway and Finland) were interested in V2G. The study concludes that the public knows little of the potential of V2G and calls for greater education and awareness-building regarding V2G to increase EV drivers' willingness to participate. However, monetary incentives seem to be popular if people are aware of the potential. Sæle [16] conducted a survey to examine the willingness of Norwegians to change their electricity user habits and found that up to 64% was willing to either allow remote control of appliances, water heating, etc. or to contribute with a manual response if they save 200 Euros or more in a year.

Another challenge, or rather a criticism, is that many studies of V2G and electricity efficiency take the idea of the rational human for granted and that cost-benefit analyses fail to include human factors (human beings are not necessarily rational) or social inequality. Smart equipment can be costly and is not necessarily something everyone can afford. There is also the question of what is the underlying philosophy of this constant "surveillance" of users [17]. While the ethics of technology is beyond the scope of this paper, the topic should definitely be on the agenda of researchers.

C. Crisis management

Crisis management is a sub-field of organizational studies, which draws on various fields such as psychology, management, technology, and politics. Coombs defines crisis management as "a set of factors designed to combat crises and to lessen the actual damage inflicted by a crisis" [18] Pearson and Clair [19] define crisis management as a process, where some kind of event (blackout, natural disaster, terrorism, etc.) triggers a crisis, which is met by individual and collective reactions and handled in both planned and ad hoc ways. Successful handling of a crisis depends on a range of contextual and environmental factors, of which preparedness and adoption of a crisis management mindset are among the most important ones [19].

Crises come in many shapes and sizes, ranging from the local pub running out of beer via industrial-scale crises (metal quality reports being falsified, the VW diesel scandal, BPs oil spill in the Gulf, or unexpected side effects of drugs) [20] to natural disasters such as earthquakes, floods and extreme weather [21]

The power industry is not exempt from crises. Literature shows issues ranging from natural disasters via short-term power failure to more deep-seated issues such as lacking infrastructure or too low capacity for energy generation. Examples include Pakistan, which struggles with massive energy shortages and power outages ranging between 8 hours a day in cities and 18 hours a day in rural areas [22]. In Brazil, seasonal changes in weather patterns have proven to be a challenge for their hydropower dams, with the latest major supply challenge in 2015 [23], and Nepal has struggled with both earthquakes and blockades [24].

Western countries also face electricity-related crises. In the UK, strikes in the 1980s threatened the entire power grid [25]. The US state of California had supply issues in the early '00s, forcing energy companies to introduce incentives for reducing consumption [26]. More recently, we have seen electricity prices soar in Texas due to extreme weather conditions. The current transition towards renewable energy sources also brings challenges and potential crises that need to be handled [27]. Zyadin and colleagues [28] point out lack of storage and variations in production as major challenges. The wind is not always blowing, and the sun doesn't always shine, so we need backup sources or energy storage. Traditionally, coal-fired or nuclear power plants have provided this, but environmental concerns and social pressure mean this is no longer an option. This is where V2G comes in as a possible (partial) solution to the problem, as discussed by Zdrallek et al. [29].

III. RESEARCH APPROACH

We used data from statistics Norway for household energy use, which has been fairly constant over the past years. Thus, we assume that household energy needs will remain at the same level for the next decade. To calculate the number of EVs in 2025 and 2030, we examined data from the Norwegian Information Council for the Road Traffic [32] and from the Norwegian Public Roads Administration's open data platform [33]. In addition, we conducted a document analysis of white papers on V2G and smart grid from Distribution/Transmission System Operators (DSO/TSO) and the EU. Finally, we have conducted interviews with regional DSO and TSO to discuss their views on V2G as a viable source for backup electricity.

Using the available statistical data and input from white papers and interviews, we have made a calculation of the potentially available energy from EVs, using the following approach (calculations and details are presented in detail in section IV):

1. Calculate daily energy needs nationally and for a mid-sized city
2. Calculate potential number of EV's in 2025 and 2030
3. Estimate available battery capacity in 2025 and 2030
4. Estimate available power available, taking use into account

IV. FINDINGS – SCENARIOS FOR BACKUP POWER

In this section, we present the potential of EVs as a power source in a crisis, using Norway as our case and looking at both the national level and a mid-sized city of 80.000 inhabitants.

Household energy demand

We started by examining data from statistics Norway on energy use for households (Table I). We have kept this number constant, as increased demand from EV charging so far has been offset by more efficient appliances and heating. Demand is higher in winter (about double) due to the cold climate. Nationally, households consume 70,5 GWh/day in summer and 140 GWh/day in winter. For our mid-sized city, demand is 1 GWh/day in summer and 2 GWh/day in winter.

TABLE I. DAILY ENERGY DEMAND, HOUSEHOLDS

	National demand	City demand
Summer	70,5 GWh	1 GWh
Winter	140 GWh	2 GWh

Estimation of EV numbers

The Norwegian government has said all new cars should be electric from 2025, and annual EV sales growth has been 10% in the last four years. Based on total annual sales of 150.000 cars (average new car sales 2017-19) and 10% annual sales growth, this means about 900.000 EVs nationwide, and 11.000 in a mid-sized city by 2025, and 1,7 million/18.000 in 2030 (Table II). This number is close to the calculations by Saele [30], who estimates around 1,5 million EVs in Norway by 2030

TABLE II. ESTIMATED NUMBER OF EV'S

	Nationally	Mid-sized city
2025	900.000	11.000
2030	1.700.000	18.000

Estimation of battery capacity in EV's

This is, of course, nothing more than an informed guess, based on current battery sizes and predicted battery size for coming models. Currently, city cars and small cars have battery packs of 30-50 kWh, compact cars average 50 kWh, and medium-large cars have battery packs ranging from 75-100 kWh [34]. As costs of batteries go down, battery pack size is likely to increase. However, the current information on coming models shows the increase might not be as big as expected, with most models announced for the coming years have battery packs between 50 and 80 kWh.

Thus, a conservative estimate is that the average EV in 2025 has a 40 kWh battery pack, increasing to 60 kWh in 2030, as the oldest models with 18-24 kWh battery packs are gradually decommissioned.

Estimation of available energy in EV batteries

Battery capacity is one thing, state of charge something else. In order to estimate how much energy is available, we need to consider the average state of charge on parked cars at different times of the day. We have calculated this for morning and evening. As smart meters allow dynamic pricing of electricity, we assume most people charge their cars at night when prices are low. Thus, there should be more electricity available in the morning than in the evening when cars have been driven back and forth to work and activities. As with gasoline-powered vehicles, there is no reason to assume that everyone keeps a "full tank" of electricity every morning, but also that few people let their "tank" remain empty for long since both a high and a low state of charge can damage the battery. Thus, we estimate 30 kWh/car in the morning in 2025 and 40 in 2030 (Table III).

The average private car drives 11.883 km in a year, or 33 km a day. Based on the current US Environmental Protection Agency numbers from fueleconomy.com [35], if the average car mileage is 200 Wh/km, this means 6,6 kWh spent for driving each day. As we drive more some days than others, we round this up to 10 kWh, which leaves a conservative estimate of 20 kWh (2025) and 30 kWh (2030) available energy from each EV in the evening (Table III). This is, of course, again an informed guess, based on what we know of EV users' current charging habits – According to the Norwegian EV survey, most people charge at home, during the night, every 2-3 days [31]

TABLE III. AVAILABLE ENERGY IN THE MORNING AND EVENING, AVG/CAR

	Morning	Evening
2025	30 kWh	20 kWh
2030	40 kWh	30 kWh

EV's potential as a backup power source

Given the above assumptions and estimates, we can calculate the backup power potential of EVs is as follows: Multiply the number of EVs (nation and city) with available energy (morning and evening) as a percentage of daily energy demand. Tables IV and V below show how much of daily energy demand can potentially be covered by EV batteries:

TABLE IV. POTENTIALLY AVAILABLE ENERGY IN EVS, 2025. SUMMER AND WINTER, AS A PERCENTAGE OF AVERAGE HOUSEHOLD DEMAND

2025	Nation, morning	Nation, evening	City, morning	City, evening
Available energy	28 GWh	18.7 GWh	0.3 GWh	0.21 GWh
Summer, percentage of demand	40%	27%	30%	21%
Winter, percentage of demand	20%	13%	15%	10%

TABLE V. POTENTIALLY AVAILABLE ENERGY IN EVS, 2030. SUMMER AND WINTER, AS A PERCENTAGE OF AVERAGE HOUSEHOLD DEMAND

2030	Nation, morning	Nation, evening	City, morning	City, evening
Available energy	67 GWh	42 GWh	0,72 GWh	0,45 GWh
Summer, percentage of demand	95%	60%	72%	45%
Winter, percentage of demand	48%	30%	36%	23%

These numbers are not meant as absolutes, and much can change between now and 2030 in terms of household demand, EV battery sizes, and charging habits. However, they do provide us with an indication of the potential of EV batteries as part of a crisis management plan to address power outages. This is probably an optimistic estimate, as it assumes every EV sold has V2G capabilities and that households have equipment in place for feeding electricity back to the grid – both assumptions that are not true as of today. Our intention with this paper is, however, simply to point out the potential, which is not insignificant, at least for shorter-term power outages. In winter, heating is critical in the northern countries, and even a few hours can lead to people freezing in their homes. At least in 2030, the potential is there to use the energy stored in EV batteries in case of power outages. The challenge then is to be ready both on a technological level and with proper crisis management plans for distribution and priorities.

In the next section, we outline some of the future research challenges that need to be addressed for this to be feasible in the near future.

V. CONCLUSION AND FUTURE RESEARCH

This paper has examined the potential of using energy stored in EV batteries, so-called V2G technology, as part of a crisis management strategy in case of power outages. Using numbers from Norway, we have shown that in 2030, the energy stored in EV batteries can potentially cover almost the entire household energy demand in the summertime. Our estimates are based on current energy demand, a careful increase in battery capacity, and Norway reaching its objective of all new cars being sold from 2025 are electric.

Of course, many factors can push this estimate both higher and lower. The percentage of new cars might decline, new battery technologies might significantly increase the potentially available energy, to name but a few.

To realize the potential, there are several challenges and factors in need of further research, both on the technical and social level:

Technical issues: As EVs cannot necessarily cover all of the demand in an emergency, grid balancing and demand needs to be carefully managed, most likely using automated algorithms and requiring smart hubs installed in homes with the ability to control household energy use. One possible research approach could be to examine "neighborhood grids", attempting to balance supply and demand within, for example, the grid served by one transformer.

Currently, few homes have the technology to reverse the current and draw power from EV batteries. Mostly we find this in households with solar panels or other forms of battery storage, such as Tesla's powerwall. Thus, equipment supporting energy transfer between home, EV, and grid needs to be installed in homes. These challenges are technically possible to overcome, but so far, households have few incentives to install expensive equipment. The most likely scenario is perhaps not V2G, but V2H – using the car's battery as a backup for individual homes. This brings us over to the **social and organizational issues:**

As the literature review showed, monetary incentives are important for households to invest in smart energy products, so research on business models that facilitate this is important. Other areas that need examination include transaction handling, where studies have appeared on, for example, the use of blockchain to handle micro-transactions between households. From a crisis management perspective, plans need to be made and implemented on both technical and social aspects. One important issue is the creation of guidelines for prioritizing demand. Even if the equipment is there to switch households appliances on and off, there is still a need for a plan on how to prioritize. Should families with small children be allowed to use more than other households? What about essential medical equipment for the elderly living at home, with various home care appliances? Heating in winter and cooling in summer demands a lot of energy, and here too, there is a need to plan and prioritize.

In summary, EVs have the potential to become a significant part of energy crisis management, but in order to make this feasible, numerous challenges need to be overcome in the coming years. As we are still in the early days of smart grids/meters/hubs/homes, we have the opportunity to plan for these things now in order to make the energy system more robust in the future.

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