Electric School Bus to Grid: Emissions and Economic Benefits (B2G-EEB)

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1 Introduction

This report presents modeling results detailing the emissions reduction potential and projections of the economic benefits of electric school buses (ESB). The model quantifies the emission benefits and reduced fuel costs from displacing diesel fuel with electricity using ESBs for a variety of school bus fleets across Ameren's service territory in central Illinois. The study also quantifies the additional emissions and economic benefits of utilizing vehicle-to-grid (V2G) technology.

V2G is a smart charging technology that allows electric vehicle (EV) batteries to feed electricity back into the grid when connected to a bidirectional charger. It allows high-capacity batteries in light or heavy-duty vehicles including ESB to serve as electrical storage for the electricity grid, in addition to powering the vehicles. V2G capable charging stations are bidirectional chargers that can pull energy from the grid and supply energy back to the grid from the connected vehicles at standard frequency and voltage. V2G charging stations are capable of communication with the grid and interact based on the operator signals (see Figure 1).[1]

The study model is titled Bus to Grid: Emissions and Economics Benefits (B2G-EEB). This work serves as a case study to evaluate the potential benefits to the region from the electrification of school bus fleets utilizing V2G technology to charge during low cost and low emissions periods and dispatch electricity to the power grid during peak demand hours with higher costs and marginal emissions.

[1] Nuvve, https://nuvve.com/technology/

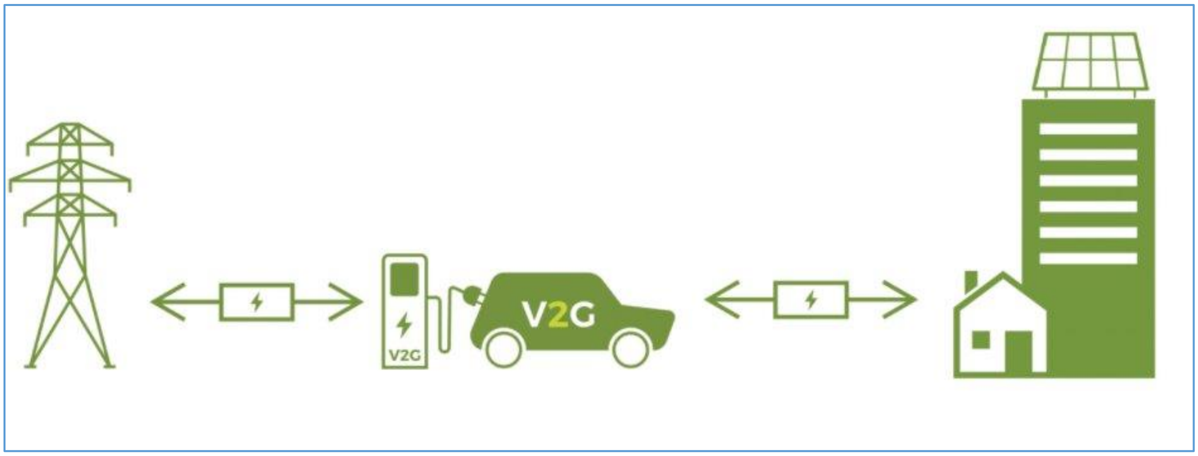

Figure 1: Vehicle to Grid Illustration *(Source: Nuvve)*[2]

Electricity in Illinois is dispatched by two different system operators. Utilities in the northern part of the state connect to the PJM Regional Transmission Organization (RTO), which manages the operation of the transmission system in all or parts of 13 states and the District of Columbia. Utilities located in southern and central Illinois including the Ameren service territory are members of the Midcontinent Independent System Operator (MISO) RTO, which covers a region in the mid-west including 15 U.S. states and the Canadian province of Manitoba.

Ameren Illinois is a regulated electric distribution company serving 1.2 million electric and 816,000 natural gas customers in central and southern Illinois and is a member of the MISO. Ameren's service territory was selected for this study given the high emissions from its non-baseload generation. In addition to the reduced tailpipe emissions from school bus electrification, V2G resources can be used to displace generation from non-baseload resources helping to reduce the health and environmental impacts of power production. Furthermore, the MISO region is facing pressing reliability challenges that V2G could help to address.[3]

Battery energy storage (BES) is viewed as a key technology to support the decarbonization of the electric grid.[4] BES systems are being used today to reduce energy costs and peak demand, thus increasing grid resiliency and reliability. The Illinois Clean Energy Jobs Act (CEJA) aims to achieve 100 percent renewable energy by the year 2050. CEJA provisions include beneficial electrification plans to support at least a 5% investment target to electrify school buses and public transportation serving environmental justice communities, and low-income and eligible communities. CEJA aims to facilitate the electrification of public transit and other vehicle fleets

[2] https://vacleancities.org/wp-content/uploads/2021/03/NUVVE-V2G-Graphic.png

[3] MISO has been identified as being at risk of rolling blackouts during the summer of 2022 due to increased demand from high temperatures and a shortage of generation, see North American Electric Reliability Corporation's 2022 Summer Reliability Assessment available at https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2022.pdf.

[4] See Arbabzadeh, M., Sioshansi, R., Johnson, J.X. et al. The role of energy storage in deep decarbonization of electricity production. Nat Commun 10, 3413 (2019). available at https://doi.org/10.1038/s41467-019-11161-5

in the light, medium, and heavy-duty sectors.[5] The Illinois Commerce Commission (ICC) staff Beneficial Electrification Workshops Report recommends that the state's investor-owned utilities (IOUs) develop ESB V2G programs with school districts located in low-income, environmental justice, and eligible communities.[6]

EV adoption has seen substantial growth in the last decade with over 2.6 million EVs sold in the U.S. between 2011 and 2022, and more than 200,000 EVs sold in the first quarter of 2022 alone.[7] The global market for EVs is expected to grow four-fold by the year 2026.[8,9] The 2021 Illinois Reimagining Electric Vehicles Act (REV Illinois Act) strengthens the state's bold climate change agenda by setting a goal of 1 million EVs on Illinois roads by the year 2030.[10] Furthermore, the passage of the Inflation Reduction Act of 2022 includes numerous incentives and programs to accelerate transportation electrification across the nation, complementing Illinois' existing and proposed transportation electrification programs.[11]

EV sales in the MISO region have lagged other regions at 34% of the annual U.S. average sales. However, EV adoption in the MISO region is projected to increase to between 1.6 to 36 million EVs by the year 2039. MISO collaborated with Lawrence Berkeley National Laboratory to study the potential grid impact of EV charging in the service territory. The study also explored advanced EV technologies including V2G operation demonstrating that this technology could support load optimization.[12] This study builds on this prior analysis by providing an analysis of the emissions and economic benefits of school bus electrification including V2G.

Several original equipment manufacturers (OEMs) today sell ESB, some of which have V2G capabilities. The health and economic benefits of ESB have been thoroughly documented.[13] This includes reduced emissions exposure to students relative to a standard diesel bus in addition to lower fuel and maintenance costs. Today, however, an ESB is significantly more expensive than a standard diesel bus. The federal Bipartisan Infrastructure Investment and Jobs act includes $5 billion over five years in rebates for the replacement of existing school buses with low- and zero-emission school buses, with half of the available funding dedicated to ESB. The U.S. Environmental Protection Agency has been promoting the potential to use ESB for V2G given the large onboard batteries and the long dwell times during the summer months to

[5] https://ilcleanjobs.org/wp-content/uploads/2021/03/CEJA-Overview.pdf
[6] The ICC Staff Beneficial Electrification Workshops report is available at https://www.icc.illinois.gov/downloads/public/informal-processes/ICC%20Beneficial%20Electrification%20Workshops%20Staff%20Report%20and%20Appendices.zip.
[7] https://electrek.co/2022/04/28/us-electric-car-sales-jumped-record-high-last-quarter/
[8] https://www.statista.com/topics/4421/the-us-electric-vehicle-industry/#dossierKeyfigures
[9] https://www.statista.com/statistics/271537/worldwide-revenue-from-electric-vehicles-since-2010
[10] https://www.ilga.gov/legislation/102/HB/10200HB1769lv.htm
[11] See Electrification Coalition Inflation Reduction Act Impacts on Electric Vehicles, available at https://www.electrificationcoalition.org/work/federal-ev-policy/inflation-reduction-act/.
[12] Quantifying the Potential of Electric Vehicles to Provide Electric Grid Benefits in the MISO Area, 2019 https://cdn.misoenergy.org/Quantifying%20the%20Potential%20of%20Electric%20Vehicles%20to%20Provide%20Electric%20Grid%20Benefits%20in%20the%20MISO%20Area354192.pdf
[13] See U.S. Environmental Protection Agency, Benefits of Clean School Buses: Benefits of electric School Buses, available at https://www.epa.gov/cleanschoolbus/benefits-clean-school-buses.

provide valuable grid services generating revenue for school districts and thereby helping to overcome the higher cost of an ESB and reduce the total cost of ownership (TCO).[14]

The geographic focus of the study is the Ameren Illinois utility service territory and the school bus fleets that operate within that area. We estimate that approximately 4,500 school buses are operating within Ameren's service territory (see Table 1).[15]

Table 1: School Bus Fleet in Ameren Territory

Average Ratio Enrollment per Bus[16]	Total # Students Enrolled Ameren Territory	Estimated Total Number of School Buses in Ameren Territory
93	419,004	**4,499**

The model assesses the financial and emissions impact of three different ESB and V2G adoption scenarios. In the short term (3-5 years) the model assumes that 10 percent of all 4,499 buses in Ameren territory will be electrified with 20% of the electrified buses adopting V2G chargers. In the long term (5-10 years) the model projects that half of all buses will be electrified with 80% adopting V2G technologies (see Table 2). These represent plausible future ESB and V2G adoption scenarios. The "Full Deployment" scenario represents the bookend potential assuming all diesel buses are replaced with ESB paired with bidirectional chargers.

Table 2: ESB and V2G Adoption Scenario

	Short Term	Long Term	Full Deployment
Percent of Fleet Electrified	10%	50%	100%
Percent of ESB with Bi-Directional Chargers	20%	80%	100%

Finally, the model can be parameterized with different emissions rate assumptions. The considered emissions scenarios include V2G charging during baseload plant operations as well as during renewable curtailment periods. Discharging can be modeled during peak periods using different peaking plant emission rate assumptions depending on how generation resources are categorized as either baseload or peaking units. The modeling includes two different sensitivities for these parameters as described later in the report.

[14] See U.S. Environmental Protection Agency, What If Electric School Buses Could be Used to Supply Power When Off Duty?, available at https://www.epa.gov/greenvehicles/what-if-electric-school-buses-could-be-used-supply-power-when-duty.

[15] The total Number of school buses in Ameren territory was estimated using the data captured through a controlled study completed by Levo Mobility in selected school districts. The calculated blended school bus per student enrolled ratio was used to estimate the total number of school buses for all school districts in Ameren service territory in Illinois.

[16] This ratio was calculated based on a sampling of representative school districts in Illinois with data on both enrolled students and school bus fleet size.

2 Electric Load and Generation Environment for V2G

The opportunities for V2G technologies to reduce overall grid emissions and generate financial benefits arise from the varying demand profile of a regional grid, which prompts a changing set of generation resources to be dispatched to meet the demand for electricity over time. Figure 2 shows three distinct load profiles for a day in March, May, and August in the MISO territory.[17] Characteristically, the spring demand profile shows morning and evening peaks, which coincide with people's home appliances and HVAC (heating ventilation, and air-conditioning) use before and after work. During the summer, the load profile switches to a longer daytime peak reflective of air conditioning loads used in homes and businesses. In August, the peak load is significantly higher than in May (over 100GW as compared to under 80 GW)).

[17] Source: MISO Real Time Market Data https://www.misoenergy.org/markets-and-operations/real-time--market-data/real-time-displays/

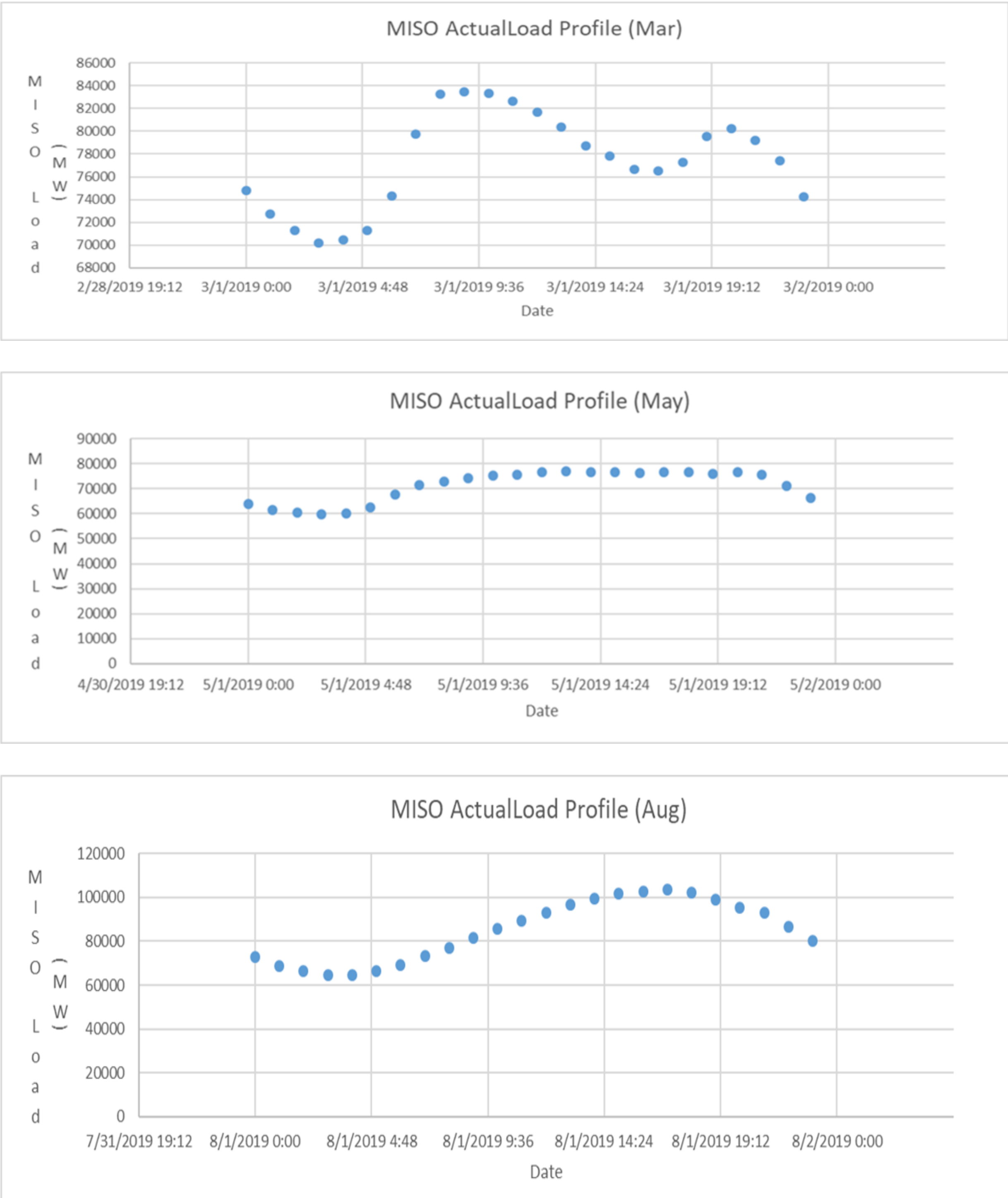

Figure 2 Load Shape Examples of the MISO Electricity Grid Region

Prices for electricity throughout the day typically follow closely the load profile. Table 3 below shows Ameren's electricity rates (Ameren Illinois Power Smart Pricing) for several days (May 1-7) during the early hours of each day (1 am-10 am).[18] Overlaid in Table 3 is a color-coded heat map where higher prices are highlighted in increasing red shading while lower prices are shown in increasingly green shading.

Table 3 Ameren Illinois Power Smart Pricing - Snapshot of Selected Dates and Early Morning Times

								Hour of Day			
Date	Weekday	1	2	3	4	5	6	7	8	9	10
1-May	Sun	$0.023	$0.022	$0.022	$0.022	$0.021	$0.022	$0.022	$0.022	$0.023	$0.023
2-May	Mon	$0.017	$0.016	$0.015	$0.016	$0.017	$0.017	$0.018	$0.019	$0.021	$0.022
3-May	Tue	$0.020	$0.019	$0.018	$0.019	$0.020	$0.025	$0.027	$0.028	$0.030	$0.032
4-May	Wed	$0.021	$0.020	$0.020	$0.020	$0.022	$0.024	$0.025	$0.027	$0.027	$0.028
5-May	Thu	$0.022	$0.021	$0.021	$0.021	$0.024	$0.033	$0.039	$0.043	$0.043	$0.040
6-May	Fri	$0.019	$0.019	$0.019	$0.020	$0.020	$0.026	$0.029	$0.030	$0.030	$0.029
7-May	Sat	$0.019	$0.018	$0.018	$0.018	$0.019	$0.022	$0.026	$0.028	$0.029	$0.028

Figure 3 below shows a whole day of Ameren Illinois Power Smart Pricing ranging from below $0.02/kWh to close to $0.04/kWh and the supporting heat map table (now for the full 24-hour days). The graph shows a very conservative arbitrage day. Much larger price spikes during the day can be observed during August peak days when prices reached over $0.12/kWh (see Figure 4).

[18] Ameren Illinois Power Smart Pricing reflects the hourly wholesale energy price and does not include the supplier charge, ancillary service energy cost, renewable energy compliance cost, market settlement cost, and distribution system losses. https://www.ameren.com/illinois/account/customer-service/bill/power-smart-pricing.

			Hour of Day																							
	Date	Weekday	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
May	1-May	Sun	$0.023	$0.022	$0.022	$0.022	$0.021	$0.022	$0.022	$0.022	$0.023	$0.023	$0.023	$0.023	$0.022	$0.021	$0.022	$0.022	$0.023	$0.025	$0.025	$0.027	$0.027	$0.024	$0.023	$0.021
May	2-May	Mon	$0.017	$0.016	$0.015	$0.016	$0.017	$0.017	$0.018	$0.019	$0.021	$0.022	$0.023	$0.024	$0.024	$0.025	$0.026	$0.027	$0.029	$0.029	$0.029	$0.030	$0.029	$0.024	$0.022	$0.021
May	3-May	Tue	$0.020	$0.019	$0.018	$0.019	$0.020	$0.025	$0.027	$0.028	$0.030	$0.032	$0.033	$0.035	$0.036	$0.037	$0.038	$0.039	$0.039	$0.038	$0.038	$0.038	$0.035	$0.028	$0.022	$0.020
May	4-May	Wed	$0.021	$0.020	$0.020	$0.020	$0.022	$0.024	$0.025	$0.027	$0.027	$0.028	$0.030	$0.030	$0.032	$0.031	$0.030	$0.029	$0.029	$0.029	$0.028	$0.032	$0.035	$0.025	$0.023	$0.021
May	5-May	Thu	$0.022	$0.021	$0.021	$0.021	$0.024	$0.033	$0.039	$0.043	$0.043	$0.040	$0.037	$0.037	$0.035	$0.033	$0.032	$0.035	$0.034	$0.033	$0.034	$0.035	$0.036	$0.029	$0.026	$0.024
May	6-May	Fri	$0.019	$0.019	$0.019	$0.020	$0.020	$0.026	$0.029	$0.030	$0.030	$0.029	$0.028	$0.027	$0.026	$0.025	$0.025	$0.026	$0.025	$0.026	$0.028	$0.029	$0.033	$0.026	$0.022	$0.021
May	7-May	Sat	$0.019	$0.018	$0.018	$0.018	$0.019	$0.022	$0.026	$0.028	$0.029	$0.028	$0.027	$0.026	$0.025	$0.024	$0.024	$0.023	$0.023	$0.023	$0.023	$0.026	$0.026	$0.022	$0.020	$0.019

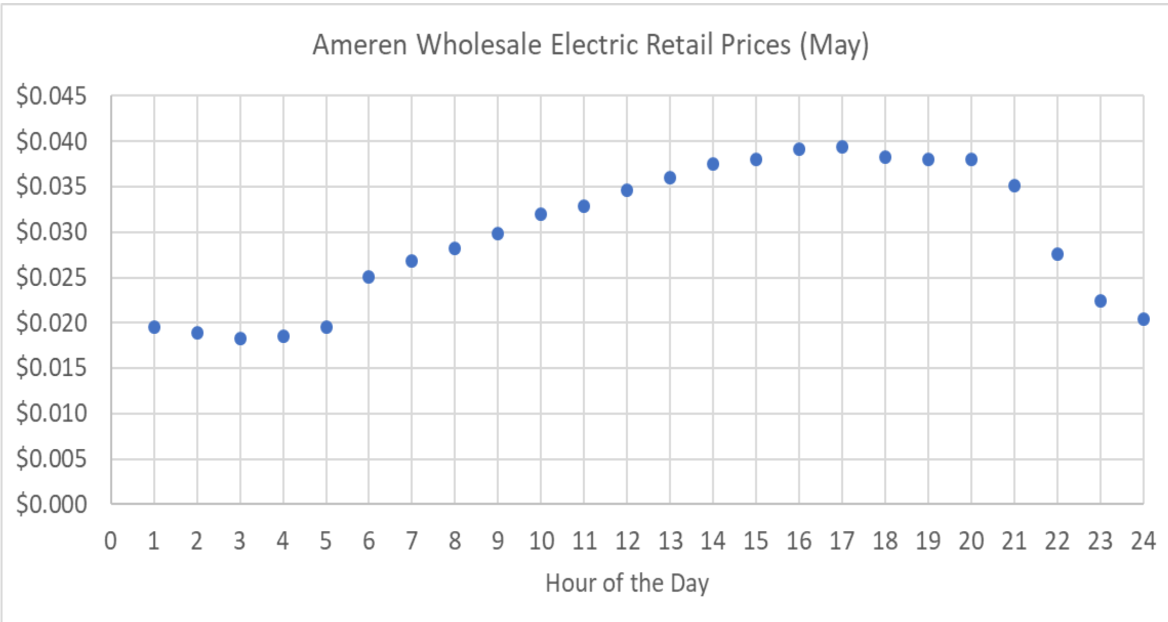

Figure 3: Ameren Electric Prices – Snapshot of One Whole Day in May

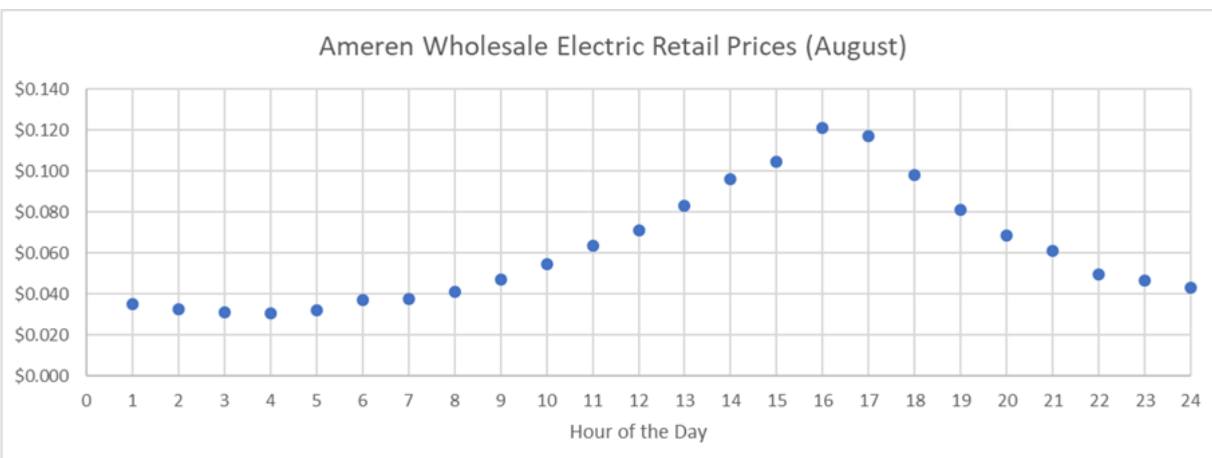

Figure 4: Ameren Electric Prices – Snapshot of One Whole Day in August

Figure 5 provides a summary pricing heat map for a whole year. The heat map colors reveal the changing peak prices from two winter peaks to one summer peak. These changes in energy prices create financial arbitrage opportunities for V2G resources that can charge during lower price hours and discharge during high price hours. The pricing heat map also indicates that the

V2G arbitrage opportunities change throughout the year, which will require frequent adjustments in the V2G scheduling operations (time of charging and discharging throughout the day as the year progresses).

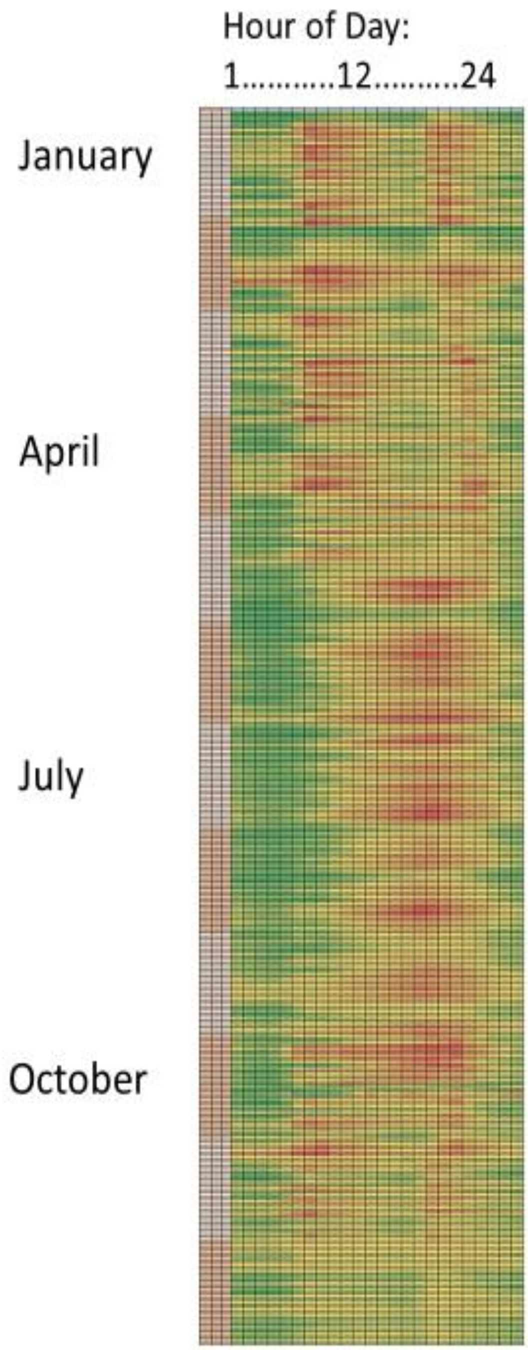

Figure 5: Ameren Electric Prices – Snapshot for One Whole Year (2022)

In general, higher prevailing loads throughout a day in a utility territory will prompt the dispatch of less efficient peaking power generation resources. Often, these non-baseload peaking resources will consist of coal, oil, or natural gas-fired fossil power plants whose emissions profile is higher than that of baseload resources that are dispatched consistently throughout the day. Figure 6 shows the change in generation mix for several hours throughout a day usingreal-time market data from MISO for all major fuel sources.[19] Figure 7 focuses only on coal-fired power plants. As can be seen for a typical day in May (with a mid-day load peak, see above) the generation mix indicates that more coal and natural gas-fired resources have to be dispatched to meet the peak load, increasing the total emissions of the generation mix needed to serve the region's load. Not only are more power plants being dispatched to meet peak load the dispatched assets also have higher emissions rates. The EPA eGRID database for the interconnect sub-region that includes the Ameren utility territory shows consistently lower emissions factors for baseload resources than non-baseload power plants (more detail provided in a later section).

Overall, this analysis shows that higher loads not only prompt higher prices as shown above but also higher emissions within a grid region. The following section introduces a spreadheet-based model that enables the optimization of ESB and V2G bidirectional charging within the MISO territory taking its load, pricing, and emissions profile into account.

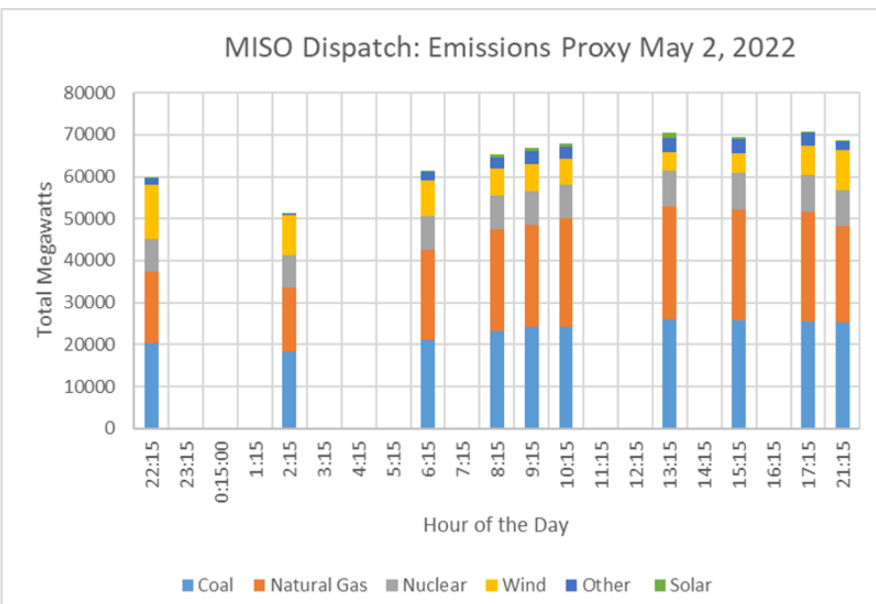

Figure 6: Daily Change in Generation Mix by Fuel Source

[19] Note that this data is sourced from screen captures from the MISO real time market system. Screen captures were only taken for the distinct times when the system was accessed. Therefore, not all hours of the day are populated with data.

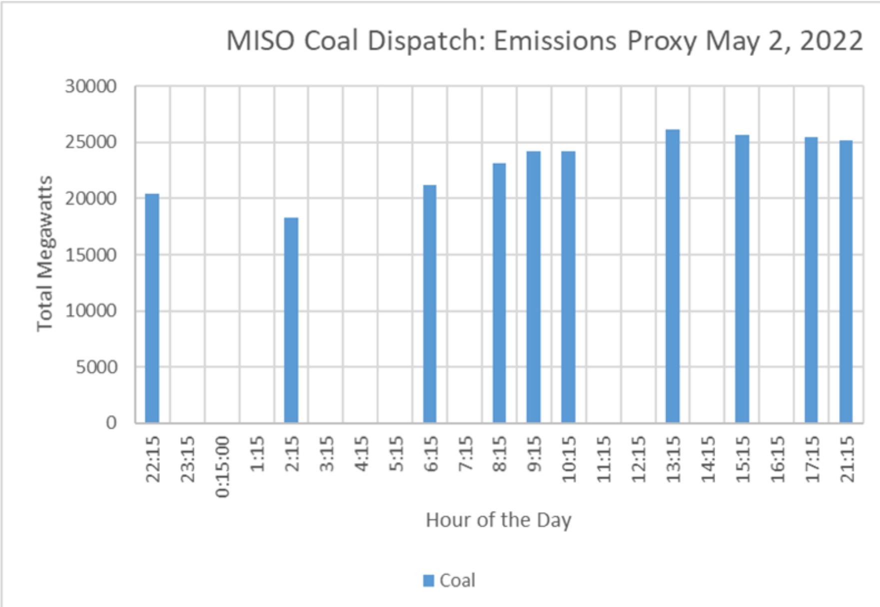

Figure 7: Daily Change in Coal Generation

3 Model Overview

The model consists of two main components:

1) The Scheduling Table
2) The Financials and Emissions Calculation Table (FE Table)

Additional details on the two main model components are provided next.

3.1 Scheduling Table

The Scheduling Table in the spreadsheet model allows the user to input the individual school bus route schedule and energy consumption of each bus trip as well as the V2G operation parameters. The spreadsheet table shows each day of a year across the columns and each hour of the day across its rows (see spreadsheet table snapshot in Figure 8). Days are further grouped by month. Since the bus operation will vary with the school year, the Scheduling Table also shows the summer and winter breaks, weekends, as well as holidays in color-coded cells.

Above the Scheduling Table is a representative one-day MISO load profile for each month. This allows the user to identify the anticipated load peaks each month for V2G scheduling. The Scheduling Table also allows the user to schedule charging (e.g. nighttime charging on baseload power and recharging after bus trips). The total charging requirement is calculated as the complement of the electricity needs incurred from the bus route transportation service and the V2G operation. The sum of all charging and discharging operations is transferred into the FE Table.

	121	122	123	124	125	126	127	198	199	200	201	202	203	204
	May	May	May	May	May	May	May	Jul	Jul	Jul	Jul	Jul	Jul	Jul
	1	2	3	4	5	6	7	17	18	19	20	21	22	23
	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	School Hours							Summer Hours						
	Weekend	School Weekday					Weekend	Weekend	Summer Weekday					Weekend
1														
2														
3	60	60	60	60	60	60	60	60	60	60	60	60	60	60
4	60	60	60	60	60	60	60	60	60	60	60	60	60	60
5														
6														
7		(24)	(24)	(24)	(24)	(24)								
8		(24)	(24)	(24)	(24)	(24)								
9		48	48	48	48	48								
10	(30)	(30)	(30)	(30)	(30)	(30)	(30)							
11	(30)	(30)	(30)	(30)	(30)	(30)	(30)							
12														
13														
14		(24)	(24)	(24)	(24)	(24)								
15		(24)	(24)	(24)	(24)	(24)		(30)	(30)	(30)	(30)	(30)	(30)	(30)
16		48	48	48	48	48		(30)	(30)	(30)	(30)	(30)	(30)	(30)
17	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)
18	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)	(30)
19														
20														
21														
22														
23														
24														

Charging
Discharging

Figure 8: Scheduling Table snapshot for the proposed charging and discharging cycles

Figure 8 shows the proposed charging and discharging cycles during a typical school week and summer hours for a single electric school bus. In this example, the bus charges overnight during the hours of 3 AM and 5 AM using a 60 kW direct current fast charger (DCFC) before heading out to complete the morning routes for transporting students during a school week. It is estimated that a typical route of 37 miles requires 48 kWh of electricity (2 x 24 kWh). In the particular case shown (early May time frame with prevailing morning and late afternoon peak hours) the bus immediately charges after returning from the morning route, before immediately discharging in V2G operation over 2 hours (2 x 30 kWh) during the morning peak of 10 AM to 12 PM. Alternatively, the bus could discharge the remainder of the battery capacity left after school bus operation to serve the morning peak and then recharge before the afternoon bus route operation and the early evening V2G operation (2 x 30 kWh). During the summer break, the bus is scheduled to discharge once during the summer evening peak between the hours of 3 PM and 7 PM during the peak demand window resulting from increased load from air-conditioning.

The ESB charging and V2G scheduling referenced above can be altered depending on the objective. The above charging and discharging schedule are proposed to maximize the emissions and energy arbitrage opportunities. This study does not attempt to evaluate the battery degradation costs from increased cycling for V2G operations. As a result, the above scheduling scenario may not be optimal regarding battery warranty constraints and degradation costs. Rather, the above scenario is proposed to demonstrate one possible approach to V2G charging for an ESB given actual routes and dwell times.

3.2 Economic Analysis

Electricity can be both a less expensive and less polluting fuel relative to diesel fuel for school bus operations. The economic analysis calculates the annual fuel cost savings from displacing diesel fuel in school buses with electricity. The literature also finds that ESBs are less expensive to maintain than a standard diesel school bus.[20] This study did not attempt to estimate the reduced maintenance costs of ESB relative to a diesel school bus.

The economic analysis also quantifies one potential value stream associated with V2G operations. Given there are no current utility programs or other market opportunities that provide compensation for V2G exports in Illinois, the study infers value based on energy arbitrage. This involves buying low-cost energy during off-peak hours and selling that energy back during peak, high-price times.

There have been numerous studies on the economic value of V2G providing different grid services in different regions. A study by the Electric Power Research Institute (EPRI) finds the benefits to all California ratepayers under a high EV scenario with V2G is over $1 billion annually.[21] Another study finds that fleet managers can expect to offset 5-11 percent of the total cost of ownership with V2G revenue.[22]

3.2.1 Electric Rate and Diesel Price Assumptions

The model can be parameterized with two cases: a) the base case with Ameren-Illinois electricity rates and b) a sensitivity case with values from California. For the present (initial) model parameterization, a simplified electricity rate-based arbitrage approach was chosen which is detailed below. V2G technologies are expected to capture significant additional benefits from grid services (see Appendix A) and ancillary services (see Appendix B). Furthermore, as markets evolve and the need for grid flexibility increases, it is anticipated that new services will be required that would likely be more lucrative while requiring fewer V2G cycles. These additional services are currently not quantified in the model.

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[20] See American Council for an Energy Efficient Economy, Electrifying Trucks: From Delivery Vans to Buses to 18-Wheelers, available at http://www.aceee.org/research-report/t2102.
[21] See EPRI, Open Standards-Based Vehicle-to-Grid: Value Assessment, available at https://www.epri.com/research/products/000000003002014771.
[22] See A. De Los Ríos, et al., Economic Analysis of Vehicle-to-Grid (V2G)-Enabled Fleets Participating in the Regulation Service Market, available at https://ctl.mit.edu/sites/default/files/IEEE_2012_DeLosRios_Goentzel_Nordstrom_Siegert.pdf.

Case 1: MISO/Ameren-Illinois Arbitrage Prices

Based on U.S. Energy Information Administration rate data, the average cost of delivered retail electricity in Illinois is $0.0975/kWh.[23] This value is used as the charging price incurred by the bus fleet.

The heat map shown in Figure 5 visualizes the hourly residential supply rate for the Ameren Illinois Power Smart Pricing Program. Optimizing the V2G dispatch for on-peak pricing and charging during off-peak hours allows the customer to harness the arbitrage potential of this highly flexible storage resource. To quantify the arbitrage opportunity the average difference between the maximum and the minimum hourly pricing throughout the year was calculated. This resulted in an average annual value of $0.03/kWh for the pricing arbitrage opportunity. Note that during peak summer days the daily arbitrage value can exceed $0.09/kWh.

Case 2: California/PG&E Arbitrage Prices

The rate structure of California's largest investor-owned utility (IOU) PG&E was analyzed as a sensitivity. This derived an average charging price of $0.33/kWh (blended PG&E EV-A Rates based during likely charging hours) and an average discharging price of $0.51/kWh (blended PG&E EV-A Rates during likely discharging hours) resulting in a net arbitrage of $0.18 /kWh.[24] These rates are contained in one of the spreadsheet model worksheets and can be substituted for the Ameren rates for Case 2 model runs.

Diesel Cost Assumption

Diesel cost in the model was assumed to be $5.40/gallon.[25]

[23] U.S. Energy Information Administration, https://www.eia.gov/electricity/state
[24] https://www.pge.com/en_US/residential/rate-plans/rate-plan-options/electric-vehicle-base-plan/electric-vehicle-base-plan.page?
[25] https://gasprices.aaa.com/?state=IL as of 6/2/2022

3.2.2 Performance for Bus Route Operation for EV Compared to Diesel Bus

Default data in the Argonne Alternative Fuel Life-Cycle Environmental and Economic Transportation - AFLEET Tool assumes a total of 15,000 miles per year for a school bus. A paper published by SAE from the National Renewable Energy Laboratory analyzed school bus driving cycles and concluded that an average trip distance totals 31.7 miles.[26] At approximately 180 school days for public schools throughout the year, this would total 11,520 annual miles for a school bus which is lower than the AFLEET default assumption. However, school buses are likely also used for other activities including sporting events and school field trips.[27] The average school bus annual mileage in the present model totals 14,430 which is below AFLEET but higher than the NREL bus route cycle. To complete these miles an electric school bus will consume 48 kWh per route and 18,639 kWh annually. A diesel school bus with a fuel economy of 8.2 miles/gallon (fuel economy derived from AFLEET) will consume 4.51 gallons per route and 1,759 gallons annually.

At a consumption rate of 48 kWh per route, a bus can be recharged in less than an hour with a 60 kW DCFC. Data from the Blue Bird All American Electric School Bus indicates that the battery capacity of the bus models is 155 kWh with a preferred operating range of 80% or 124 kWh of usable energy per cycle. This matches approximately data for the Lion All-Electric Type C School Bus. A summary of the operational data for an ESB compared to a diesel bus is provided in Table 4.

Table 4: Operational Data for EV Bus compared to Diesel Bus

	Operation	**Unit**
A) Electric Bus Route		
Annual Bus Operation	14,430	miles
Bus Route	1.29	kWh/mile
Electric Bus Consumption per Trip	48	kWh
Electric Bus Consumption per Year	18,639	kWh
Charging Capacity	60	kW
Charging Duration	0.8	hours
Annual Bus Route Charging	18,639	kWh
B) Diesel Bus Route		
Diesel Consumption Per Trip	4.51	gallons
Annual Bus Route Discharging	1,760	gallons

[26] Duran, A. and Walkowicz, K., "A Statistical Characterization of School Bus Drive Cycles Collected via Onboard Logging Systems," SAE Int. J. Commer. Veh. 6(2):2013, doi:10.4271/2013-01-2400.
[27] https://www.rohrerbus.com/typical-day-school-bus-driver/

3.2.3 Performance for V2G Operation

Table 5 details the key performance data for the buses when operating in V2G mode. Based on the system characteristics we determined that the buses could dispense 30 kWh per hour back to the grid while based on the Scheduling Table a total of 4 x 30 kWh discharge cycles per day would provide the greatest benefits to offset peak loads. In total, we determined that the bus in V2G mode could provide 43,800 kWh annually. At an assumed round-trip efficiency of 90%, this would require total annual charging need of 48,700 kWh.

The model assumes that the buses charge to full capacity during nighttime off-peak hours. Furthermore, the model assumes that the buses are recharged after route operation to be ready for V2G mode. In some cases, recharging after route operation may be delayed if current peak load conditions on the grid would favor immediate V2G operation with the remainder of the battery's available energy.

Figure 9 and Figure 10 show the operation for the V2G Discharging and Charging of the ESBs during a typical weekday and vacation/weekend, respectively. The estimates for charging and discharging assume an average electric consumption per trip of 48 kWh. The blue bars represent the flow of energy from the grid to the ESB batteries and the orange and green bars represent the flow of energy from ESB batteries for bus and V2G operations, respectively. The line graph represents the battery's state of charge in kWh (max storage capacity of 155 kWh).

Table 5: Performance of V2G Operation

V2G Charging	**Operation**	**Unit**
V2G Energy Charging per Cycle	133	kWh
Charging Capacity	60	kW
Charging Duration	2.2	hours
Energy Charge per Hour	60	kWh
V2G Charging Hours per Year	811	hours
Total Annual Energy Charge Delivered	43,800	kWh
Roundtrip Efficiency	0.90	kWh
Total Annual Energy Charge Needed	48,667	kWh
V2G Discharging for Energy Offset		
Max Dispatch Cycle Per Day	4	Hours
V2G Energy Discharge per Cycle	120	kWh
Energy Dispatch per Hour	30	kWh
V2G Discharging Hours Per Year	1,460	hours
Bus V2G Annual Discharge	43,800	kWh

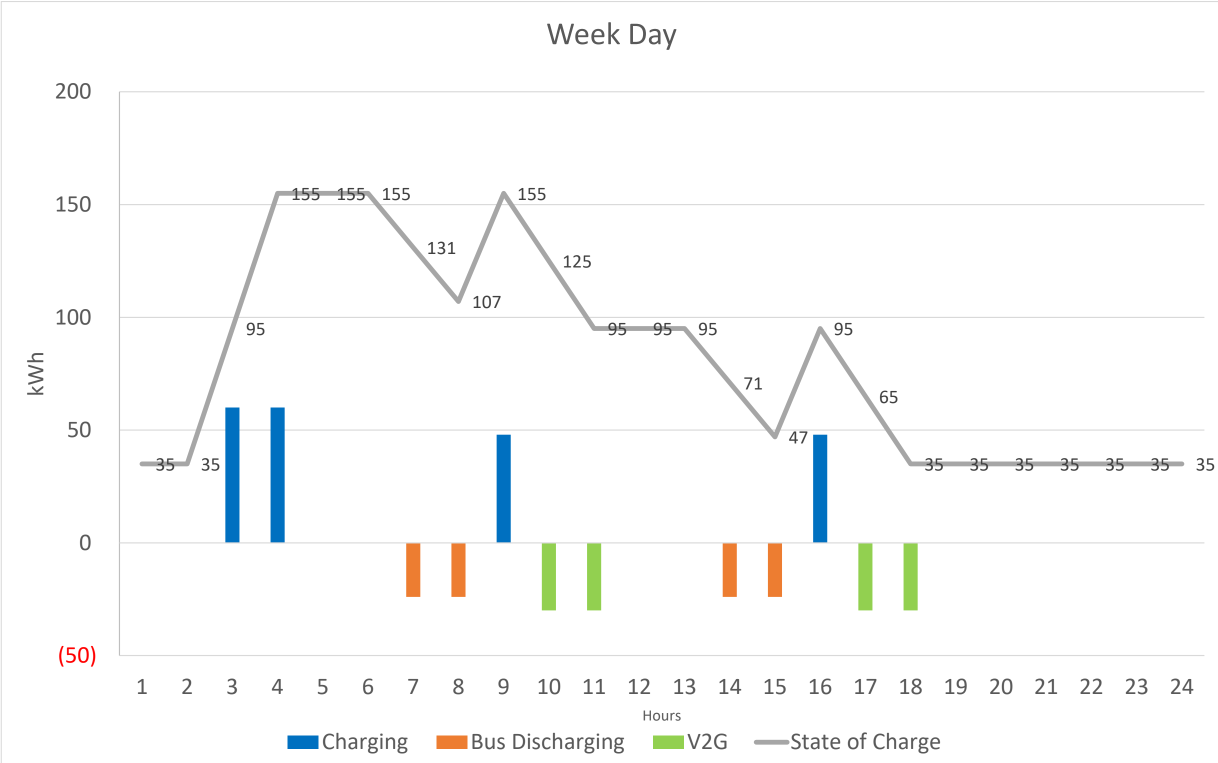

Figure 9:V2G Operation on Week Day

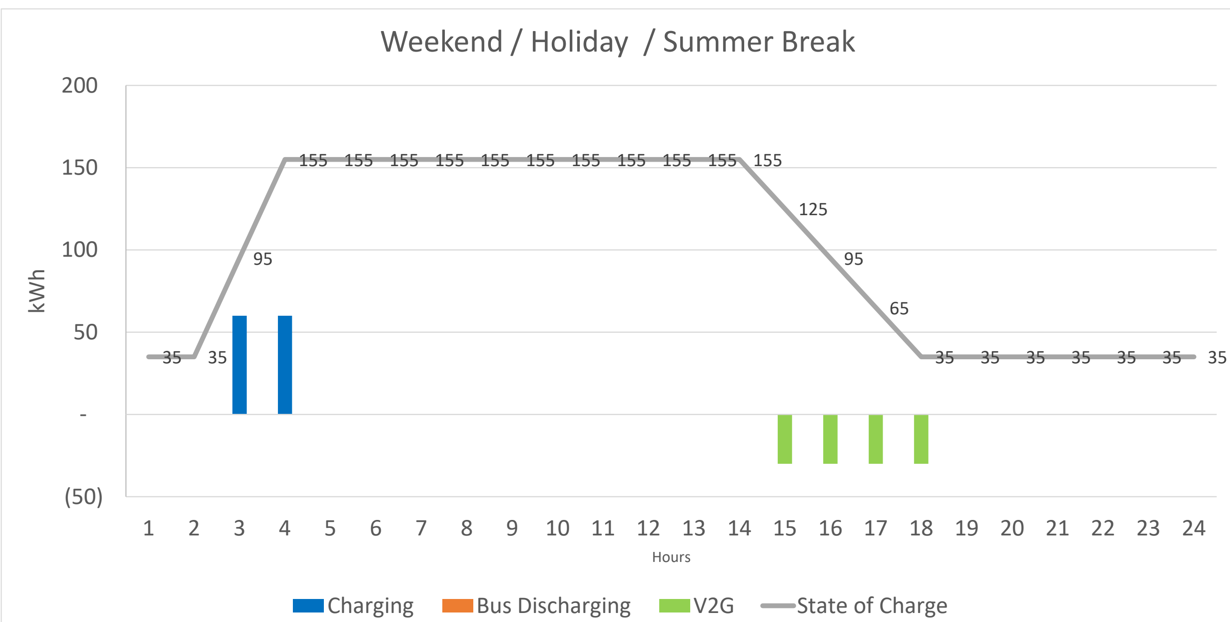

Figure 10: V2G Operation on Weekend/Vacation

3.3 Emissions Analysis

3.3.1 Emissions Rate Assumptions

In Table 6 the average annual non-baseload and baseload emissions factors from the latest year (2020) EPA eGRID database were extracted.[28] The difference between these factors is often used to characterize the emissions of new incremental load and load reduction measures. Our area of interest is the SRMW eGRID subregion which includes Ameren's service territory (see Appendix C). MISO (see Appendix D) dispatches power plants in this grid region. The emissions difference between baseload and non-baseload facilities for the US is well documented but varies by geographic aggregation. Within eGRID, non-baseload emissions rates are calculated as the output emission rates for plants that combust fuel and have capacity factors less than 0.8. [29] Results from EPA's AVoided Emissions and geneRation Tool (AVERT) model for avoided emissions resources from energy efficiency measures match closely the non-baseload factors from eGRID (see Appendix E). The eGRID definition of non-baseload resources includes significant shares of intermediate resources. As a sensitivity, we considered another definition of non-baseload generation based on eGRID emissions factors for the SRMW territory for generation resources with a capacity factor less than 0.6. The list of plants identified to meet this definition is shown in Appendix F.

Table 6: Baseload and Non-Baseload Emissions Factors for the SRWM SERC eGrid Subregion

	NO_x	CO_2
Baseload (lbs./MWh)	1.21	1,568
Non-Baseload (lbs./MWh); 80% Capacity Factor	1.65	1,977
SRMW Peaking Plants; 60% Capacity Factor	2.08	2,286

3.3.2 Emissions from Bus Route Operation for EV compared to Diesel Bus

Bus charging for bus route operation is generally assumed to be optimized for charging during baseload hours, which in the Midwest results in lower emissions relative to charging during on-peak hours since dirtier peaking plant dispatches are avoided. This means the bulk of the charging is done during nighttime hours and non-peak daytime hours.

In the current model, a school bus travels 14,400 miles per year. The equivalent diesel bus emissions were calculated in Argonne's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool. The AFLEET results were transferred into the FE Table as an emissions credit. AFLEET uses data from Argonne's Greenhouse gases, Regulated

[28] For the present study we focus on greenhouse gas emissions (CO2) and one criteria pollutant category (nitrogen oxides). Additional criteria pollutants will be assessed in future studies.
[29] https://www3.epa.gov/ttnchie1/conference/ei18/session5/rothschild.pdf

Emissions, and Energy use in Technologies (GREET) fuel-cycle model and the EPA Motor Vehicle Emission Simulator (MOVES) to generate emissions profiles.

3.3.3 Emissions from V2G Operation

Charging for V2G operation is assumed to occur according to two scenarios: a) off-peak (similar to charging for bus route operation) or b) during renewable curtailment. Emission rates during renewable curtailment are assumed to be zero. Discharging for V2G operation is assumed to be optimized for on-peak hours which, in the aggregate will displace dirtier grid emissions from peaking sources of power generation.

Note that the eGRID based emissions rates do not constitute full life cycle emissions. The eGRID rates include power plant emissions. Transmission losses were added. Emissions upstream from the power plant are excluded. Likewise, for diesel bus emissions, upstream fuel manufacturing emissions are excluded from the model.

4 Financial and Emissions Impact of B2G Technology for Bus Fleet Scenarios in the Ameren Utility Territory

4.1 Financial Impact

For this study, the model assumes that in the short term (3-5 years) 10 percent of all 4,499 buses in Ameren's service territory will be electrified with 20 percent of the electrified buses adopting V2G chargers. In the long term (5-10 years) the model projects that half of all buses will be electrified with 80 percent adopting V2G technologies. The "Full Deployment" scenario assumes 100 percent of the diesel school buses are replaced with ESB, which are all paired with V2G bidirectional chargers.

The annual financial benefits from school bus fleet electrification with V2G are summarized in Table 7. In the short term, long term, and full deployment scenarios these technologies could save annually $3.5 million, $18.4 million, and $37.6 million, respectively.

The analysis also shows that in the full adoption scenario the ESB fleet will represent a grid resource of close to 270 MW of power and 200,000 MWh of storage capacities respectively.

Table 7: Annual Financial Benefits of B2G Technology under Ameren Territory Rate Assumptions

Financial Scenario	Bus Fleet Size	Fleet Power Capacity	Fleet Energy Storage	Fuel Cost Savings / V2G Revenue
Operating Mode	#	MW	MWh	$
		Short Term		
Bus Route Operation	450		8,385	-$3,386,770
V2G Resource	90	5.4	3,941	-$74,442
Totals				-$3,461,212
		Long Term		
Bus Route Operation	2,249		41,927	-$16,933,849
V2G Resource	1,800	108.0	78,821	-$1,488,846
Totals				-$18,422,695
		Full Deployment		
Bus Route Operation	4,499		83,854	-$33,867,698
V2G Resource	4,499	269.9	197,053	-$3,722,116
Totals				-$37,589,814

In another analysis, the model was parameterized with rates from California’s largest IOU PG&E. As discussed above the rate assumptions for this utility provide higher charging prices for EVs but also significantly higher arbitrage potential for V2G operation. As a result, the total savings from displacing diesel fuel with electricity for bus operations under this rate structure are lower, while importantly, much larger savings are achievable from V2G operation (Table 8). For example, the bus operation in Ameren territory generated approximately $33.9 million in savings in the “Full Deployment” scenario while in PG&E those savings are only $14.7 million. Conversely, V2G savings in Ameren are $3.7 million compared to $27.6 million in PG&E. While these results may, in reality, be significantly influenced by utility incentives to charge EVs (not considered here) the general finding is that in areas with high prevailing base electricity prices and large variations (arbitrage) of prices throughout the day operating a bus in V2G operation can outweigh the financial returns incurred from displacing diesel fuel with electricity.

Table 8: Financial Benefits under California/PG&E Rate Assumptions

Financial Scenario	Bus Fleet Size	Fleet Power Capacity	Fleet Energy Storage	Fuel Cost Savings / V2G Revenue
Operating Mode	#	MW	MWh	$
		Short Term		
Bus Route Operation	450		8,385	-$1,472,093
V2G Resource	90	5.4	3,941	-$552,479
Totals				-$2,024,572
		Long Term		
Bus Route Operation	2,249		41,927	-$7,360,466
V2G Resource	1,800	108.0	78,821	-$11,049,575
Totals				-$18,410,041
		Full Deployment		
Bus Route Operation	4,499		83,854	-$14,720,932
V2G Resource	4,499	269.9	197,053	-$27,623,937
Totals				-$42,344,869

4.2 Emissions Impact

For emission rates, we parameterized the model with different assumptions The considered emissions scenarios include V2G charging during baseload plant operations as well as during renewable curtailment periods (with “zero” emissions). Discharging can be modeled during peak periods using different peaking plant emission rate assumptions (detailed earlier in Table 6).

The first scenario assumes charging for bus operations with baseload generation units and discharging during V2G operations is assumed to displace non-baseload generation units with higher emissions rates, relative to baseload generation units. In this case, the NO_x and CO_2 emissions savings under full deployment scenario would total 65.3 metric tons and 42,000 metric tons, respectively. These CO_2 savings are equivalent to the carbon sequestered by close to 50,000 acres of US forest.[30]

The impact and externality costs of a pollutant including the cost of adverse human health effects are often quantified using the social cost metric. These costs were quantified based on citations which show that the annual social cost of NO_x and CO_2 total $9,400/ton and $43/ton,

[30] US Environmental Protection Agency, Greenhouse Gas Equivalency Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

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respectively.[31,32] These social cost savings total $633 thousand from NO_x and $1.8 million from CO_2 reductions annually.

Table 9: Annual Emissions Benefits of ESB2G Technology in Ameren Territory with Charging under Baseload and Discharging under Non-Baseload Emissions Factors

Emissions Scenario	NOx: Emissions	NOx: Social Cost	CO2: Emissions	CO2: Social Cost	CO2 Equivalency Forest Sequestration (acres)
Operating Mode	metric tons	$	metric tons	$	
			Short Term		
Bus Route Operation	-3.8		-2,101		
V2G Resource	-0.6		-421		
Totals	-4.3	-$41,924	-2,521	-$108,415	2,984
			Long Term		
Bus Route Operation	-18.9		-10,503		
V2G Resource	-11.0		-8,414		
Totals	-29.9	-$289,835	-18,917	-$813,422	22,387
			Full Deployment		
Bus Route Operation	-37.7		-21,006		
V2G Resource	-27.6		-21,035		
Totals	-65.3	-$633,146	-42,040	-$1,807,741	49,752

The second scenario assumes V2G charging during the times when renewable energy generation is being curtailed ("zero" emission rates) and discharging under capacity-adjusted peaking plant emissions rates (Table 10). In 2020, 5% of all wind generation in MISO was curtailed, meaning it is produced but not delivered to load due to oversupply or other grid constraints.[33] The curtailment of both solar and wind is expected to increase over time as more of these resources are added to the MISO grid. Emissions savings are significantly higher under this scenario and total now over 220 metric tons of NO_x and 225,000 tons of CO_2 annually in the full deployment scenario. These CO_2 savings are equivalent to the carbon sequestered by close to 270,000 acres of US forest. The social cost savings total $2.2 million from NO_x and $9.7 million from CO_2 reductions annually.

[31] https://iopscience.iop.org/article/10.1088/1748-9326/ab1ab5/pdf

[32] Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, 2016); https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf

[33] See U.S. Department of Energy, Land-Based Wind Market Report: 2021 Edition, available at https://www.energy.gov/sites/default/files/2021-08/Land-Based%20Wind%20Market%20Report%202021%20Edition_Full%20Report_FINAL.pdf.

Table 10: Annual Emissions Benefits of ESB2G Technology in Ameren Territory with Charging under Renewable Curtailment and Discharging under Capacity Adjusted Peaking Plants Emissions Factors

Emissions Scenario	NOx: Emissions	NOx: Social Cost	CO2: Emissions	CO2: Social Cost	CO2 Equivalency Forest Sequestration
Operating Mode	metric tons	$	metric tons	$	(acres)
			Short Term		
Bus Route Operation	-3.8		-2,101		
V2G Resource	-3.7		-4,095		
Totals	-7.5	-$72,737	-6,196	-$266,417	7,332
			Long Term		
Bus Route Operation	-18.9		-10,503		
V2G Resource	-74.6		-81,903		
Totals	-93.4	-$906,083	-92,406	-$3,973,456	109,357
			Full Deployment		
Bus Route Operation	-37.7		-21,006		
V2G Resource	-186.4		-204,757		
Totals	-224.1	-$2,173,765	-225,763	-$9,707,826	267,177

5 Summary and Conclusions

The University of Illinois at Chicago, Energy Resources Center with support from Nuvve Holding Corp. developed a spreadsheet-based model to assess the financial and emissions impact from deploying electric school buses (ESB) with vehicle to grid (V2G) bidirectional charging capabilities in the Ameren Illinois service territory. The analysis shows that at full adoption the ESB fleet could create a grid resource of close to 270 MW of power and 200,000 MWh of storage capacities respectively, close to 6 times the installed battery storage in MISO at the end of 2019.[34] Displacing diesel fuel with electricity and using V2G capabilities under full adoption would save up to $37.6 million, annually.

The model was also parameterized with rate data from California's IOU PGE with higher charging rates but also larger arbitrage opportunities. In this scenario, the bus operation generates substantially fewer savings while the savings from V2G operation dominate: V2G savings in the full deployment scenario under Ameren rates are $3.7 million compared to $27.6 million under PGE rates. This has important implications for policymakers with the recommendation to consider encouraging V2G infrastructure early as a hedge against potential rate increases that occur on a consistent basis.

Emissions savings from school bus fleet electrification would be substantial. The analysis showed that ESB buses operated in V2G mode charged during renewable curtailment periods and discharged during peak periods would save over 220 metric tons of NOx and 225,000 tons of CO2 annually in the full deployment scenario. These CO_2 savings are equivalent to the carbon sequestered by close to 270,000 acres of US forest. The social cost savings total $2.2 million from NO_x and $9.7 million from CO_2 reductions.

Overall, the ESB and V2G technology stack can capture arbitrage opportunities within the Ameren territory that arise from the fact that higher loads not only prompt higher prices but also higher emission rates within the grid region. The Scheduling Table developed as part of the model shows that the V2G emissions and financial arbitrage can be integrated and optimized around the ESB route requirements.

A large share of the V2G revenue would be generated during the peak summer months when the arbitrage price differential can exceed $0.09/kWh. This coincides with the summer break for school bus operation and increased availability of the resources for V2G operation. The peak loads incurred during summer months on the Ameren electricity grid also mean that low-capacity-factor, higher-polluting peaking plants are operating longer to meet load. V2G technologies can provide relief by reducing the times that these plants operate or in the longer-term allow the plants to retire as the V2G resource grows.

[34] See U.S. Energy Information Administration, August 2021, Battery Storage in the United States: An Update on Market Trends, available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage_2021.pdf.

Finally, roundtrip battery efficiency losses reduce financial returns and emissions savings. Minimizing the impact of battery efficiency losses is important. Future research should focus on better quantification of V2G benefits from other services including regulation services and capacity market revenues.

6 Constraints of the Model

A list of model constraints is provided below:

- The effect of greater cycling on battery life from V2G operations is still being studied, and additional operational limits may be required to keep batteries properly maintained.[35]
- The analysis only assumes a maximum battery capacity of 155 kWh and 60 kW charging capacity of the charging stations.[1, 36] In reality, various battery and bidirectional charger sizes will likely be commercially available in the future.
- The price assumptions for electric rates are historic and subject to change.
- The analysis does not include any system upgrade costs and grid congestion costs.
- Our analysis assumes an average roundtrip efficiency of 90% between the charging and discharging of the ESB battery. Roundtrip efficiency can vary by different factors including climate and usage.
- New markets for ancillary services, capacity, and regulation services may provide significant additional revenue in the future. Today, however, behind-the-meter distributed energy resources cannot access these value streams. This is likely to change as RTOs seek to comply with the Federal Energy Regulatory Commission's Order 2222, which requires RTOs to revise market rules to allow distributed energy resource aggregations to access wholesale markets. We have not assessed the value of these services.
- While this report assesses NO_x reductions from ESB and V2G technologies it does not account for the health benefit that the reductions from these technologies occur in urban areas (unlike NO_x reductions at central power plants located outside urban areas). The health impact from urban NO_x reductions has been shown to be much larger than reductions in non-urban areas.

[35] EPRI, Open Standards-Based Vehicle-to-Grid: Value Assessment, https://www.epri.com/research/summary/000000003002014771

[36] Expected range of 120 miles from a 155 kWh battery capacity - https://www.blue-bird.com/images/brochures/SB-RE-EV-1020.pdf

Appendix A: Overview of Real Time Pricing Opportunities and Grid Services

Independent System Operator and Regional Transmission Organizations are neutral and independent organizations responsible for the reliability, operations, resource planning, and expansion in the deregulated electricity markets in North America. They play the pivotal role of keeping the power grid balanced, managing the energy markets, capacity markets, financial transmission rights, and ancillary service markets. They do so by forecasting loads and scheduling generation to assure power reliability for level grid operation. RTOs and ISOs account for required generation and backup needed to match all unexpected demands or loss in generation during any possible interruption events on the grid.[37] [38]

Day-ahead Markets (DAM) and Real-Time Markets (RTM) markets are two components of Energy markets used to manage generation and consumption of electricity in North America.[39]

For this model, we summarize the possible utility for the electric school buses on the time domain arbitrage opportunities for battery storage in the day ahead markets (DAM) and the real-time markets (RTM). School busses can be aggregated at a V2G capable depot facility to create a virtual power plant (VPP) and participate in the DAM with possibility to make corrections in the RTM price.[39] With growing numbers and the modularity in the design, the fleet owners/ battery storage generation assets/generation assets can theoretically enter the DAMs by submitting bids to the RTOs to participate in supplying to the grid in real-time. The grid operators manage the grid production and consumption throughout the day by optimizing the generation dispatch schedule, usually in half hour increments. The Locational marginal price (LMP) is what the participants agree upon considering the system energy price, grid constraints, and cost of marginal losses at a specific location on the grid.[40]

In the real-time market, grid operators send dispatch instructions to all participating generation assets in real-time subject to the actual grid conditions across the grid (node and bus). The RTOs and ISOs operate the capacity markets to maintain the stability of the grid.
The commitment to provide electrical generation capacity is auctioned in capacity markets to ensure that generation surpasses load for an extended period of time. The capacity market incentivizes long-term capital investment in generation resources by paying capacity providers

[37] Survey of U.S. Ancillary Services Markets, Argonne National Laboratory, 2016, https://publications.anl.gov/anlpubs/2016/01/124217.pdf
[38] FERC, https://www.ferc.gov/power-sales-and-markets/rtos-and-isos
[39] D. Krishnamurthy, C. Uckun, Z. Zhou, P. R. Thimmapuram and A. Botterud, "Energy Storage Arbitrage Under Day-Ahead and Real-Time Price Uncertainty," in IEEE Transactions on Power Systems, vol. 33, no. 1, pp. 84-93, Jan. 2018, doi: 10.1109/TPWRS.2017.2685347.
[40] MISO, www.misoenergy.org

for their availability, regardless of whether those generation assets delivered power to the grid or remained on standby.

Grid Services Overview:

A) Customer Side Service

1. Residential demand shaving during the on-peak hours. The stored energy from the EVs would be used to reduce the severity of the peak demand during the morning and evening hours.[35] Vehicle to grid Electric School buses (V2GESB) allow power to be deployed strategically to insulate the fleet owners/ customers from the high real-time electricity prices. A V2G peak shaving program would allow the customers to offset the on-peak demand charges by charging the stationary buses during off-peak hours and dispatching it when it is most expensive during peak consumption between 4 PM and 8 PM.[35] The V2G would allow the end user to extract the stored energy from the bus batteries and reduce the electricity required from peaker plants. Charging ESBs off-peak and discharging on-peak reduces the customer bill, but provides limited value to the grid in this instance.

2. Provide resiliency in the event of a power outage or rolling blackouts. V2GESB customers and EV owners can draw power from the EV batteries for their use. V2GESB technologies to be deployed as localized distributed energy resources that support customers, individuals, communities, and schools in case of power outages and other unforeseen circumstances.

3. Charging using on-site renewable energy resources – V2GESBs can be paired with on-site solar to enable peak shaving and reduce the severity of the high price of electricity during those hours of the day.[35]

B) Value Added Services to the Grid

1. Grid level services like net-metering, demand response, and critical reserves (minimizing local marginal costs), where the battery storage using V2GESB can be deployed in sections of the distribution grid as a Non-Wires Alternative (NWA) by using the aggregated fleet storage to increase capacity while deferring the necessity for expensive capital transmission and infrastructure upgrades.[41] Mostly categorized under front of the meter applications where EVs can be aggregated to form a larger battery storage and used to diminish the severity of the on-peak demands on the grid. V2G operations would enable the fleet of EVs to be used as a utility scale storage or demand response program. V2GESB can be used as an energy resource in reserve, ready to dispatch and inject power to the grid as on-peak hour generation asset.

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[41] Published April 11, 2022. (2022, April 11). Energy Storage for utilities: Is it better to own or contract a battery storage system? Utility Dive. Retrieved May 21, 2022, from https://www.utilitydive.com/spons/energy-storage-for-utilities-is-it-better-to-own-or-contract-a-battery-sto/621374/

2. Minimizing Renewable energy curtailment in select markets. Battery storage can provide both grid services, mitigate congestion risk in the local distribution network, and provide community-scale energy supply. V2GESBs can be paired with renewable energy resources like wind and solar to enable more renewables on the grid. V2G capable electric school buses would allow integrating more solar, wind, and distributed energy resources into the grid by adding flexibility to the grid. It can also boost grid efficiency by boosting the capacity factor of current resources, reducing the need for new polluting peak power plants to be built.

3. Bidirectional charging capable electric school buses to engage in energy arbitrage within markets offering real time pricing (RTP) or time of use (TOU) rates. V2G as a solution enables energy stored in the batteries to be used to offset the daily on-peak demand.[35, 41] V2G capable EVs allow fleet owners and homeowners to assist balance the load on their grid. Variability in electricity demand, such as on a hot weekday evening when residential loads and commercial operations are overlapping, making it more difficult for grid managers and system operators to maintain system voltage and increase the cost of electricity in real-time.

4. Frequency Regulation and Reactive Voltage compensation. Although there is a lack of thorough analysis in the literature review, inverter topologies similar to the bidirectional charging stations used by V2G technologies have been studied to require minimal changes for reactive support applications.[42]

[42] M. Falahi, H. Chou, M. Ehsani, L. Xie and K. L. Butler-Purry, "Potential Power Quality Benefits of Electric Vehicles," in IEEE Transactions on Sustainable Energy, vol. 4, no. 4, pp. 1016-1023, Oct. 2013, doi: 10.1109/TSTE.2013.2263848

Appendix B: Ancillary Services Overview

Ancillary Services (A/S) are generally limited to the local distribution grid.[43] Ancillary services and demand response programs ensure the balance between the real-time supply and demand. This is achieved in real-time by only allowing the uneconomic generation resources are not dispatched when the demand is low and only brought online during the system peak demand. Meeting the services' criteria for ESB aggregators would be difficult since the aggregated number of ESBs at various levels of the grid will not always be sufficient to meet their requests for the ESB aggregators. In addition, the aggregators must have ample information to give a certain bidding capability, which is dependent on the services for which they are competitors. The amount of energy in the form of power and the time interval are the two most important needs. V2G capable ESBs have the potential for providing the following ancillary services:

1. **Frequency Regulation or Frequency Response**
   Between 5-minute economic dispatch orders, the Grid operators use frequency Regulation or just “regulation” to keep track of the real-time imbalance of power supply and demand. The operators send out a frequency regulation signal and handle independent frequency regulation up and down products. This ensures the balance of the electricity supply and demand in the grid at any instant.[35] Regulation assets are online and synchronized to the grid, able to respond to the automated signals within short time periods (typically seconds) and adjust their output according to the grid requirements.[37]

2. **Voltage Regulation**
   All electric vehicles are essentially electrical loads. Increased electrical loads may lead to problems such as overload and disturb system voltage. EVs have a tremendous potential for providing services for the grid, such as voltage regulation and frequency regulation.[44] Bidirectional chargers enable electric school buses (ESB) to participate in reactive voltage regulation with minimum discharge to the ESB battery, making them suitable for reactive grid regulation during any transients, reducing distribution line loss.[42]

3. **Spinning Reserves**
   Spinning reserves, or synchronized reserves in certain regions, are used to protect the system from unforeseen events, such as unscheduled outages of important infrastructure like transmission lines or generators. Spinning reserve units are assets that are online and synchronized to the grid but generating at less than full capacity.

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[43] Siyamak Sarabi, Arnaud Davigny, Vincent Courtecuisse, Yann Riffonneau, Benoît Robyns, “Potential of vehicle-to-grid ancillary services considering the uncertainties in plug-in electric vehicle availability and service/localization limitations in distribution grids”, https://doi.org/10.1016/j.apenergy.2016.03.064

[44] X. Wu, L. Li, J. Zou and G. Zhang, "EV-based voltage regulation in line distribution grid," 2016 IEEE International Instrumentation and Measurement Technology Conference Proceedings, 2016, pp. 1-6, doi: 10.1109/I2MTC.2016.7520568.

They are capable to quickly ramp up their generation (typically, minutes) once they receive the signal from the grid operators.[37] Spinning reserves can be generation or demand-side resources capable to reduce loads.

4. **Non-Spinning Reserves**
Non-spinning reserves, also referred to as supplemental reserves or primary reserves in certain regions,[37] are also used to protect the power system from unplanned and unforeseen contingencies. These resources need not necessarily be online at all times, but must respond by increasing their generation within the required time after the event signal from the grid operators. Non-Spinning Reserves are typically offline or online generation units.

Ancillary Services in MISO:

According to MISO, the Ancillary Services are services necessary to support the transmission of electric power from generators to consumers given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.

STR: Short Term Reserves
The Short Term Reserve product is a 30-min market-based solution providing rampable generation capacity by online or offline generation resources. MISO STR products, launched in December 2021, are designed to address short-term needs working in tandem with the ancillary and other service products. STR assures that the rampable assets are available whenever required and follows the Independent Market Monitor guidelines to implement the 30-min product incorporating the Voltage and Load Reliability (VLR) and Regional Directional Transfer (RDT) commitments. The STR product will be cleared in the DAM and RTM co-optimized with the other ancillary services. Failure to participate in the deployment after receiving instructions are subjected to charges. All assets cleared as capacity in the Planning Resource Auction (PRA), including Generation, Demand Response Resource Types I and II, Stored Energy Resource Type II, and External Asynchronous Resources, must participate in the STR.[45]

EVCP: Electric Vehicle Charging Program
Ameren's EVCP describes the rate design to promote implementation of electric vehicle charging in the utility jurisdiction. The EVCP tariff provides for seasonal time varying rates with up to three periods for distribution, transmission, and default service rates/ time of use and demand.[46]

[45] MISO, https://cdn.misoenergy.org/Short%20Term%20Reserve%20Fast%20Facts%20-%20Primer530762.pdf
[46] Ameren Illinois Company, https://www.ameren.com/-/media/rates/files/illinois/aiel21rdevcp.ashx

The rate is available to residential customers with separately metered EV charging equipment and a rebate program for eligible customers to install EV L2 Smart Chargers at Multi-Unit Dwellings. This optional rate program is also available to eligible non-residential customers like multifamily facilities, Education facilities, and transit facilities etc.[46]

Delivery Service Type	Rate structure	PCP Hours			Peak Non-Preferred Charging Period
		11 PM to 7 AM		Monthly Credit	11 AM to 7 PM
		PCP Delivery Credit ($/kWh)		Electric Vehicle Bill Credit ($)	Peak Hourly Delivery Charge ($/kWh)
		Summer Period	Non-Summer Period	First Year	
Residential Delivery Service	DS-1	$0.020	$0.010	$48	$0.650
Small Commercial / Volumetric	DS-2	$0.023	$0.012	$180	$0.460

For DS-1 and DS-2 customers, a credit for your electric delivery service is awarded for every kWh of usage during the preferred charging period (11 PM to 7 PM) or the PCP. There will be an extra fee for each kWh used during the Non-Preferred Charging Period's (NPCP) highest one hour of usage that falls within the timeframe of 11 AM to 7 PM. There are no additional credits or charges for electric usage during the hours of 7 AM to 11 AM and 7 PM to 11 PM. For DS-3 and DS-4 customers, customers pay a distribution demand charge based on the rate multiplier. The multiplier is based on the maximum on-peak demand and 50% of the off-peak demand. Customers can receive unlimited off-peak charging without increasing delivery service charges. As per Ameren, DS-3 and DS-4 customer participation in the charging programs are limited to 30 corridor-charging facilities, 25 educational facilities, and 10 transit facilities.[46, 47]

Ancillary Services in California:

Ancillary services (AS) are mostly purchased in the day-ahead CAISO market based on total load forecasts for the next day. CAISO already does view storage resources as a generation asset and will be reviewing rules and regulations for the operation of ever-growing storage resources in the mix.[48] CAISO may also award ancillary services to these resources in the DAM and RTM if they have been assessed and certified to offer such services by the CAISO. Total Resource Adequacy resources committed in California for 2020 fluctuated from 33,095 MW in March to 48,099 MW in August.[49, 50] System peak for the CAISO ranged from 43,982 MW to 47,121 MW in the last three years, in the months of August and September in the hours between five to six PM Pacific time. (*This value is an instantaneous MW value at the time

[47] Demand represents the rate of power (voltage x current) consumption at a given moment in time and is measured in kW (real power) or kVA (apparent power), depending on the metered data available. Demand is billed separately for commercial customers based on the peak demand in a given time period. Those charges are referred to as demand charges. Commercial customers also pay a rate based on consumption, kWh, over the billing period. https://www.ameren.com/illinois/business/electric-vehicles/rate,

[48] CAISO, www.caiso.com

[49] California Public Utilities Commission, www.cpuc.ca.gov

[50] Dupre, E., Chow, L., Brant, S., Kito, M., & Ikle, J. "2020 RESOURCE ADEQUACY REPORT", cpuc.ca.gov, Retrieved May 23, 2022, from https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/resource-adequacy-homepage/2020_ra_report.pdf

specified in the Time column). Note that this type of service has not been used by behind the meter resources.

Proxy Demand Resource (PDR) allows third parties to bid demand response into the CAISO market for load curtailment in wholesale Energy and Ancillary Services markets, independent of the Load Serving Entity.[51] PDR – Load Shift Resource (PDR-LSR) enables bidirectional capable assets for increasing consumption during the negative pricing events or when supply exceeds the demand on the grid. PDR and PDR-LSR can participate in the DAM, RTP energy markets (100 kW minimum curtailment) and the Day-ahead and Real-time Spinning and Non-Spinning Reserve markets (500 kW minimum curtailment for 30 min). Allows for unit aggregation.

DER Provider (DERP) enables aggregated Distributed Energy Resources (DERs) to meet minimum capacity thresholds as a 'virtual' resource. DERP can participate in the DAM, RTP energy markets (500 kW minimum capacity, maximum of 20 MW when aggregated with no individual resource more than 1 MW in capacity) and the Day-ahead and Real-time Spinning and Non-Spinning Reserve markets.[48] Note that this type of service has not been used by behind the meter resources.

Non-Generating Resource (NGR) is a market participation model designed to account for a storage resource's positive-negative range. It can be used as a storage resource or provide generation. Subtypes include the **Limited Energy Storage Resources (LESR)**, such as batteries and flywheels, which have continuous positive to negative operating range subjected to their state of charge (SOC), **Dispatchable Demand Response DDR)** which cannot generate electricity and are constrained by their curtailment energy limit, and Generic NGRs which unlike batteries aren't constrained by an SOC. NGRs can participate in the Regulation markets (60 min minimum) along with the DAM, RTP energy markets, and the Day-ahead and Real-time Spinning and Non-Spinning Reserve markets (500 kW minimum capacity and 15 min continuous energy requirement).[51] Note that this type of service has also not been used by behind the meter resources.

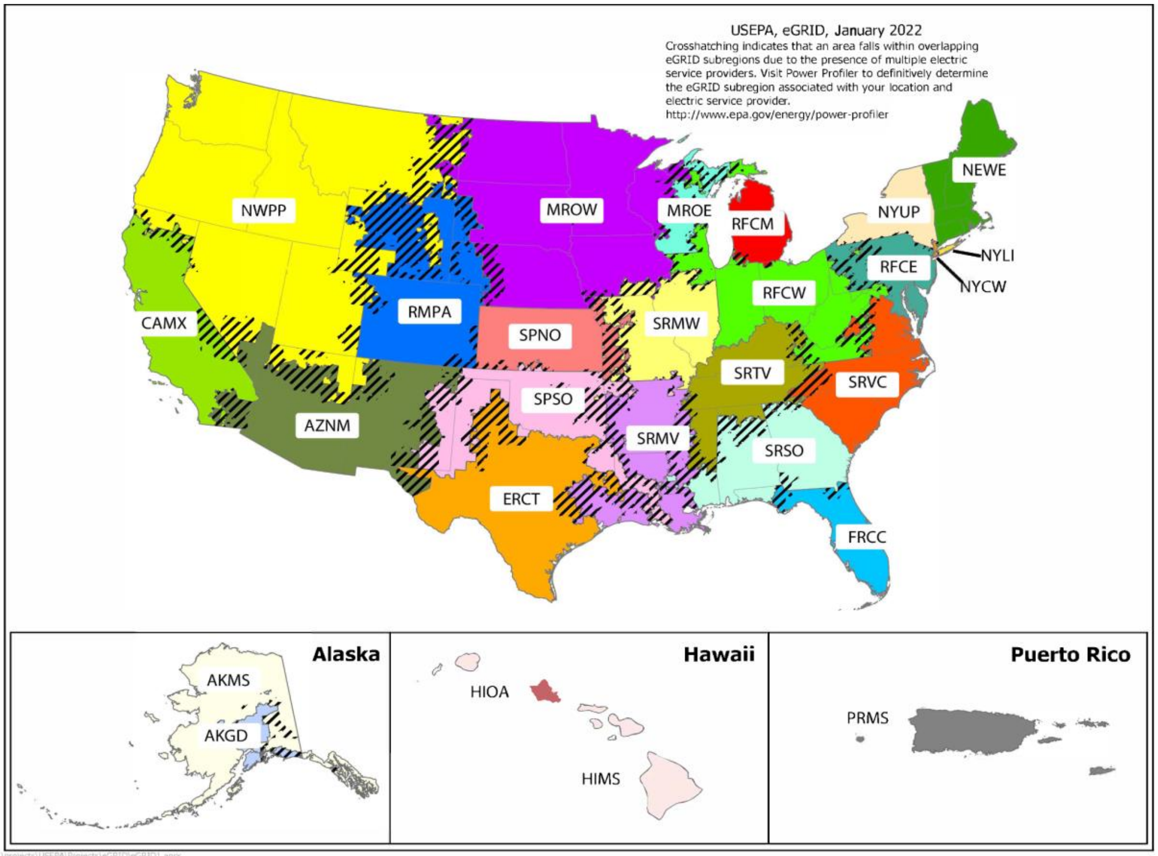
ELRP: Emergency Load Reduction Program

The ELRP is a five-year pilot program, available from May through October, during the hours of 4 PM to 9 PM, that rewards Group A: Non-residential consumers (not currently enrolled in demand Response or Group B (Demand Response enrolled consumers) for lowering their energy consumption or increasing their supply during power outages. The ELRP enables electric grid operators and utilities to limit energy consumption during a grid emergency in order to lessen the risk of power outages when available energy supply is insufficient to meet expected demand. V2G aggregators that can provide managed charging services are eligible. For every kilowatt-hour of power usage reduced voluntarily during an ELRP event, participants are rewarded at a predetermined compensation rate of $2/kilowatt-hour reduced during an event. The reduction in consumption during an ELRP event is calculated by comparing how

[51] CAISO, https://www.caiso.com/Documents/ParticipationComparison-ProxyDemand-DistributedEnergy-Storage.pdf

much energy the customer used on days before the event day during hours identical to the event hours. During an ELRP event, there are no penalties for either not reducing or increasing energy use. Event duration is 1-hour minimum; 5-hour maximum, and consumers can participate consecutive days. Annual dispatch limit Up to 60 hours. Event triggers utilized are both Day-Ahead and Day-Of per the CAISO Alert, Warning, and Emergency escalation Process.[48]

Appendix C: eGrid Subregions



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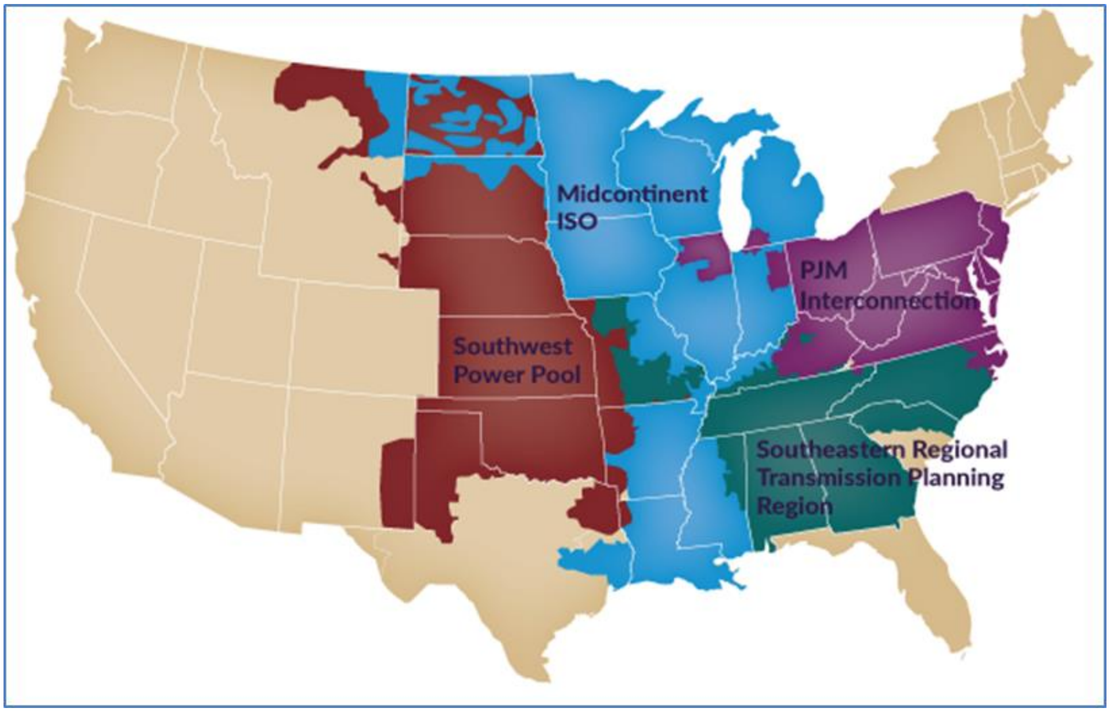
Appendix D: Midcontinent Independent System Operator Territory



Source: misoenergy.org

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Appendix E: AVoided Emissions and geneRation Tool (AVERT)

AVERT Subregion	Avoided CO2 Rate	Avoided NOx Rate	Avoided SO2 Rate	Avoided PM 2.5 Rate
National	1,550	0.85	0.92	0.11
California	1,061	0.27	0.06	0.04
Carolinas	1,664	1.00	0.64	0.12
Central	1,800	1.29	1.36	0.08
Florida	1,087	0.35	0.23	0.08
Mid-Atlantic	1,540	0.73	1.18	0.13
Midwest	1,860	1.26	1.67	0.16
New England	1,104	0.20	0.09	0.03
New York	1,090	0.36	0.17	0.05
Northwest	1,636	1.15	0.75	0.09
Rocky Mountains	1,904	1.05	0.58	0.04
Southeast	1,563	0.83	0.34	0.09
Southwest	1,544	0.95	0.29	0.08
Tennessee	1,479	0.56	0.74	0.10
Texas	1,282	0.54	0.65	0.06

Source: Fuel and Carbon Dioxide Emissions Savings Calculation Methodology for Combined Heat and Power Systems U.S. Environmental Protection Agency Combined Heat and Power Partnership June 2021

Appendix F: Peaking Power Plants in SRMW Region and Emission Rates

Plant State	Plant name	Plant transmission or distribution system owner name	Balancing Authority Code	eGRID subregion acronym	Plant primary fuel category	Plant capacity factor	Plant nameplate capacity (MW)	Plant annual NOx total output emission rate (lb/MWh)	Plant ozone season NOx total output emission rate (lb/MWh)	Plant annual CO2 equivalent total output emission rate (lb/MWh)
				SRMW	COAL	0.0109	1,041.0	2.144	1.910	2,972
MO	Meramec	Union Electric Co - (MO)	MISO	SRMW	COAL	0.1397	617.8	1.007	0.733	2,525
IL	Dallman	City of Springfield - (IL)	MISO	SRMW	COAL	0.1482	5.1	3.170	2.868	1,206
IL	SIUC	Ameren Illinois Company	MISO	SRMW	COAL	0.2433	1,234.8	1.428	1.467	2,313
IL	Newton	Ameren Illinois Company	MISO	SRMW	COAL	0.2447	1,894.1	0.879	0.857	2,217
IL	Baldwin Energy Complex	Ameren Illinois Company	MISO	SRMW	COAL	0.2466	422.0	2.369	2.505	2,997
IL	Marion	Southeastern IL Elec Coop,	MISO	SRMW	COAL	0.2855	1,099.4	2.558	2.576	2,324
MO	Sioux	Union Electric Co - (MO)	MISO	SRMW	COAL	0.4016	335.0	0.578	0.551	836
IL	Archer Daniels Midland Co.	Ameren Illinois Company	MISO	SRMW	COAL	0.4265	1,099.8	1.222	1.266	2,181
IL	Joppa Steam	Ameren Illinois Company	EEI	SRMW	COAL	0.4543	780.3	1.590	1.614	2,229
IL	E D Edwards	Ameren Illinois Company	MISO	SRMW	COAL	0.5428	1,300.0	5.898	5.811	2,022
MO	New Madrid Power Plant	Associated Electric Coop, In	AECI	SRMW	COAL	0.6137	1,242.0	0.902	1.074	2,268
MO	Rush Island	Union Electric Co - (MO)	MISO					1.979	1.936	2,174