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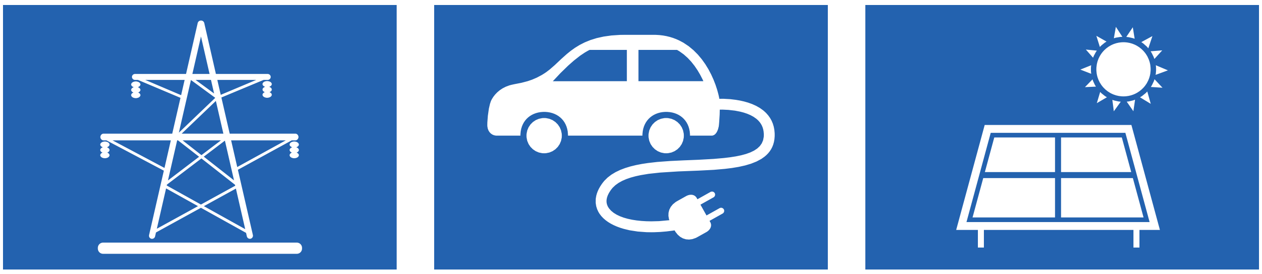
Creating the Grid-Connected Car

International Experiences Using Demand Response with Electric Vehicles



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Acknowledgement

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List of Abbreviations

CPP = Critical Peak Pricing
DR = Demand response
DSM = Demand-side management
EV = Electric vehicle
E3 = Energy and Environmental Economics, Inc.
GHG = Greenhouse gas
ICT = Information communications technology
IOU = Investor-owned utility
KEPCO = Korea Electric Power Corporation
KSGI = Korea Smart Grid Institute
PG&E = Pacific Gas & Electric
PV = Photovoltaic
RPS = Renewable Portfolio Standards
RTP = Real Time Pricing
SDG&E = San Diego Gas & Electric
T&D = Transmission and Distribution
ToU = Time of Use
UD = University of Delaware
VGI = Vehicle-grid integration
V2G = Vehicle-to-grid
W2V2G = Wind-to-vehicle-to-grid
ZEV = Zero Emission Vehicle

A Note on Terminology:

Demand response (DR) is a technique in which consumer demand for electricity is adjusted in accordance with signals from utility operators in order to maintain stability and improve efficiency on the electricity grid. With electric vehicles (EVs), DR is typically implemented indirectly by providing incentives for EV owners to change their charging times, or directly by utility operators or third-party DR providers managing EV charging remotely using specialized hardware/software. Managing EV charging using either of these methods is often referred to as "vehicle-grid integration" (VGI).

Throughout this report, the terms "managed charging," "VGI," and EV-DR integration will be used interchangeably to refer to the use of DR to adjust EV charging.

1 Introduction

Energy and transportation markets worldwide are facing a structural shift that will fundamentally change the way electricity and mobility are supplied. This transition is at different points of development in different parts of the world, but the trend exists everywhere and shows no signs of reversing. To understand these changes and their implications – and opportunities – it's necessary to look to the areas where they have advanced the furthest.

As prices for renewable energy technology plummet and concerns over climate change and other environmental damage push public opinion away from fossil fuels, energy from sources like wind and solar are being added to the grid in increasingly high quantities. Utilities have less control over when these types of variable resources produce electricity than they do with more traditional power generators, meaning that, in order to ensure that supply and demand for energy are matched, the ability for utilities to influence electricity demand becomes more important. As a result, sources of flexible demand – technology and appliances that have some flexibility in when they will use electricity – are becoming more valuable.

In addition, the rising use of distributed renewable energy systems like distributed photovoltaic (PV) solar panels means that a growing number of utility customers are producing electricity on-site. PV solar penetration in markets like Germany and California has already increased dramatically. In some utility service areas in California, distributed solar PVs can already meet over 10% of peak demand,[1] and in Germany, almost one-third of energy demand can be supplied by solar installations,[2] over 60% of which are distributed.[3] A sustained drop in PV panel prices is causing these penetration levels to increase rapidly,[4] creating a growing potential for the electric utility's customers to go "off-grid" by generating their own electricity completely from distributed sources.

This poses a potential risk for the current business model generally employed by electric utilities, which requires a large customer base to finance the utilities' extensive transmission infrastructure. However, a potential solution has already arisen from a parallel revolution in transportation technology: electric vehicles (EVs). EV batteries, impacted by the same economies of scale and focus on technological improvements as solar panels, are getting cheaper, making EVs increasingly competitive against conventional vehicles. Places like Germany, California, and the Netherlands already have fast-growing EV fleets,[5],[6] and the adoption of EVs is expected to grow as battery prices continue to decline, more charging infrastructure is installed, and consumer interest grows.

As this happens, utility companies stand to gain by becoming the new suppliers of the input fuel for the transportation industry. Almost 74 million passenger vehicles are forecasted to be sold worldwide in 2015,[7] and the portion of this market that utilities can access will only grow as the market penetration of EVs accelerates. Californian utilities are already taking advantage of this development, constructing charging infrastructure and signing up new EV users to augment their customer base.[8]

However, especially savvy utilities see this trend as not only an opportunity to increase revenues and improve utilization of existing assets, but also as a potential resource to help manage their daily electricity load distributions. The large energy demand that makes EVs a great source of revenue also makes them potentially destabilizing forces for the grid. But the flexibility with which they can be charged means that, with the implementation of demand response (DR) techniques, grid-connected EVs can instead be used to balance load distributions, charging at times of low demand to improve grid stability and make use of latent generation potential. More advanced versions of this approach can also be used to absorb variable renewable energy like solar and wind, or use the EVs to feed energy back into the grid to meet spikes in demand.

The potential in this approach has attracted the attention of utilities and other stakeholders in a number of different regions and markets, many of whom have already established pilot projects to test its efficacy. In order to prepare this approach for large-scale adoption, these pilot efforts should be expanded to other regions to test the concept in different conditions and electricity markets. This report first provides a literature review on the importance of EV and DR integration and the potential models for adjusting EV demand in accordance with utility needs. It then looks at several pilot projects in the US, Europe, and Asia (South Korea) that employ these models for vehicle-grid integration (VGI). In the final section, a brief summary of key components for these projects is developed, with the intention of providing a reference for those who wish to develop these types of pilot projects in other countries and markets

1. Savenijie, Davide. "How SDG&E is dealing with high penetrations of rooftop solar." UtilityDIVE. July 25, 2014. Available at http://bit.ly/1kiWYEu.
2. Del Franco, Mark. "North American Solar Seeks To Learn From Germany's Grid Integration Trials." Solar Industry. March 12, 2014. Available at http://bit.ly/1KPzsbt.
3. Trabish, Herman K. "Why Germany's Solar Is Distributed." Greentech Media. May 29, 2013. Available at http://bit.ly/1ZweRjj.
4. Ibid at footnote 1.
5. Autoblog. "The World's Top EV Nations." July 12, 2015. Available at http://bit.ly/1ZMpfU2.
6. Electric Vehicle News. "Electric vehicles account for almost 10% of Californian new-car sales." November 14, 2014. Available at http://bit.ly/15FMEA7.
7. Statistica. "Statistics and Facts about the Global Automotive Industry." Available at http://bit.ly/1E7jG75.
8. San Diego Gas & Electric. "SDG&E To Install Thousands of Electric Vehicle Charging Stations." SDG&E Newsroom. January 28, 2016. Available at http://bit.ly/1WKIhZ2.

2 Drivers of EV industry development vary across countries

Much of the advancement in electric vehicle development across the world is driven by environmental concerns about the tailpipe emissions from conventional vehicles. This includes not only the smog-causing pollutants that create urban pollution but also the greenhouse gas (GHG) emissions that contribute to climate change. In Europe, the need to reduce NO_x emissions under the 2008 EU Air Quality Directive[9] provides a driver for cities to push for increased adoption of EVs.[10] Concerns over climate change are also a critical motivator; the EU has ambitious CO_2 reduction targets for vehicles, aiming for a 95g CO_2 per km cap in vehicle emissions by 2020.[11] This will require most automobile manufacturers in Europe to reduce their fleet emissions by almost 30% over the next five years.[12] To support this transition, the EU has offered generous incentives for automobile companies to introduce electric vehicles to the market.[13]

Compared to Europe, the United States' national-level EV promotion efforts put greater stress on the benefits to energy security. In 2011, U.S. President Barack Obama announced support for EV adoption in the form of grants and tax incentives, emphasizing EVs' potential to reduce America's reliance on oil from politically turbulent areas in the Middle East.[14] However, local policy support in California, America's largest EV market, is largely driven by environmental concerns similar to those in Europe. The state's Air Resources Board mandates that a certain percentage of vehicles sold in California each year have no tailpipe emissions, a policy that the Board sees as a key component for maintaining the state's air quality.[15] California has also adopted statewide climate legislation with long-term GHG emissions targets, and state planners expect that in order to meet these targets, the state will need to electrify the majority of its passenger vehicle fleet by 2050.[16]

Similar to the U.S., South Korea's motivation for promoting EVs stems from a mix of energy security and

9. "Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe" Official Journal of the European Union. Available at http://bit.ly/1UE8GKY.
10. Amsterdam Roundtable Foundation and McKinsey & Company. "Electric Vehicles In Europe: Gearing Up For A New Phase?" April 2014. Page 14. Available at http://bit.ly/1dMwqsM.
11. "REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles." Official Journal of the European Union. Available at http://bit.ly/1PH1IfF.
12. Ibid at footnote 10. Page 14.
13. International Council on Clean Transportation. "CO_2 emissions from new passenger cars in the EU: Car manufacturers' performance in 2014." July 2015. Page 10. Available at http://bit.ly/1Or9V9I.
14. U. S. Department of Energy. "One Million Electric Vehicles By 2015: February 2011 Status Report." Page 2. http://1.usa.gov/1TNbD9f
15. California Air Resources Board. "Zero-Emission Vehicle Legal and Regulatory Activities and Background." Available at http://bit.ly/233QFH6.
16. Williams et al. "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity." Science. January 6, 2012. Page 53. Available at http://bit.ly/1U81juA.

resources and relies on imports for almost all of its crude oil.[18] South Korea's "Low Carbon Green Growth" policy, introduced in 2009, attempts to address both of these issues by promoting the uptake of EVs in the transportation sector, with an initial target of replacing 10% of its passenger car fleet with EVs by 2015.[19]

17. "South Korea confirms 30% carbon reduction target by 2020." Climate Home. January 31, 2014. Available at http://bit.ly/1TXWG3W.
18. Energy Information Agency webpage on South Korea. Available at http://1.usa.gov/1RPzEbh.
19. Presidential Commission on Green Growth website. Available at http://www.greengrowth.go.kr/menu001/sub002/GRG_001_202.do.

3 An integrated approach to EV development brings multiple benefits

3.1 Integration of EV and DR to improve grid system efficiency

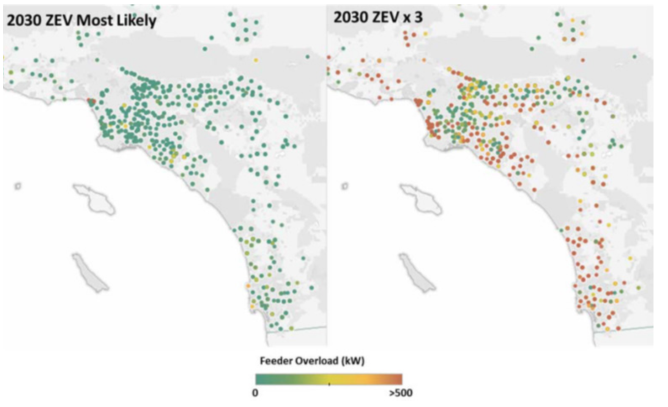
With the adoption of EVs increasing in key markets, there is concern among electricity providers and grid operators that the relatively large power demand of electric vehicles might disrupt the functions of the power grid by creating destabilizing spikes in energy demand. Although most utilities have enough spare capacity to deal with the additional electricity requirements generally, there is a risk that EV charging could overload local grid capacities if a large number of EVs are charged simultaneously. For example, most EV owners plug their electric vehicles in as soon as they come home from work. If charging commences as soon as the cars are plugged in, it would create a demand spike during a time of the day when the grid is already facing peak demand. This is compounded by the fact that EV charging – particularly quick charging installations – can have a significantly higher power demand than other household energy uses.[20]

As the number of EVs in an area increases, there is a larger likelihood that their electricity demand will overload local distribution equipment. The proper functioning of the electricity grid depends on the grid's distribution equipment – the substations, feeders, or circuits that help transport electricity from the transmission lines to customers' homes – having enough capacity to handle the amount of electricity that runs through them. If spikes in energy demand begin to require more electricity than the equipment is designed to handle, then that infrastructure must be upgraded to accommodate the higher demand.[21] Because such upgrades can be costly for utilities, the penetration levels at which EV demand would trigger upgrades is currently a subject of study by utility operators and related professional organizations.

A 2014 study by the energy consulting firm Energy and Environmental Economics (E3) looked into this question in California, where it modeled the impact of large-scale EV charging on California's distribution equipment within the next 15 years. Figure 1 (below) shows the number of upgrades to distribution equipment that EV growth would trigger in the Los Angeles and San Francisco metropolitan areas by 2030, modeling for both medium (ZEV Most Likely, around 2.2 million EVs) and high (ZEV x3, around 6.6 million EVs) levels of EV penetration. The study found that, although the grid's current distribution system could handle EV charging demand at medium levels of penetration, high numbers of EVs would quickly overload the grid's distribution capacity.[22]

20. U.S. Department of Energy. "Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviors – Experiences from Six Smart Grid Investment Grant Projects." Smart Grid Investment Grant Program. December 2014. Page iv. Available at http://1.usa.gov/1Ci7bWK.
21. Energy and Environmental Economics (E3), Inc. "California Transportation Electrification Assessment Phase 2: Grid Impacts." October 2014. Page 38. Available at http://bit.ly/1RwI9bp.
22. Ibid at footnote 21. Page 41

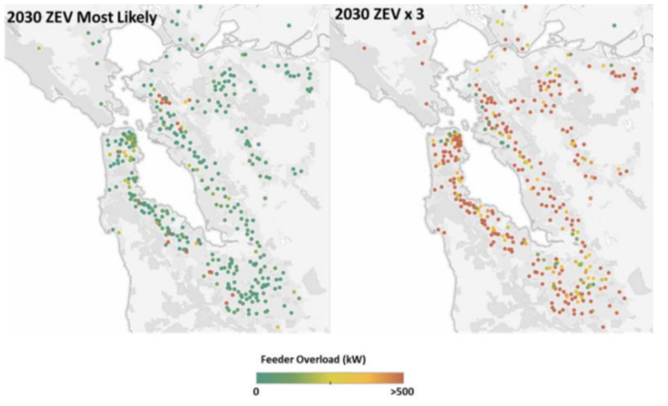
Figure 1: Impact of EVs on California's distribution system



ZEV Most Likely = ~2.2 million EVs

ZEV x3 = ~6.6 million EVs

2030 Distribution system upgrades driven by EV charging: Los Angeles area



2030 Distribution system upgrades driven by EV charging: San Francisco Bay area

Source: E3, "California Transportation Electrification Impacts Phase 2: Grid Impacts."

At the moment, the impact of EVs on distribution infrastructure is still small, even in areas like California where the EV market is relatively developed. In 2015, California had a total of 150,000 EVs operating within the service areas of its three largest investor-owned utilities, but only 208 of these EVs, or 0.1% of the total number of EVs in operation, triggered an upgrade in local distribution equipment.[23] Based on the above study, California still has ample time before EVs constitute a threat to its grid, giving it an opportunity to institute demand response measures that would aid their integration with the current electricity infrastructure. The E3 study also concluded that these DR measures would be profitable,

23. Pacific Gas & Electric, San Diego Gas & Electric, Southern California Edison, "Joint IOU Electric Vehicle Load Research Report 4th Report," Filed April 2015. Page 1.

providing economic benefits at least 33% higher than would be realized without managed charging.[24] (See Section 3.1.1)

This has prompted several utilities to begin investigating the feasibility of shifting EV charging times, even in areas where EV penetration has not yet reached a level where it might be a problem. Pilot projects on this issue are being conducted preemptively with small numbers of EVs, with the intention of scaling up the projects as EV deployment increases and the risk of EV charging triggering equipment upgrades increases. A selection of these pilot projects are described in detail later in this report.

Although these pilot projects are often based in areas with fast-growing EV fleets, they don't always involve a large number of EVs. The E3 report indicated that, when EV penetration reaches a certain level, distribution system upgrades can be triggered quickly and in rapid succession.[25] As a result, most utilities working on these projects are not waiting until EV penetration is large enough to begin requiring upgrades to equipment. Rather, they are taking advantage of the available time window to begin testing demand response measures with EVs, so that they can be fully developed when issues begin to manifest.

3.2 Potential to shift EV charging times using DR

The simplest method of integrating EV charging with DR is through the use of price signals to induce consumers to shift charging times for their EVs to off-peak hours. There are a number of pricing methods used for this purpose, described below:

- *Time of Use (ToU) pricing: Utility sets different electricity prices for different times of the day, usually varying hourly.*
- *Critical Peak Pricing (CPP): Utility initiates further price increases if an unexpected shortage of electricity supply occurs for a limited number of days of the year*
- *Real Time Pricing (RTP): Electricity is priced in real time depending on the supply and demand during that period.*

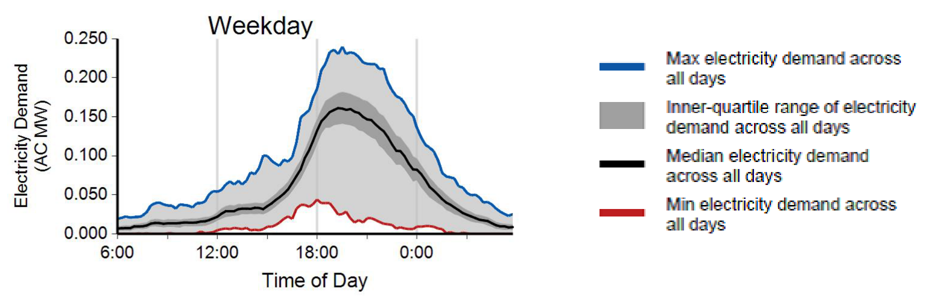
Note: the above mentioned pricing signals are also commonly used in price-based demand response programs.

The effects of the first method, Time of Use rates, was examined in a 2013 study by the EV Project, a U.S. Department of Energy-funded program that examined EV driving patterns in metro areas across the

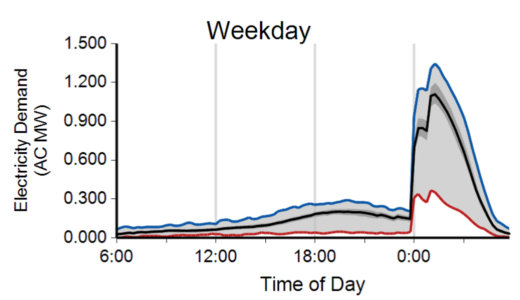
24. Ibid at footnote 21. Page 41.
25. Ibid at footnote 21. Page 43.

US.[26] Working with a sample size of approximately 8,000 residential participants, the study measured the start time for charging in areas with both flat and ToU rate structures. The results showed that customers were largely willing to switch their charging times in the face of such incentives, with the difference in charging times for EV chargers in Fort Worth (flat rate) and California (ToU rate) showcasing this effect.

Figure 2: Impact of ToU rates on load shifting



Electricity demand from EV charging in Fort Worth, Texas (Flat rate)



EV charging electricity demand in San Diego, California (ToU rate, lower rate beginning at midnight)

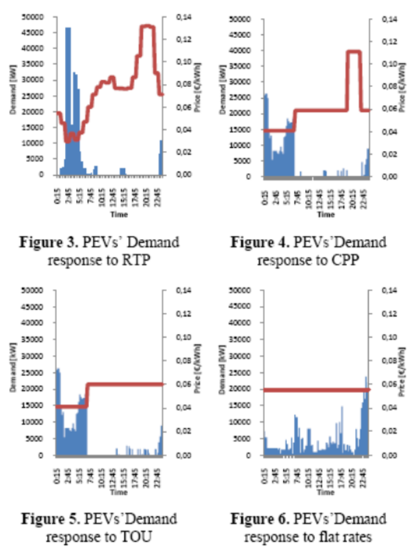
Source: The EV Project. "EV Project Electric Vehicle Charging Infrastructure Summary Report."

A similar study in Spain looked at the impact of ToU pricing alongside CPP and RTP methods. Instead of observing a sample of EV users, the study modeled the impact that such pricing schemes would have on grid demand for a hypothetical penetration of EVs (30.8% penetration of plug-in hybrid EVs, 37.7% penetration of pure EVs, chosen according to EU target rates of EV adoption in 2030).[27] The study found that each price scheme succeeded in shifting charging times to the target periods (i.e. the periods with lower electricity prices). However, in terms of system congestion, the results were not entirely positive,

26. The EV Project. "EV Project Electric Vehicle Charging Infrastructure Summary Report." July 13, 2014. Available at http://1.usa.gov/1MFrXsr.
27. Cruz-Zambrano et. al. "Demand Side Management and Electric Vehicle Integration." 21st International Conference on Electricity Distribution. June 6-9, 2011. Page 2. Available at http://bit.ly/1o5XN5M.

as lower price periods created unwanted demand spikes when a large numbers of EV owners scheduled their vehicle charging for the start of a low price period.[28] This was especially problematic with RTP, leading the study's authors to suggest that these pricing methods be combined with other demand response strategies to avoid these undesirable results.

Figure 3: EV charging responses to different pricing methods



Note: Blue bars indicate EV charging, red line indicates electricity price levels.

Source: 21st International Conference on Electricity Distribution. "Demand Side Management and Electric Vehicle Integration."

One possible solution is to use "end charge" time programming. This technology, already available in many EVs, allows EV owners to program when their cars will finish charging, rather than what time they want the charging session to start. For an EV owner charging their vehicle overnight, the period of time available for charging is often longer than what is necessary for a full recharge, allowing the utility to delay charging for a select number of vehicles and avoid an inrush of electricity demand at any particular time. Southern California Edison, a utility company in California that offers this service to its customers, found that it helped minimize the impact that EVs in its service area had on its grid functioning.[29] In this approach, ToU prices can still be used to incentivize customers to charge during off-peak hours, with an additional incentive possibly given to those who choose to set an "end charge" rather than a "start charge" time.

There are other, more complex methods of using demand response with EVs, such as giving utilities the

28. Ibid. Page 4.
29. Southern California Edison. "Southern California Edison's Key Learnings about Electric Vehicles, Customers and Grid Reliability." August 6, 2013. Page 3. Available at http://on.edison.com/22vuxbN.

ability to delay charging directly when they need to reduce load or allowing EVs to bid into utility markets for ancillary grid services. The various available approaches are discussed later in the report through the introduction of different pilot projects that are making use of them.

3.3 Renewable energy integration potential

Successfully implementing DR with EVs would also allow EVs to be used as a resource to integrate greater levels of renewable energy with the grid. This has been a growing concern for utilities: renewable energy sources like wind and solar PV can only be produced when the input resources (i.e. wind or sunlight) are available, giving renewable energy generators very little flexibility to match their supply with actual electricity demand. If the renewable energy supply exceeds demand (for example, in off-peak periods), then that electricity would need to be curtailed by the grid operator.

This is an especially salient issue in California as it experiences higher levels of renewable energy penetration, particularly solar energy. In 2014, California had to curtail 465 MW of wind and 657 MW of solar.[30] Although these overall curtailment rates are still relatively low, they're expected to ramp up as California's renewable energy supply increases. Forecasts indicate that as California's renewable energy penetration scales up from 33% (its current commitment) to 40% (what it considers an achievable goal), up to 15% of the additional renewable energy might need to be curtailed. This would mean that California would have to add even more renewable energy to meet its targets at a diminishing return, unless steps are taken to minimize these curtailment issues.

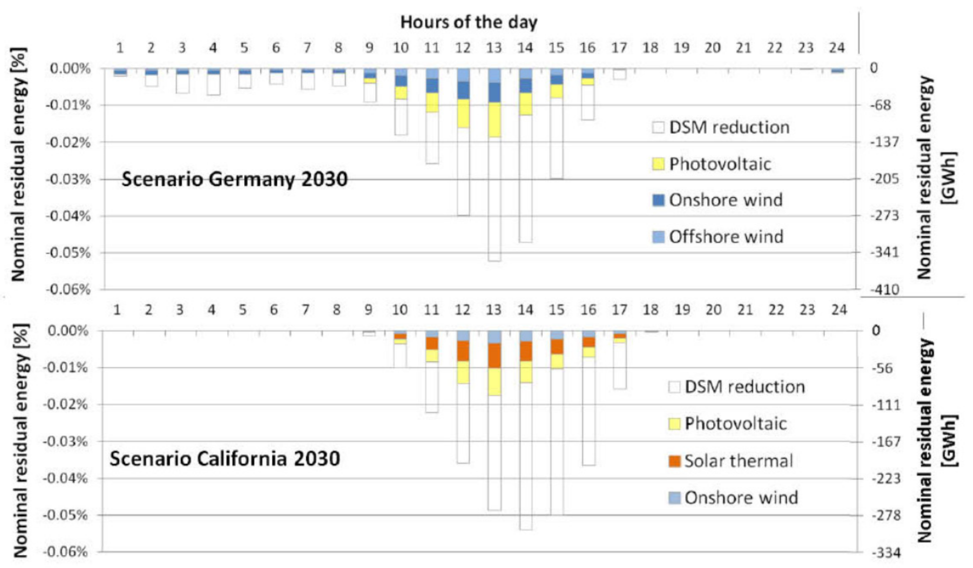
Using DR to manage EV charging offers a way to do this. EVs constitute a "flexible load," i.e. their charging times can be coordinated with renewable energy generation to ensure that demand is able to ramp up in accordance with supply of clean energy. This can often be done using optimized pricing methods like those described in Section 2.2. If electricity prices are adjusted in real time so that lower prices correspond to periods of high renewable energy supply, EV charging software can be programmed to charge during those periods to simultaneously integrate renewable energy and lower the EV user's electricity bill. One study modeling this type of approach found that, based on expected renewable energy penetration in California in 2030, this type of demand-side management (DSM) could reduce oversupply of renewable energy by up to 72.6%.[31] The impact was also substantial (albeit slightly lower) for Germany, which was predicted to reduce oversupply by 64%.

The chart below shows the reductions in oversupply of renewable energy on an hourly basis, corresponding to periods of the day when production of wind and solar energy are high. In the graph, "residual energy" refers to the energy demand that cannot be satisfied by renewable energy at a given

30. Howarth, David and Bill Monsen. "Renewables Face Daytime Curtailments in California." Project Finance Newswire. November 2015. Page 12. Available at http://bit.ly/1Ker5qO
31. Dallinger, David, Gerda Schubert, and Martin Wietschel. "Integration of intermittent renewable power supply using grid-connected vehicles: A 2030 case study for California and Germany." Fraunhofer ISI, No. S4/2012, http://bit.ly/1ShbIkf.

time (i.e. there is not enough wind or solar power available to meet demand). A negative amount of residual energy means that more renewable energy is being produced than is needed to satisfy demand. The parts of each bar blanked out by "DSM reduction" indicate the amount of this oversupply that could be used if EV charging was managed with optimized pricing signals.

Figure 4: Reduction of renewable energy oversupply using DSM with EVs in Germany and California



Source: Dallinger et. al. "Integration of intermittent renewable power supply using grid-connected vehicles: A 2030 case study for California and Germany."

In recent years, numerous pilot projects have been established across the world to test the potential to integrate EVs with DR and renewable energy. The following sections introduce several of these projects in various countries. Most of these projects are either still in progress or recently completed, so many of them have not yet released information on their results. However, each case offers a potential model for how such a project could be developed, providing lessons for the design of future projects on EV-DR integration.

4 Cases in the U.S.

4.1 SDG&E Electric Vehicle Grid Pilot Programs

San Diego Gas & Electric (SDG&E), one of California's three largest investor-owned utilities, is developing a handful of EV-grid integration projects to respond to the increasing use of EVs in its service territory.

4.1.1 Drivers and Conditions

California's government has a long history of supporting alternative fuel vehicles like EVs. The state is also one of the main areas of growth for clean energy technologies like renewable energy and storage technology. SDG&E's pilot project is driven by a number of factors related to these conditions, including:

- State support for EV adoption: California is the largest market for electric vehicles in the United States, a result of concentrated policy support that the state has developed for EVs. The most impactful policy is California's Zero Emission Vehicle (ZEV) mandate, which requires that a set percentage of vehicles sold in the state each year have no tailpipe emissions.[32] The program is run by the California Air Resources Board and was initially created to address air pollution issues in major metropolitan areas like Los Angeles. The current Action Plan for the mandate aims to have 1.5 million ZEVs operating in California by 2025.[33]

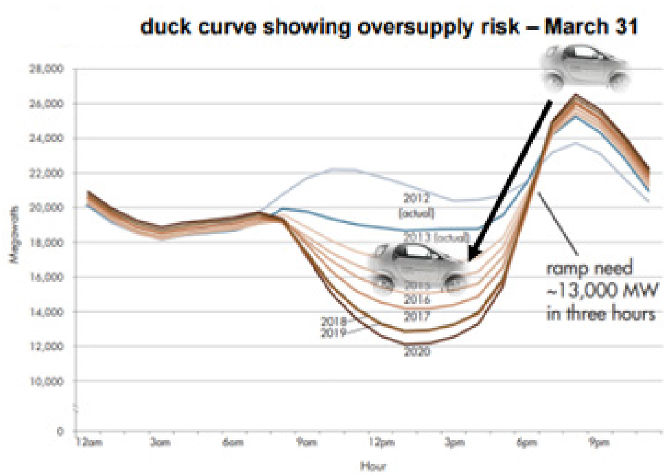
- A large and rapidly growing EV fleet: SDG&E currently has around 19,000 EVs in its service area, and it expects this number to increase though California's ZEV mandate.[34] As a result, the utility is not only exploring methods to ensure it can accommodate this increased energy demand without overstressing its distribution grid, but also ways it can use EVs as a resource that can be harnessed to improve grid stability.[35] This is especially of interest to the utility because of the growing penetration of renewable energy in its service territory (below).

- Growing need to integrate variable renewable energy into the grid: SDG&E's service area also has large capacities of renewable energy; in 2015, it became the first California utility to source one-third of its energy from renewable sources.[36] A large proportion of this is solar energy, a variable resource that, at high penetrations, can create surges in energy supply during daylight hours. These surges are creating a condition that's become known as a "duck curve," where large supplies of solar energy create a low "net load" (i.e. energy demand minus renewable energy supply) in the daytime, with a sudden ramp-up when the sun goes down and the supply of solar energy is cut. This dramatic ramp-up is difficult for utilities to manage because it requires conventional thermal generation to be brought

32. "History of California's Zero Emission Vehicle (ZEV) Program." Union of Concerned Scientists. Available at http://bit.ly/1K8SJWd.
33. San Diego Gas & Electric. "SDG&E to Install Thousands of Electric Vehicle Charging Stations." SDG&E Newsroom. January 28, 2016. Available at http://bit.ly/1WKIhZ2.
34. Ibid at footnote 33.
35. San Diego Gas and Electric. "SDG&E Integrates Electric Vehicles and Energy Storage Systems into California's Energy and Ancillary Service Markets." SDG&E Newsroom. Available at http://bit.ly/1GFHUtE.
36. San Diego Gas & Electric. "SDG&E Seeks Energy Storage, Renewable, and Other Clean Energy Resources." SDG&E Newsroom. March 7, 2016. Available at http://bit.ly/1Un1UZS.

online at an unusually fast pace. If solar energy development continues as expected, then this trend may become even more problematic over the next few years[37] (see Figure 5). Managed charging of EVs offers one way to balance electricity supply and demand; if EVs are charged during daylight hours (i.e. the "belly" of the duck), then they can smooth out the load curve and make the demand ramp-up in the evening hours smaller and easier to handle.

Figure 5: Duck curve: Switching EV charging times to "belly" of the duck



California hopes to direct EV charging to periods when solar energy is plentiful in order to avoid steep increases in energy generation needs going into the evening (x-axis is net load, y-axis is time of day)

Source: California Independent Systems Operator, "Explanation of Data, Assumption, and Analytical Methods"

- Avoided system upgrade costs: Upgrades to existing utility infrastructure can often run into the millions of dollars, and there's evidence that ZEV-mandated EV growth will increase the need to make such upgrades. The E3 study (mentioned in section 2.1) found that costs from EV-driven upgrades through 2030 would approach $400 million. Controlling charging to off-peak periods using price signals cuts this price tag to under $150 million.[38] In addition, when considering the costs and benefits of increased EV use holistically, the study found that the use of off-peak charging delivered regional economic benefits of $4.34 billion, over one-third more than would be developed without such charging controls[39]

37. California Independent System Operator. "Explanation of Data, Assumptions, and Analytical Methods. January 22, 2016. Available at http://bit.ly/1N9FWXD.
38. Ibid at footnote 21. Page 43.
39. Ibid at footnote 21. Page 56.

4.1.2 Actions and Measures

SDG&E has set up two pilot projects within its service area to address the above concerns. The components of these two projects are outlined in more detail below.

SDG&E Application VGI Rate Pilot:

This pilot is designed to expand access to EV charging stations and collect data on the ability for different pricing structures to impact charging times. It was approved by the California Public Utilities Commission in January 2016 and is scheduled to last four years. Specific measures include:

- EV charging station construction in multi-unit dwellings: The project identified that, although over 50% of San Diego residents live in residences with more than one tenant, 88% of current EV drivers live in single-family homes.[40] In order to expand EV ownership opportunities beyond people living in detached houses, SDG&E proposed to build 3,500 charging installations in a mix of workplace and multi-unit dwellings within SDG&E's service area. These new charging stations will also provide data for the rest of the project.[41]

- Data collection on price signals' impact on charging behavior: In order to encourage off-peak EV charging and test the potential for charging to be integrated with DR, SDG&E has developed a variable Vehicle Grid Integration (VGI) Pilot Rate for EV owners, which will display hourly differences in electricity rates on a day-ahead basis. Differences in electricity prices will reflect different grid conditions, such as peak vs. off-peak generation and availability of renewable energy. Customers can view these rates on the VGI Pilot Program smart phone application or website and plan their charging accordingly. SDG&E plans to collect data from the impact of this variable pricing structure to understand how it affects charging behavior and grid utilization.[42]

SDG&E Optimized Pricing and Resource Allocation Pilot:

This pilot is testing the ability for SDG&E to use electric vehicles within its territory as a grid resource. It includes:

- Integration of EVs into the grid as a service provider: SDG&E is attempting to "aggregate" EV fleets in five locations throughout San Diego County to act as a single grid resource in California's electricity markets. The EV chargers are equipped with remotely controlled software that allows the charging schedule of participants to be adjusted in order to provide DR services to the grid. The adjustments are made according to wholesale energy prices: participants agree not to charge their EVs during certain high-price periods and are paid the marginal energy price during those hours. By developing the connection between grid conditions and customer response, SDG&E ultimately hopes to not only use EVs to reduce charging during peak hours but also to begin charging when signals from the grid

40. San Diego Gas & Electric. "Application of San Diego Gas & Electric Company (U 902-E) For Authority to Implement A Pilot Program For Electric Vehicle-Grid Integration." Application No. 14-04. Filed April 11, 2014. Page 2. Available at http://bit.ly/194csaQ.
41. Ibid at footnote 39. Page 4.
42. Ibid at footnote 39. Page 4.

show that renewable energy is available.[43]

- Incorporation of stationary storage: To ensure that these EV fleets are able to deliver the necessary level of demand response, SDG&E also included stationary storage units in the pilot. These storage units were also "aggregated" with the EV fleets and can respond to signals to absorb or discharge energy if the EVs alone are unable to meet the utility's DR needs.

4.2 BMW i ChargeForward Program

The BMW i ChargeForward program is a joint program between vehicle manufacturer BMW and California utility Pacific Gas & Electric (PG&E) Company. PG&E is the largest investor-owned utility (IOU) in California and one of the largest in the US, providing electricity and natural gas to 16 million people in Northern and Central California.[44] Both stakeholders had monetary incentives for joining the project, as described below:

4.2.1 Drivers and Conditions

- Pre-existing demand response program: PG&E has various DR programs, where it offers financial incentives to participating customers who reduce energy use in response to signals from the utility.[45] The DR programs provide resources necessary to allow PG&E to meet peak demand, as well as helping to address concerns over possible demand emergencies.[46] The DR programs also play a key role in achieving demand reductions, delaying the need for PG&E to upgrade power lines and other equipment to handle spikes in demand.[47]

- Large number of EVs: PG&E currently has over 60,000 EVs in its service area, a number that it expects to increase with policy support from California's ZEV mandate. It hopes that this project will provide them with information on how to make greater use of these vehicles as a grid service resource in the future.[48]

- Financial opportunities for EV manufacturer: BMW receives monetary compensation from PG&E for participating in the utility's DR program, which it can leverage to lower the cost of ownership for its EVs.[49] BMW hopes that pay-outs from utilities to EV owners could provide an additional incentive for buying an EV, offsetting battery or charging installation costs.[50] The program also allows BMW to use the old batteries from its demonstration EV models as a grid resource, generating revenue from equipment that would otherwise have needed to be recycled or disposed (described below).[51]

43. Ibid at footnote 35.
44. Pacific Gas and Electric. "PG&E and BMW Partner to Extract Grid Benefits from Electric Vehicles." PG&E News Releases. Available at http://bit. ly/1GIHu5Q.
45. PG&E Website. Available at http://bit.ly/1SXApDl
46. California Public Utilities Commission. "Order Approving the Applications of Pacific Gas and Electric Company and Southern California Edison Company for Approval of Demand Response Agreements." May 3, 2007. Page 7.
47. Ibid at footnote 43.
48. Ibid at footnote 43.
49. Ibid at footnote 43.

4.2.2 Actions and Measures

In this project, BMW served as the intermediary between PG&E and the EV users who constituted the program's participants, using the electricity demand from their EVs as a resource for PG&E's DR program. The specific actions taken by BMW include:

- Communication with EV customers: BMW allowed 100 owners of BMW i3 EVs to sign up for its initial 18-month program. During periods where PG&E must curb customer demand, these participants receive alerts through a smartphone app asking them to delay charging of their EV. The participants can decide either to accept the delay or to continue charging. If they accept, software in the charging equipment allows BMW to halt the charging remotely. Participants are paid $1000 up-front (in the form of a BMW gift card) as well as additional payments depending on how many charging delays they accept.[52]

- Utilization of retired EV batteries: This grid resource is supplemented by a collection of "second life" EV batteries, taken from BMW EV demonstration vehicles, which serve as stationary storage. They can fulfill similar functions to the customer-owned EVs and also provide grid balancing for intermittent renewable energies, absorbing the energy when demand for the energy is low and then releasing it when demand picks back up again. [53]

4.3 eV2g Project

The eV2g project is an attempt to develop commercial scale vehicle-to-grid (V2G) services, providing a direct financial benefit for customers who are paid for the grid balancing services provided by their EVs. The primary stakeholders are NRG Energy, a New Jersey-based electricity generator, and the University of Delaware (UD).[54] These two entities created a joint venture called eV2gSM to commercialize a V2G technology developed by UD. The technology allows EVs to send electricity in their batteries back to the grid, a function that expanded the ability for PJM Interconnection, the local transmission operator, to use the vehicles as a DR resource.

50. Boeriu, Haratiu. "BMW Announces The BMW i ChargeForward Program." BMW Blog. January 5, 2015. Available at http://bit. ly/14sllJs
51. Pacific Gas and Electric. "PG&E and BMW Partner to Extract Grid Benefits from Electric Vehicles." PG&E News Releases. Available at http://bit.ly/1GIHu5Q.
52. BMW i ChargeForward project description page. Available at http://www.bmwichargeforward.com/ .
53. Ibid at footnote 43.
54. NRG Energy Investor Relations News Release. April 26, 2013. Available at http://bit.ly/1FSLzCD.

PJM Interconnection operates the wholesale electricity market and manages the supply of electricity to customers in 13 states on the east coast and mid-west of the U.S., including Delaware, New Jersey, and Pennsylvania. It directs the operation of transmission lines in a service area of 60 million people. NRG Energy is an energy provider that manages a power generation portfolio that includes fossil fuel, nuclear, solar, and wind facilities. It serves almost two million customers throughout the US and manages around 50,000 MW of generation capacity.[55]

4.3.1 Drivers and Conditions

The eV2g project grew out of synergies between EV smart charging technology and the frequency regulation market that was already in place with grid operators. Frequency regulation is a type ancillary grid service that balances short-term disparities between energy supply and demand. The service providers in charge of frequency regulation must be able to respond to these disparities within seconds, meaning that fast-acting technologies like EV batteries are ideal providers.

PJM already pays compensation to grid service providers for frequency regulation, so the introduction of EVs as a potential source of this service took advantage of pre-existing understandings and regulations. Specific factors influencing this project include:

- A need for more frequency regulation to balance increased levels of renewable energy: PJM believes electric vehicles can be a useful tool to help smooth out frequencies on the grid, absorbing and discharging electricity to accommodate short-term fluctuations in supply and demand. This would be an especially useful service to integrate a growing supply of renewable energy; short-term fluctuations in wind speeds or sunlight levels can create corresponding fluctuations in supply and demand on the grid, increasing the need for frequency regulation. Many of the states within PJM's operation area have Renewable Portfolio Standards (RPS) which require that their energy providers include a certain amount of renewable energy in their supply portfolios,[56] and as a result PJM is expecting a scale-up in the level of renewable energy in its operating area in the near future.

  The intermittent nature of renewable energy means that PJM will also have to expand its frequency regulation resources to maintain stability. A recent study for the grid operator found that an increase in keeping with the RPS scenario (a 14% penetration of renewable energy) will require a 30% increase in regulation services compared to what is needed for the regular load.[57] As the penetration of renewable energy increases, so does the need to expand regulation resources, meaning that the frequency regulation services provided by EVs have a valuable role to play in PJM's operations.

- Technology commercialization potential: The V2G technology developed by UD proved to be cash-positive in a small-scale campus trial, earning UD $2000 per year for each car's frequency regulation services even when including the cost of retrofitting the cars with the V2G technology.[58] NRG sees this technology as a potential complement to its expanding eVgo charging network that it launched in 2011.[59] With the continued growth of renewable energy technology, the regulation market is expected to double by 2020, reaching $12 billion worldwide,[60] a sizeable increase that NRG would be able to take advantage of with UD's V2G technology. This pilot project is meant to demonstrate the viability of the technology as an asset for owners of EV fleets and, eventually, individual EV owners.

55. Ibid at footnote 53.
56. PJM Interconnection. "A Greener Grid." Page 4. Available at http://bit.ly/1ShcGx1.
57. General Electric International Inc. "PJM Renewable Integration Study: Executive Summary Report." PJM Interconnection. Feb 28, 2014. Page 15. Available at http://bit.ly/22UmhIT.

4.3.2 Actions and Measures

Although the frequency regulation market was already established before this project was set up, adjustments needed to be made to the entry rules for it to take effect. After that, the business venture between NRG and UD designed their own approach to advancing the project.

- Small-scale technology demonstration: UD initially tested its V2G technology in a trial project on UD's campus, where a small fleet of EVs were equipped with bi-directional V2G charging equipment and operated as a grid resource for PJM. In 2011, the pilot used seven vehicles and a large stationary storage system to take part in PJM's frequency regulation market, which required market participants to have at least 500 KW capacity.[61] In 2014, the fleet had expanded to nine EVs and, following changes to PJM's capacity requirements (described below), was able to participate directly in PJM's markets without the assistance of a stationary storage system.[62]

- Reduction of required frequency regulation generator size: In order to allow UD's EVs to be incorporated directly into the frequency regulation market, PJM had to decrease the required size of service providers from 500 KW to 100 KW.[63] This was changed in 2011,[64] allowing the eV2g project's EV fleet to bid directly into PJM's frequency regulation market as a grid resource in 2013.[65] Even with this change, however, the technology to aggregate multiple EVs into a single grid resource (also developed by UD) is critical for the project, allowing a single aggregator to control charging in multiple EVs and offer a frequency regulation resource large enough for the grid to use.[66]

- Provision of car leases to program participants: The eV2g joint venture offers 2 year leases of BMW EVs to vehicle fleet owners in the greater Philadelphia area at rates comparable to their other vehicle leases. Those leasing the vehicles would be participants in the V2G pilot project and be incorporated

58. Fitzgerald, Michael. "Electric Cars Sell Power Back To The Grid." Wall Street Journal. September 28, 2014. Available at http://www.udel.edu/V2G/resources/Fitzgerald-EV-grid-WSJ-28-Sep-2012.pdf.
59. Loveday, Eric. "NRG Energy Launches Nation's 1st Commercial-scale V2G Project." Autoblog. September 27th, 2011. Available at http://aol.it/1If7He7.
60. Gies, Erica. "The Cash-Back Car: Monetizing Electric Vehicles." Forbes. June 23rd, 2011. Available at http://onforb.es/1IbsaO7.
61. Ibid at footnote 59.
62. Ibid at footnote 57.
63. Ibid at footnote 59.
64. PJM Interconnection. "First "Small Scale" Demand-side Projects in PJM " PR Newswire. November 21, 2011, Available at http://prn.to/1SqDiJs.
65. Ibid at footnote 53.
66. Ibid at footnote 59.

into PJM's regional frequency regulation market. Participants would also receive a Level 2 charging device with each leased vehicle.[67]

4.4 Experiences and Lessons Learned

Although these U.S.-based projects adopted different models for EV-DR integration, there are several commonalities among the approaches that point to broader lessons for designing VGI projects.

- Proper structuring of incentives: Each pilot project used different forms of monetary incentives to encourage optimized charging of EVs. SDG&E varies electricity rates based on availability of electricity to promote EV charging during periods of abundant supply. PG&E and BMW provide direct payments to EV owners who agreed to short-term interruptions in their cars' charging cycles. The eV2g project was only made possible because of PJM's payments to providers of frequency regulation. These incentives not only encourage the development of these projects but also create the potential for business models to be built around EV-DR integration (as with the eV2g project), which would help these projects scale up over the long term.

- Engagement with utilities: In each project, the utility was either a leading stakeholder or an important collaborator. This showcases the fact that project implementation is most successful when the utility is informed and understands the potential benefits of the project to their operations.

- Incorporation of stationary storage: Pilots by both SDG&E and PG&E used stationary storage to help manage DR events, and the eV2g project initially employed a stationary storage system to allow its EV fleet to meet the capacity requirements for the transmission operator's frequency regulation market. Incorporating stationary storage into the project helps to further improve grid flexibility and can serve as a back-up DR provider in the event that EVs alone prove incapable of providing a required load reduction.

67. Grid on Wheels project website. Available at http://grid-on-wheels.com/

5 Cases in Europe

5.1 FINESCE Project (Ireland)

The main stakeholder in this project is ESB Networks, Ireland's electricity distributer, which has over 2 million customers with a total energy consumption of more than 23,000 gigawatt hours (GWh, statistics from 2010).[68] The project is largely a scoping study conducted by the utility to understand the effect of EVs on its grid operations and was motivated by a number of factors.

5.1.1 Drivers and Conditions

- Expected increase in EV use: Although the uptake of EVs in Ireland has been slower than expected, the country has a target of 10% penetration of EVs by 2020 (about 230,000 cars total) under the EU Renewable Energy Directive.[69] Because Ireland's electricity grid was not built with EVs in mind, the utility wanted to conduct a scoping study to determine the potential impact this development would have on the grid and how it can potentially be used as a resource. ESB Networks, expecting EV uptake to accelerate in the near future, wants to begin preparing its adjustments early so that it will not be caught off-guard by future growth.[70]

- Lack of local data on EV impact: ESB was concerned that international studies on EV charging behavior would not necessarily represent the habits of EV users in Ireland.[71] It thus proposed this project as a way to gain local data that it could use to more accurately predict what steps it would need to take to control the new demand on the grid from EVs.

5.1.2 Actions and Measures

The project has two parts, which collectively address both the data-gathering and test implementation components of the project. These include:

- Observation of EV charging behavior: This will be an observational study of EV charging patterns in Ireland to determine their overall impact on Ireland's grid. To do this, ESB installed metering and communication systems into the charging infrastructure of a select number of participating EV owners throughout Ireland. The scope of this observational study extended to what types of charging were most popular, whether EV charging was clustered in certain locations, and other macro-level data on EV user behavior.[72] Customer surveys were used to better understand EV owners' intentions and attitudes in each area of charging behavior.[73]

68. ESB Networks website. Available at http://www.esb.ie/esbnetworks/en/about-us/index.jsp
69. ESB Networks. "Electric Vehicle Pilot: R&D Project Submission Summary." Page 3. Available at http://bit.ly/1S7RvL3.
70. Ibid at footnote 68. Page 4.
71. Ibid at footnote 68. Page 4.
72. ESB Networks. "Preparation for EV's On The Distribution System Pilot Project Implementation Document." May 27, 2013. Page 23. Available at http://bit.ly/1VHJySs.
73. Ibid at footnote 71. Page 24.

- Smart charging pilot project: After this initial data collection, the project plans to demonstrate how smart charging can be used to enable effective load management and, potentially, absorb power from variable renewable energy. The project set up trial operations in rural neighborhoods around Dublin, some of which already had pre-existing smart grid pilot projects, in order to measure the effect that smart charging solutions have on overall grid management of EV power demand. [74] In one proposed trial, ESB planned to provide up to 15 participants with EVs and smart meters to measure the impact of unmanaged charging for eight weeks. The project would then test simple managed charging (i.e delaying the start of charging, or setting charging to begin at a specific time), and then install Smart Charging units to measure the further benefits of more advanced smart charging.[75]

5.2 BMW Controlled Charging Berlin Pilot (Germany)

As a major market for both renewable energy and electric vehicles, Germany was a natural site for this type of project. In this pilot, German car manufacturer BMW collaborated with Swedish utility Vattenfall to examine the potential for managed EV charging to benefit grid functioning. The program began in March 2013 and is scheduled to run through 2015.[76]

5.2.1 Drivers and Conditions

- High renewable energy penetration: Like California, Germany's renewable energy capacity has been expanding rapidly. In 1991 the German government instituted a feed-in tariff for renewable energy that jump-started the industry and turned Germany into one of the world leaders in renewable energy production.[77] The country currently receives 30% of its energy supply from renewable sources on average,[78] and the government has a target of having renewable energy make up 80% of its net energy consumption by 2050.[79]

- Introduction of storage capacity on grid functioning: With the share of variable renewable energy continuing to increase, Germany's need for additional storage resources are especially salient. Estimates forecast that managing a renewable energy share of 80% will require between 950 GWh and 1,534 GWh of storage capacity.[80] The growing market for EVs in the country can contribute a portion of this storage capacity, providing the utility with a resource to maintain grid stability.

74. Ibid at footnote 71. Page 30.
75. Ibid at footnote 71. Page 31
76. BMW Group. "Power Up: How E-Mobility Will Support The Transition To Renewable Energies." Presentation at the 2015 International Renewable Energy Storage Conference 2015. Available at http://bit.ly/1RyR9my.
77. Dr. Lang, Matthias and Annette Lang. "Overview Renewable Energy Sources Act." German Energy Blog. Available at http://www.germanenergyblog.de/?page_id=283
78. Martinot, Eric. "Grid Integration of Renewable Energy: Flexibility, Innovation, Experience." Beijing Institute of Technology. February 2016. Page 4. Available at http://bit.ly/1q1O9mu.
79. Ibid at footnote 77. Page 3.
80. stoRE Project. "GERMANY: Overview of the electricity supply system and an estimation of future energy storage needs." Page 49. Available at http://bit.ly/1ZrJp5x.

- Existing base for EV production and sales: BMW is headquartered in Munich and counts Germany as one of its primary market for its EVs. The EVs it sells in the country constitute a potentially large source of flexible demand that could be used to smooth the integration of Germany's renewable energy supply with the grid. BMW's pilot project in Berlin is meant to examine how incentives and smart energy management systems could be used with EVs to stabilize the grid and increase uptake of renewables.

5.2.2 Actions and Measures

- Test Pilot with BMW EV users in Berlin: The project looked at the charging behavior of a small sample of 30 BMW EV customers in three phases, testing how different incentives could promote grid-friendly charging behavior. Participants could take advantage of these incentives through a smartphone app. BMW compared the participant's charging time to the previous two years of charging data from BMW EV users and found that they were effective at shifting charging times to more ideal periods.[81] The eventual introduction of V2G technology is expected to provide a sustainable business model for this type of project.[82]

- Wind-to-vehicle-to-grid (W2V2G): Another aspect of the project looked at whether using vehicles as an intermediary between wind energy and the grid could improve uptake of renewable energy. In this portion, wind energy produced during periods of low demand was fed into electric vehicles, which are designated as Local Load Management service providers. The EVs held onto the power until demand rose, after which they could feed it back into the grid.[83]

5.3 Denmark: EDISON Project

The EDISON project looked into the potential for EVs to help integrate high levels of variable renewable energy into the Danish power grid. The project was funded by Denmark's transmission system operator Energinet.dk and involved collaboration among a number of different stakeholders, including IBM, Siemens, Dong Energy (Denmark's primary energy provider), and the Danish Energy Association.

Energienet.dk is a Danish not-for-profit company that operates the transmission system for gas and electricity in Denmark. It's tasked with maintaining Denmark's electricity supply and transmission infrastructure, as well as creating transparent conditions for the functioning of Denmark's energy markets.[84]

81. Westerburg, Michael and Xaver Pfab. "Grid Integration of E-Mobility – 'Controlled Charging V3.0.'"Presentation at Kraftwerk Batterie. April 28-19, 2015. Slide 15.
82. Ibid at footnote 75.
83. "E-Mobility News: Two-Way Communication Between EV and Charging Infrastructure." Vattenfall project website. July 26, 2012. Available at http://bit.ly/1SVW26V
84. Energienet.dk website About Us page. Available at http://bit.ly/1Srbkx7.

5.3.1 Drivers and Conditions

- High levels of wind energy penetration: As a percentage of total energy use, Denmark has the highest levels of wind energy penetration in the world. In 2014, Denmark set a new world record by getting 39% of its overall electricity from wind energy alone, and it plans to achieve 50% by 2020. By 2050, the country aims to have totally decarbonized its power sector.[85] As a result, Energinet.dk is currently dealing with high levels of variable electricity supply that are expected to increase in the near future. EVs are being investigated as a potential "buffer" for this variable power production.[86]

- Suitable test location: The project's test site on Bornholm Island offered an ideal location to demonstrate these ideas. Located in the Baltic Sea to the east of mainland Denmark, Bornholm has sizeable levels of wind energy generation that is reflective of the expected future electricity mix for Denmark proper. As an island, it can operate largely independently of the main electricity grid, allowing it to take on exploratory projects like EDISON. Finally, because the island is small in size, most of its residents' driving distances stay within the typical available range of modern-day EVs.[87]

5.3.2 Actions and Measures

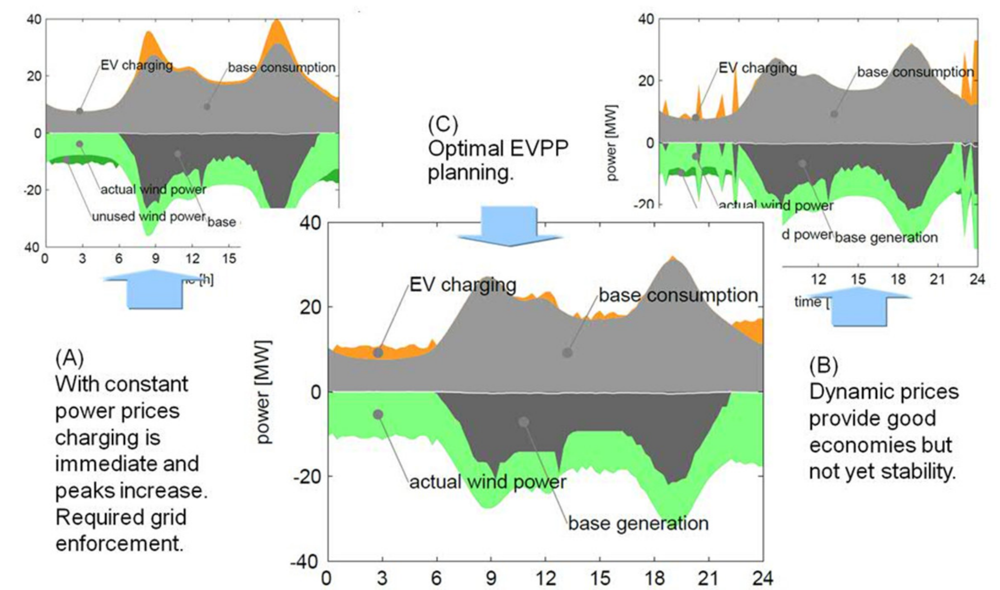
The EDISON project included seven working groups addressing several different elements of EV-grid integration. Some of the project's major activities are described below.

- Grid impact simulation: In order to determine the potential impacts of EVs on Bornholm's power system, the project used information from transportation surveys and historical price data from the Nordic day-ahead power market to model charging patterns for different charging strategies. The strategies the model considered included uncontrolled "dumb" charging, timer-set charging, and optimized charging where a third party manages the EV's charging times to correspond to low-price periods. Because a large supply of wind energy generally pushes down electricity prices on this market, cost-effectively charging EVs had the added effect of maximizing the use of clean energy. It also modeled different levels of EV penetration to gain a more complete view of the potential impacts EVs could have on Bornholm's distribution grid.[88]

- Development of communication technology to allow for optimized charging: In order to test managed EV charging, the EDISON project created the conceptual role of "Fleet Operator." This is a third party operator who oversees the charging schedules of multiple EVs, occupying a position similar to an aggregator in traditional DR programs. The Fleet Operator receives spot electricity prices and preferred load curve information from the grid operator, as well as data on historical driving trends from the EVs in their fleet. The Fleet Operator uses this information to devise an optimal charging strategy for each EV, which it forwards to the EV charging equipment for execution.[89] This third-party charging management strategy worked more effectively than having EV owners program their own charging times according to ToU rates because aggregators could schedule EV charging to avoid the unwanted charging inrushes that were described in section 2.2 (see Figure 6 below).

85. Smith, Tierney. "Five Countries Leading the Way Toward 100% Renewable Energy." EcoWatch. January 9, 2015. Available at http://bit.ly/1FJhbgt.
86. EDISON Project Executive Summary. Available at http://bit.ly/1KP2VR5.
87. Gantenbein, Dietar et al., ed. "WP3 – Distributed Integration Technology Development." EDISON Consortium. April 30, 2011. Page 37. Available at http://bit.ly/1UkaV5X.
88. Wu, Qiuwei et al., ed. "EV Portfolio Management and Grid Impact Study." EDISON Consortium. March 22, 2012. Available at http://bit.ly/1MBPyVn.

Figure 6: EV charging in EDISON project: constant pricing, variable pricing, and Fleet Operator managed



The Fleet Operator is able to create an optimized schedule for EV charging that smooth's out the load curve and takes advantage of available wind power (bottom middle graph). This is similar to the "end-use" charging method discussed in section 2.2, with the Fleet Operator scheduling charging according to directives from EV owners about when they need their vehicle to be fully charged

Source: Edison Project website

In order to automate this system, the EDISON project developed a hardware/software package that the Fleet Operator can use to communicate with the grid operator and EV charging equipment and handle the necessary calculations.[90]

- Test pilot on Bornholm Island: The EDISON project's third-party managed charging system described

89. Ibid at footnote 86. Page 24-25.
90. Ibid at footnote 86. Page 22.

above was tested on Bornholm. The test was carried out and overseen by Ostkraft Holding, the distribution systems operator on Bornholm, and included a small number of EVs owned by Ostkraft.[91] The project also ran a computer simulation of managed charging on Bornholm at higher levels of EV penetration, taking into account different driving patterns and potential distribution of charging stations.[92] Finally, five Mitsubishi EVs were equipped with data collection technology and leased to different residents of the island to gain more data on driving trends.[93]

5.4 Experiences and Lessons Learned

- Background research on driving patterns and grid impacts: Both the FINESCE and EDISON projects began with an in-depth study of driving patterns for EVs and potential impacts on the grid. Importantly, both studies looked not just at total number EVs connecting to the grid but also how the location of these EVs affected their grid impact, considering how a clustering of EVs in a single location could impact local distribution infrastructure more than if the geospatial allocation of EVs was more spread out.
- Small-scale tests with a limited number of vehicles: Each project tested the use of managed charging with a small number of EVs. Although the number of EVs used in the trial was limited (ranging from as few as five in some pilots), the opportunity to test managed charging in a real-world setting was valuable for assessing the feasibility of using DR with EVs.
- Development of effective communication technology between EVs and grid operators: An effective hardware/software package to allow grid operators or other DR providers to communicate with and adjust EV charging equipment is a necessary component of many of these projects, and the development of such a technology solution was a focus of both the FINESCE and EDISON projects. In the case of EDISON, a breakdown in communication between EVs and operators caused issues with its real-world trial of managed charging.[94] Although the project was still able to conclude that managed charging was feasible, it was able to collect less data than it originally planned.[95]

91. Bendtsen, Maja Felicia., ed. "Real Life Testing of Developed Technologies." EDISON Consortium. June 10, 2012. Page 5. Available at http://bit.ly/1VDO4RU.
92. Gantenbein, Dietar et al., ed. "WP3 – Distributed Integration Technology Development." EDISON Consortium. April 30, 2011. Page 39. Available at http://bit.ly/1UkaV5X.
93. Ibid at footnote 90. Page 17.
94. Ibid at footnote 90. Page 6.
95. Ibid at footnote 90. Page 3.

6 Cases in Asia

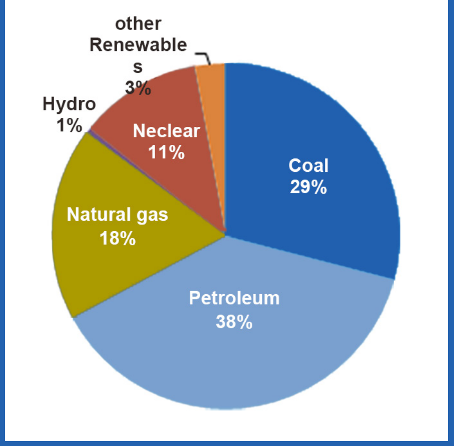
6.1 Jeju Island Smart Grid Test-Bed (South Korea)

South Korea has been aggressively promoting clean energy for the past couple of decades, and the integration of EVs and DR with renewable energy has been already partly realized through a smart grid pilot project on Jeju Island. The initial project period ended in May 2015, but Jeju's efforts are still on-going and even expanding, with efforts scaling up nationwide.

6.1.1 Drivers and Conditions

There are a few drivers and underlying conditions behind Korea's efforts to establish a nation-wide smart grid system, where advanced communications information technology enables the grid system to integrate renewable energy, demand-side resources, and electric vehicles in a more systematic and coordinated way. These factors include:

Figure 7: Korea's energy mix for primary consumption, 2012



Source: Based on KEEI data

- Heavy dependence on imported energy: Korea has scarce energy reserves and is therefore heavily dependent on imported energy resources. In 2012, Korea imported about 95% of its primary energy consumption.[96]
- Climate change mitigation and the need for sustainable development: The Korean government announced its "Low Carbon, Green Growth" initiative in 2009, presenting an aggressive GHG emission reduction target of cutting 30% of the estimated emission level in 2020.[97] With the fastest growth rate among the OECD countries, this 30% reduction target is a challenge. The Korean government needed to find a new industry development model that emphasizes clean energy while still ensuring sustainable growth.
- Stong information technology industry: Korea's information technology has been developing rapidly for the past couple of decades, and the country has built strong capacity in this area.

96. Korea Energy Economics Institute. Available at www.keei.re.kr. Also, according to the US Energy Information Administration, "In 2013, Korea was the second-largest importer of liquefied natural gas (LNG), the fourth-largest importer of coal, and the fifth-largest net importer of total petroleum and other liquids." http://1.usa.gov/1RPzEbh
97. Presidential Commission on Green Growth. "Road to Our Future: Green Growth – National Strategy and the Five-Year Plan (2009-2013). Republic of Korea. 2009. Available at http://bit.ly/1t33WmK.

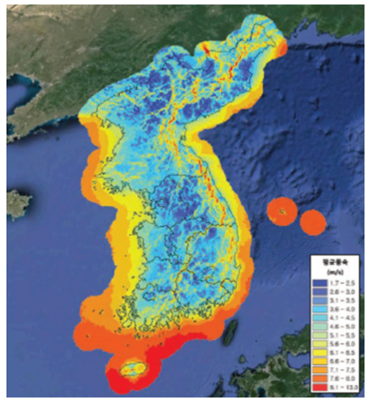
All the above-mentioned factors are key drivers for Korea to identify smart grid technology as an area for the government to promote in order to achieve low carbon development by integrating resources more effectively. The Korean government launched the Smart Grid Test-bed project in Jeju Island in 2009 to pilot the nation-wide smart grid development efforts. The project was implemented by the Korean government, Korea Smart Grid Institute (KSGI), Korea Electric Power Corporation (KEPCO), and the Jeju provincial government. The drivers and underlying conditions for Jeju to be selected as the pilot location are described below:

Figure 8: Location of Jeju

- Plans to diversify the local economy: Jeju's economy heavily relies on the tourism industry, which has been growing at an average anual rate of 10.4% for the past ten years.[98] The Jeju provincial government has been activley trying to attract information technology industries to relocate their headquarters and offices to Jeju by providing a favorable policy landscape. For example, Daum, a Korean version of Google or Baidu, has relocated their headquarters to Jeju. The local government has a strong will to develop non-tourism industries in Jeju in order to diversify the local economic portfolio.

- Ample renewable energy resources, partularly wind power: Jeju island is famous for windy weather. As shown in Figure 9, Jeju has proven to be an excellent location for wind power.[99]

Figure 9: Wind map of Jeju Island



Source: Kim, H. Korea Institute of Energy Research

- Separated grid system from mainland: The relatively independent grid system on Jeju allows the island to establish a smart grid system within their jurisdiction separated from the mainland. However, this is also a double-edged sword, increasing the island's vulberability by preventing it from fully integrating into the mainland's grid system.

- Huge rental car industry: Because of its sizeable tourism industry, the demand for rental cars on the island is high throughout the year. Rental cars are a good target group for electric vehicle penetration.

- Relatively short driving range within the island: Maximum driving range is less than 200 km in Jeju island. This short driving range is favorable for electric vehicle penetration, as people can easily drive around the island on a single charge.

With the launch of the Jeju Smart Grid Test-bed, the Jeju government announced a very ambitious goal of

98. The 19th Island Tourism Policy Form, on the Jeju government website. Available at http://www.jeju.go.kr/news/jeunews/today.htm?act=view&seq=957252.
99. Kim, H. "Onshore/Offshore Wind Resource Potential of South Korea." European Wind Energy Association. 2009.

becoming a carbon free island with 100% EV penetration by 2030.[100] Considering that renewable energy only makes up 5% of Jeju's current energy mix,[101] achieving the goal is very challenging. The following sections introduce what actions and measures have been taken in Jeju to integrate EVs, DR, and renewable energy into their smart grid test-bed, and also look into the challenges and lessons learned from the pilot.

6.1.2 Actions and Measures

The Jeju Smart Grid Test-bed is located at Gujwa-eup in the northeastern part of Jeju Island, where wind farms were already in operation. The pilot project was implemented from December 2009 through May 2013.[102] Approximately 6,000 households in the area participated, and four distribution lines and two substations were involved in the pilot. The key features of the pilot include:

- Government funding and partnership with industry: During the implementation period, $248 million was invested into the pilot, among which $76 million came from the government and the rest from the private sector. A total of 186 companies in different sectors participated in the pilot, forming 12 consortiums to focus on different areas.

- Integration of five focus areas: Five focus areas were identified to realize a full-scale smart grid that integrates EVs, DR, and renewable energy. Table 2.1 (below) shows more details on the five focus areas.

  The pilot achieved several notable impacts:

  - Infrastructure has been effectively established for integrating EVs, DR, and renewable energy. This includes charging stations for EVs, transmission lines connecting wind power to the grid, and home energy management systems with DR capabilities.
  - Relevant technologies were verified for application, and new business models were explored successfully.
  - V2G was successfully tested for the first time in Korea.
  - EVs, DR, and renewable energy integration were given priority for immediate application and scale-up in the project expansion phase.[103]

- High EV penetration and corresponding charging infrastructure development: Jeju promoted EVs to individual customers for the first time in Korea in 2013 and successfully put 852 EVs on Jeju's road

100. Jeju Government announcement. Available at http://www.jeju.go.kr/news/jeunews/new.htm?act=view&seq=966872
101. The rest, 95%, comes from oil. Ibid at footnote 97.
102. The Jeju government has been making continuous efforts to expand the project, and feasibility study results of project expansion are to be out soon.
103. Kim N. "Strategies for Exporting Energy Technology: EVs and Smart Grid Integration." KEEI. December 2013.

by the end of 2014, which is about 28% of all the EVs nationwide. (See below Figure 2.10) In 2015, EV sales jumped four-fold to 3,319, making Jeju a national leader in EV development.[104] It plans to continue this rapid development in the future, targeting 29,000 EVs by 2017 and 135,000 by 2020. By 2030, Jeju aims for its vehicle fleet to be fully electrified, and it has developed plans to build 75,000 charging stations by 2030 to support this goal.[105]

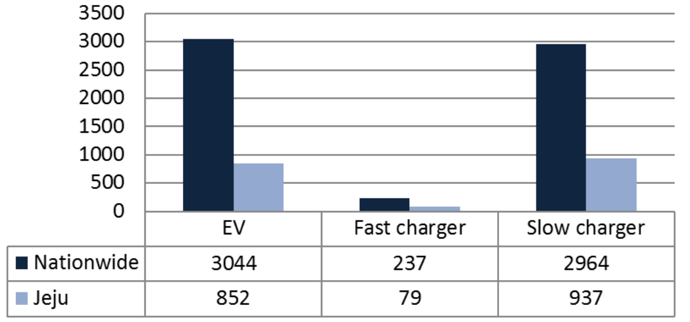
Table 1: Five Focus Areas of Jeju Smart Grid Test-Bed

Focus Areas	Goal	Key Measures
Smart Place	Improve demand-side efficiency	▪ Tried out different DR programs with various pricing signals ▪ Installed smart meters and established automated energy management systems
Smart Transportation	Increase EV penetration and charging infrastructure	▪ Expanded charging infrastructure development ▪ Established Information Communications Technology (ICT)-based EV operating system
Smart Renewable	Experiment with renewable energy technology	▪ Experimented with solar and wind generation, storage and control systems ▪ Connect micro-grid with main power grid
Smart Power Grid	Upgrade Transmission and Distribution (T&D) system	▪ Built Intelligent distribution & digitalized substations ▪ Built T&D real-time monitoring system
Smart Electricity Service	Operate energy trading market	▪ Developed customers' electricity trading system

Source: Korea Smart Grid Institute and Yoon S., SKT

104. Chung, Ah-young. "Jeju aims to be carbon-free island." Korea Times. December 3, 2015. Available at http://www.koreatimes.co.kr/www/news/culture/2015/12/320_192345.html.
105. Ibid at footnote 104.

Figure 10: EVs and charging facilities in Korea as of December 2014



Source: Based on the data from Jeju Government, March 2015

- Incentives for EVs and charging facilities: On top of central government's subsidies for purchasing EVs ($15,000), the Jeju government provides an additional $8,000 to the owner, which is the highest amount at the local level in Korea. The central government also provides incentives for charging facilities.[106] Prices of the EVs under the incentive program range from $35,000 to $69,000.[107]

6.2 Experience and lessons learned[108]

- Lack of coordination among relevant government agencies for EV industry development: Under the current system, the Ministry of Environment is responsible for EV penetration and public charging infrastructure development. The Ministry of Industry and Trade oversees private charging infrastructure, and the Ministry of Land, Infrastructure and Transport issues permits for EVs.

- Full reliance on government funding is not sustainable: Without government incentives, it is still hard to promote EVs to individual customers. The government funding for EV has been reduced for the past two years, so it's important to find another way of financing EV and charging infrastructure development.

- Narrow focus on residential and elderly demographic groups: The test-bed location is in a rural area and lacks participation from commercial and industrial customers. The electricity consumption volume itself is very low, and it is hard to make a real business case from the pilot. In addition, the residential customers in the test-bed area are relatively old and not very responsive to DR programs.

106. The government provides incentives only for slow chargers.
107. Choi, Kyong-ae. "Jeju emerging as a test-bed for EVs. Korea Times. March 10, 2014. Available at http://bit.ly/1RBdtf7.
108. Kim N. "Strategies for Exporting Energy Technology: EVs and Smart Grid Integration." KEEI. December 2013. And: Press Release. Ministry of Industry. 2013

- Technical standards and communications protocol development: With so many different market players' participation, standards and protocols are essential to operate the system. More work needs to be done on this front.
- Electricity pricing mechanism should be further diversified: The current electricity prices are too low to provide proper motivation for participating in demand response.

7 International experience can provide valuable lessons

As can be seen from the different case studies described earlier, there is no one-size-fits-all solution to integrating EVs with DR and renewable energy. Each case has adopted a different approach considering their underlying drivers and conditions to maximize the project's impact and effectiveness. (See Table 2 for a summary of all cases) Therefore, it is important to first understand local conditions so that VGI projects can be designed appropriately.

Though each case has adopted different styles and approaches, there are still common factors across countries.

- Strong government mandates and coordination/implementation capacity: The government should set a mandate and show strong will to implement the policies necessary to fulfill that mandate. In California, the ZEV mandate provided a degree of certainty for future EV growth, so utilities could plan their projects around realistic expectations of EV numbers within their service areas. Additional considerations include:
  - When these mandates involve different government agencies and organizations, it's important to facilitate coordination among the different parties. As described in the case in Korea, lack of coordination among the relevant government agencies was one of the major challenges.
  - Policymakers should also coordinate with project stakeholders to ensure that the regulatory environment will enable the project to move forward. For example, in the eV2g project, a change in the transmission operator's regulatory requirement for grid services was necessary to allow UD's grid-connected EVs to participate directly in the frequency regulation market.
- Background research on grid impacts: Most pilot projects in Europe included an information-gathering and modeling phase to understand the impacts of EV penetration on the grid, and many of the utilities involved in U.S. projects developed this research independently. This initial research stage can provide a deeper understanding of how local distribution equipment will be affected by EVs, educating utilities and other stakeholders of the potential issues with EV charging that DR can help solve.
- Collaboration with industries: In each case, utilities and often EV manufacturers were either leading the efforts or were actively engaged, even forming consortiums among different companies to increase synergy. Collaboration with local utilities is especially critical: not only does this facilitate project implementation, it also allows utilities to see first-hand what types of benefits managed EV charging can offer. The latter has been important for developing the necessary incentives to ensure the long-term sustainability of such programs.
- Initial small-scale pilot: ntegration projects are still a relatively new concept and may need to go

through a trial-and-error phase. As a result, it's often beneficial to start with a small-scale pilot to prove the benefits of integration. Because of the limited scale of these projects, they can be implemented effectively even if EV deployment in the area is still relatively small. Many pilot projects, especially those in Europe, used only 30 EVs or less to test whether using DR with EV charging is a feasible solution, providing the necessary experience and confidence to scale up the projects in the future. Lessons can be learned and policies developed so that when deployment of EVs scales up, it will be ready to take advantage of the benefits of integrating EVs with DR.

- Development of appropriate incentives: Scaling up VGI projects typically requires the development of a monetary incentive that allows participants to be compensated for the grid services they are providing. In most pilots, especially those in the U.S., this incentive was a major component of the project. There were a number of ways to structure these incentives, with international pilots experimenting with both variable electricity pricing and direct payments to participants. However, in most large-scale pilots, an incentive large enough to encourage participation was present.

- Developing the project in coordination with a pre-existing demand response program: In the i ChargeForward and eV2g projects, the pilots were able to take advantage of pre-existing DR and frequency regulation programs and markets established by PG&E and PJM. Similarly, the FINESCE project in Ireland sited their VGI pilots in areas that already had DR pilot projects running. This allowed the VGI projects to take advantage of existing policies and experience operating DR programs, which helped streamline the learning process and allowed the projects to advance more quickly.

These common factors may serve as a good starting point to consider in terms of how to approach to integrating EVs with DR and renewable energy. Because these factors were present in a majority of successful VGI pilot projects abroad, they provide the most salient features to work into the design of new projects. However, they are by no means the only features required for a successful project; other features used in only one or two projects can also be instructive, and the full range of approaches explicated in these examples should be considered for possible adoption. In addition, technical capacity and resource availability vary by region, so each approach should be customized at the local level to ensure it is appropriate for the conditions in which it is implemented.

Table 2: Summary Table of International Cases of EV-DR-RE Integration

	US			
Pilot Location	California SDG&E Application VGI Rate Pilot	California: SDG&E Optimized Pricing and Resource Allocation Pilot	California: BMW i ChargeForward Program with PG&E	Delaware: eV2g Project
Timeframe	2016-2020	2015	Mid-2015 – end-2016	2013 (ongoing)
Underlying Conditions/ Drivers	▪ State government support for EV adoption ▪ A large and rapidly growing EV fleet ▪ Need to integrate intermittent renewable energy into the grid	▪ State government support for EV adoption ▪ A large and rapidly growing EV fleet ▪ Need to integrate intermittent renewable energy into the grid	▪ Pre-existing demand response program ▪ Large number of EVs ▪ Financial opportunities from utility to manufacturers and customers	▪ EVs as a means of regulation services to integrate increased levels of renewable resources ▪ V2G technology commercialization potential
Actions/ Measures	▪ EV charging station construction in multi-unit dwellings ▪ Data collection on impact of price signals on charging behavior	▪ Integration of EVs into the grid as a service provider Incorporation of stationary storage	▪ Encouraging EV owners to participate in DR with $1000-worth gift card up-front and further incentives depending on actual participation ▪ Utilization of retired EV batteries serving as stationary storage	▪ Reduction of required frequency regulation generator size from 500 kW to 100 kW, allowing the eV2g project to bid into PJM's regulation market ▪ 2-year lease program of BMW EVs at rates comparable to conventional vehicles
Experience and Lessons Learned	▪ Proper structuring of incentives (variable electricity prices, direct payments) ▪ Engagement with utilities ▪ Incorporation of stationary storage for increased flexibility and demand response potential			

	Europe			Asia
Pilot Location	Ireland: FINESCE Project	Germany: BMW Controlled Charging Berlin Pilot	Denmark: EDISON Project	Korea: Jeju Island Smart Grid Test-bed
Timeframe	2014 (ongoing)	2013-2015	2009-2013	2009 – 2013 (currently being extended to its second phase)
Underlying Conditions/ Drivers	▪ Expected increase in EV use under the EU Renewable Energy Directive ▪ Lack of local data on EV impact to fully understand local situation	▪ Introduction of EVs with storage capacity to maintain grid stability	▪ High levels of variable wind energy ▪ Suitable test location on Bornholm Island	▪ 95% dependence on imported energy ▪ Ambitious reduction target ▪ Strong IT industry ▪ Jeju's favorable conditions, including strong government push, ample wind resources, independent grid system and short drive range
Actions/ Measures	▪ Observation of EV charging behavior with metering and communication capability installed into the charging infrastructure ▪ Smart charging pilot project to demonstrate load management potential	▪ Test with BMW EV users on how different incentives could promote grid-friendly charging behavior using a smartphone app ▪ EVs as an intermediary between wind energy and the grid to improve uptake of renewable energy	▪ Simulation study of EV impact on electricity grid ▪ Development of communication technology to allow for optimized charging ▪ Test pilot on Bornholm Island	▪ Government funding and partnership with industry consortiums ▪ Integration of five focus areas: Smart Place, Smart Transportation, Smart Renewable, Smart Power Grid, and Smart Electricity Service ▪ EV development with corresponding charging infrastructure development ▪ Incentives for EVs and charging facilities
Experience and Lessons Learned	▪ Background research on driving patterns and grid impacts ▪ Small-scale tests with a limited number of vehicles ▪ Development of effective communication technology between EVs and grid operators			▪ Lack of coordination among relevant government agencies for EV industry development ▪ Full reliance on government funding is not sustainable ▪ Customer demographic is narrowly focused on residential and elderly demographic groups ▪ Technical standards and communications protocol development

8 Conclusion

As more of the world's vehicle fleets are electrified, it's possible to capture benefits beyond reductions in tailpipe emissions. The flexible charging demand of EVs make them ideal machines to use with DR, a technique that has long been explored not just as a method for improving grid efficiency but also for accommodating the increasing use of variable renewable energy. Several studies have demonstrated that EV users respond to price incentives that encourage them to charge during off-peak periods. These measures can help minimize the impact EVs have on the grid's distribution equipment, allowing utilities to save money by avoiding costly equipment upgrades. Further research has shown that the use of DR with EVs can also help integrate variable renewable energy sources like wind and solar into the grid, allowing utilities to make greater use of these generation assets.

To test this potential, a number of pilot projects have been established around EV-DR integration. These pilots have not only tested the use of variable electricity pricing, but have also explored systems in which utilities directly request demand reductions from EV users. This type of "dispatchable" DR would further increase the functionality of EV-DR integration, expanding its ability to support utility operations. The use of bi-directional V2G charging promises even greater benefits by using EVs to provide grid resources like ancillary services. EV users and vehicle manufacturers can share in these benefits as well, through payments from the utility for the services they provide. These ideas are in the process of being tested in several places throughout the U.S., Europe, and Asia, and so far the results are promising.

The pilot projects already in place have gone a long way to proving the efficacy of using DR with EVs, but further work will need to be done before this concept can be scaled up. The introduction of more programs working with VGI, in different markets and geographic localities, will be necessary to push the concept to full-scale adoption. The projects outlined in this report contain examples of set-ups that have proved effective in the past, allowing them to serve as a useful reference point for future programs developing the potential that managed EV charging holds for utilities, for electricity customers, and for the environment as a whole.

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