ARIZONA STATE UNIVERSITY

SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

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RESEARCH REPORT

VEHICLE-TO-GRID CHARGING IN PHOENIX TO SUPPORT POWER GRID RELIABILITY UNDER EXTREME HEAT

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ABSTRACT

This research paper explores the integration of Vehicle-to-Grid (V2G) technology in Phoenix, Arizona, highlighting its potential to alleviate the pressures placed on the electrical grid which are made worse by increasing temperatures. The analysis focuses on the relationships between summer temperatures, reliability of the power grid, and the adoption of electric vehicles (EVs) equipped with bidirectional charging capabilities. Given Arizona's vulnerability to extreme heat and the significant demand for cooling, this paper employs scenario planning to assess three potential futures for the summer of 2030. The scenarios range from the optimistic best-case scenario, where EV adoption and public awareness are on the rise, to the worst-case scenario which is characterized by stagnant EV adoption rates and decreased grid reliability. The findings suggest that while V2G technology has the potential to provide essential backup power during outages, its effectiveness is contingent upon increased public awareness and supportive regulations.

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INTRODUCTION AND BACKGROUND

Electric vehicles have gained popularity over the last decade and there are now many vehicle manufactures that have entered the market. With the Toyota Prius being the first mass-produced hybrid vehicle, it has encouraged other companies to follow. Other brands such as Nissan, with their introduction of the Leaf, and the Tesla with their Model S, helped popularize all-electric vehicles. There are a few features of electric vehicles that have contributed to their rise. With gas prices constantly being a point of contention and electric vehicles eliminating the need for gas entirely it makes them more appealing. Even though the initial cost of the electric car is typically more expensive than a gas-powered vehicle, in the long run buyers feel they are able to make that money back by not having to pay for gas. This is a large selling point of the vehicles as well as the environmental benefits from the minimization of fuel emissions. According to the U.S. Department of Energy, all-electric vehicles have zero tailpipe emissions. For buyers who consider their individual emissions and carbon footprint, an electric vehicle can be appealing to them and make the higher price more palatable. Other characteristics of electric vehicles such as lower maintenance costs, safety, or popularity also help contribute to their recent growth. However, one lesser-known feature of electric vehicles can cause them to be even more appealing: Vehicle-to-Grid technology.

Vehicle-to-Grid technology, commonly referred to as V2G, is a newer technology that can work hand-in-hand with electric vehicles. "V2G… is a technology that enables energy to be pushed back to the power grid from the battery of an electric vehicle (EV)" (Virta Global). As most people know electric vehicles need to be charged and utilize power sources to do so. There are charging stations that can be located around many cities and most people will charge them at their homes. Just like plugging in a laptop or electric bike, electric cars must be charged regularly to maintain function and achieve this by receiving power from the grid. An electric grid is made up of power plants, transmission lines, and distribution centers and are able to provide power to the surrounding areas. The United States power grid is made up of three main interconnections that operate independently but can transfer power between each other if need be (Just Energy, 2021). Within the three main regions there are subsections that allow for entire regions to not experience a blackout. Blackouts to the power grid are now becoming more of a concern due to climate change.

The United States' power grid is not immune to the negative impacts that climate change causes. "In the United States, 96% of power outages in 2020 were caused by severe weather or natural disasters" (Sypher, 2021). It has also been found that almost half of these blackouts happen in just eight states, with one of those being Arizona. Arizona is located in the southwestern portion of the U.S. and nearly half of the state is within the Sonoran Desert. This results in the state experiencing some of the hottest temperatures in the entire country. The high temperatures in Arizona are nothing new and most people associate Arizona with the desert heat. However, as the climate as a whole is warming, the state has begun to experience record breaking temperatures regularly, especially in the summer months. The summer of 2024 was the hottest ever recorded in Arizona's history with an average daily temperature of 99°F (Arizona PBS, 2024). This average was two degrees warmer than the year before. If temperature trends continue in the way they have been, which they most likely will, Arizona summers will continue to become even hotter and more unbearable. These temperatures put an enormous amount of stress on the grid. This is due to the increased demand from the state's residents for air conditioning and cooling.

With the high temperatures throughout the state many people have their air conditioning running constantly just to make their homes a tolerable temperature. There is also the power that is required to cool refrigerators and similar appliances. When there is this large increase in demand from the grid it puts significant pressure on it and can result in blackouts. The effects of a blackout in Arizona can be devastating and result in the loss of life. "Almost 1 percent of the population of Phoenix may die should a failure occur" (Tara, 2023). That would be over 15,000 people. The fear of a blackout in Arizona, and especially Phoenix, the largest city in the state and the fifth largest in the country (by population), is very real and is a risk that should be addressed. Significant infrastructural changes are not likely to happen soon which results in the average citizen wondering how they can individually prepare if such an event were to happen. This is where an electric vehicle can be helpful and work with the grid to help power a home or small building.

METHODS

Bidirectional charging is the main process that can allow an electric vehicle to be useful during a blackout. The concept of bidirectional charging is simple in summary in that an electric vehicle cannot only pull energy from the grid but also put energy into the grid. According to the U.S. Department of Energy, bidirectional EVs can provide power to individual buildings or the larger grid, either through *vehicle-to-building (V2B)* or *vehicle-to-grid (V2G)* systems. In the event of a blackout the technology would allow an EV owner to be able to use their car as a sort of backup generator until the power was restored. The power an EV can provide can also be used as a proactive solution instead of just a reactive one. The following sections will outline how this technology can be used in Phoenix, Arizona in the event a blackout does occur. To allow for this possibility to be better studied, scenario planning will be used. There are four main aspects of scenario planning which include: identifying driving forces, identifying critical uncertainties, developing plausible scenarios, and discussing implications and plans (Mariton, 2016). The goal of scenario planning is to better understand how certain scenarios can cause a system to react and to identify major aspects of the system that can impact the result. The method also outlines which variables are uncertain and which are easier to predict. This process will be helpful in better understanding how an EV can work with V2G technology and help Phoenix feel more secure as the temperatures continue to increase annually.

Driving Forces and Variables

The first step of scenario planning is to identify driving forces within the system and important variables. Uncertainties within the system will also be analyzed in hopes of trying to better understand and predict their behavior. One of the most important driving forces is the climate and weather conditions in Phoenix. The long periods of high heat that the city experiences make it vulnerable to blackouts and is the main variable within the system. The future temperatures in Phoenix cannot be predicted, but recorded temperatures from the previous years can help determine what the weather could be for upcoming summers. The next variable to consider is grid infrastructure and reliability in the area. If the grid is reliable, then the event of a blackout is not as likely, but if the grid is more unstable then blackouts may be more likely. The grid that Phoenix uses will need to be analyzed to determine how likely it is that a blackout would occur due to high temperatures, and if so, how V2G technology can be utilized within the system. Another important variable is EV adoption rates. This variable encompasses not only how many EVs there are in Phoenix, but also what percentage of them can work with V2G technology. A few other driving forces within the system are battery capacity and technology, policy and regulations, and public awareness/adoption. These variables will need to be used and studied within the different scenarios to better understand how V2G technology can be beneficial if a blackout were to occur.

Not all the variables within the system are easy to define or predict which result in them being considered uncertain. "Uncertainty is not simply the absence of knowledge… uncertainty [described] as a situation of inadequate information, which can be of three sorts: inexactness, unreliability, and border with ignorance" (Funtowicz & Ravetz, 1990). For this report most of the variables have some level of uncertainty which result in the importance of scenario planning. There will be three scenarios that will be analyzed with each having different outcomes. There will be the best-case scenario which will detail what would happen if most, or all, the variables behave in the desired manner. The moderate case scenario is second which is what would happen if some variables behaved as desired while some fall short of the mark. The final scenario is the worst-case scenario where the system experiences many challenges, and the variables behave in ways that negatively impact the system. However, before the scenarios are defined the ranges of likelihood for the different variables needs to be defined.

Phoenix Climate and Weather Conditions

As mentioned, Phoenix, Arizona experiences not only high temperatures in the summer but extremely long periods of these high temperatures. In 2024, Phoenix endured more than 100 consecutive days with temperatures reaching or frequently surpassing 100°F (Uteuova, 2024). These high temperatures are not new, and the Phoenix metropolitan area has experienced these temperatures for decades, however, as most places are, the temperatures have been increasing over time. To be able to better predict the future temperatures in Phoenix past data needs to be used. NOAA provides data on how many days a year the city reached or surpassed the 100-degree mark since 1905. For this report data going back to 1995 will be used.

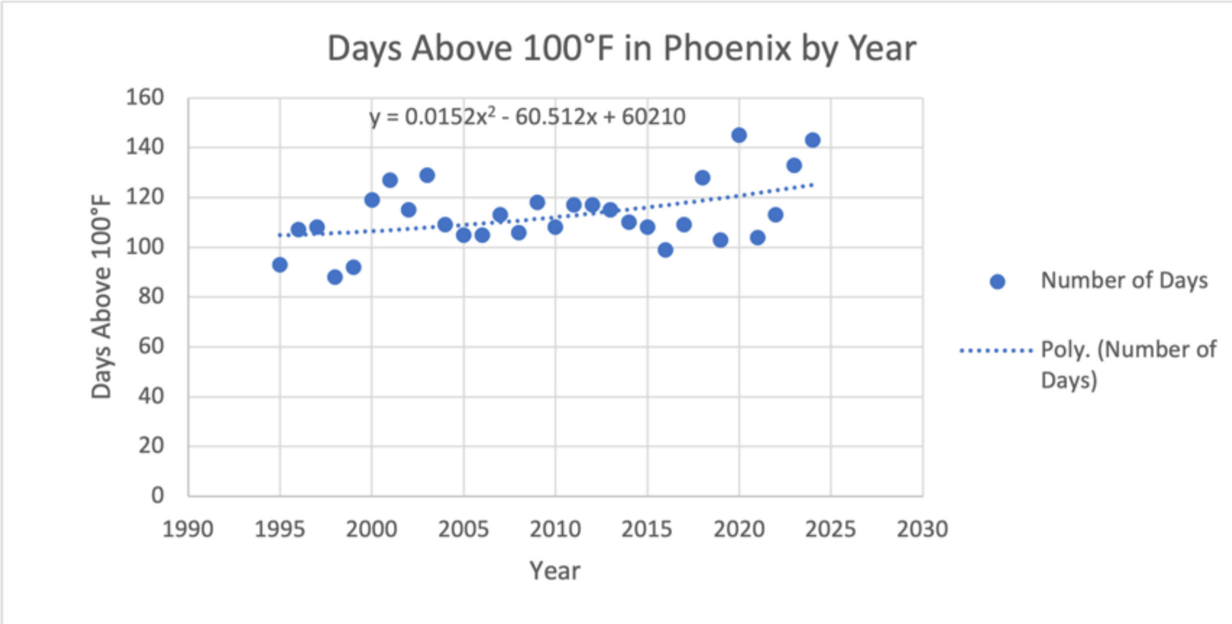

Figure 1: Number of Days Above 100°F in Phoenix According to NOAA Data.

Figure 1 shows that over the last 30 years the temperature, on average, has been trending upward. The equation shown on the graph represents the average trend of how much the temperature increases each year. This data further backs the assumption that weather in Phoenix will continue to remain hot for long periods of time in the upcoming future. The weather is expected to also increase in overall temperature. On average in Phoenix the hottest month of the year is July. This is the middle of the summer temperatures in Arizona and is when the average temperatures are at their highest. Data from July will be used moving forward since this would be the expected time for a blackout to occur when temperatures are at their hottest. Data collected from the Phoenix Sky Harbor International Airport Station is shown in *Figure 2*. The temperatures shown represent the average temperatures for each July since 1995 (Weather Underground).

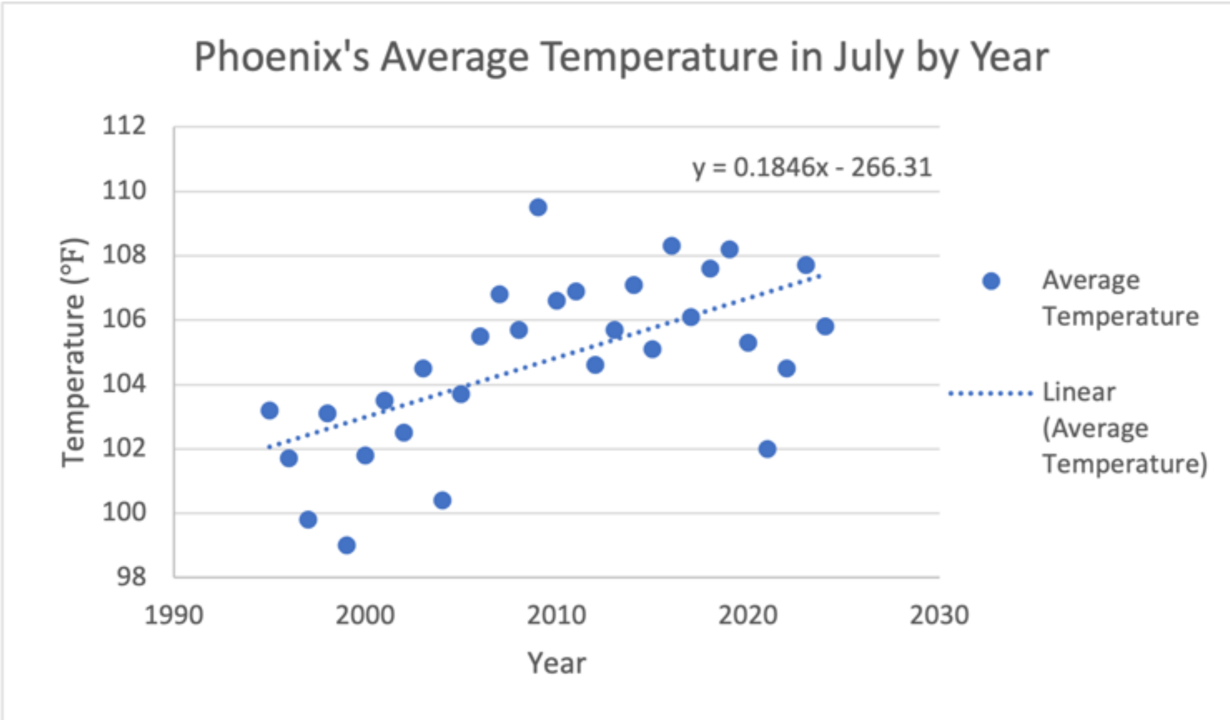

Figure 2: Average Temperature Each July in Phoenix from 1995 to 2024.

Both *Figure 1* and *Figure 2* further show that weather in Phoenix will only continue to become more extreme. This will then directly result in more demand being required from the power grid. Due to these prolonged periods of demand that the grid must endure, it calls into question the reliability of the grid and if it can handle it. If temperatures in Phoenix continue to increase, is the existing power grid enough to support the demand that will be put on it? And what is the risk of a blackout occurring? In response to these questions, the next variable to be analyzed is the reliability of the power grid in Phoenix and how it could behave in the upcoming summers.

Arizona's Power Grid Reliability

Arizona is one of the newest states in the U.S. and many developments in and around Phoenix are new when compared to the rest of the country. This results in a lot of the state's infrastructure being young and utilizing new technology. As Arizona continues to grow, new developments consider the climate of the area and build in response to it. This results in the power grid in Arizona historically being very reliable. "Arizona is now ranked 7^{th} in the nation for electric grid reliability" (Arizona Corporation Commission, 2024). Many states throughout the country experience power outages more frequently and in turn are more used to them. However, as weather becomes more extreme all throughout the country, and world, power grids may become less reliable, and this could include Arizona. According to Climate Central the number of power outages throughout the country between 2014-2023 was nearly double what the previous 10 years had experienced (2024). This statistic places a lot of uncertainty on the future of power grids throughout the country and how they will behave.

Some of the main contributors to this uncertainty is the future of extreme weather, politics surrounding energy, and upkeep/funding. One example of how politics and funding play a role in energy and power was discussed recently by Kevin Thompson who is the chair of Arizona Corporation Commission. "[Thompson] cited the need for Arizona officials to collaborate better with federal authorities, from the EPA to the U.S. Forest Service to the Federal Energy Regulatory Commission" (Wiles, 2025). If Arizona's government can't work closely with the federal government regarding energy, then the grid can be impacted by it. Factors such as this can play a large role in if the state's grid is able to remain as reliable as it has been in the past. This results in the reliability of the grid being an uncertain variable even if up until this point it has stood strong.

EV Adoption

Another important variable moving forward is the number of electric vehicles in Phoenix and how many are equipped with technology that supports bidirectional charging. As mentioned earlier in this paper EV adoption rates are increasing and more can be seen on the road now than ever before. According to the U.S. Department of Energy in 2023, Arizona had almost 90,000 EVs on the road, resulting in the state being in 10th place. California had the most EVs and was followed by Florida and Texas. The amount of EVs that are in Arizona plays an important role on how resilient and flexible the grid is. It is also important to know how many of these EVs support bidirectional charging. Brands such as Kia, Nissan, Ford, and others have vehicles that do support this type of charging, however brands such as Toyota and Tesla do not have widespread adoption of this technology. This is a problem because Toyota Prius' and Tesla's (not including the Cybertruck which does support bidirectional charging) are some of the most popular electric vehicles. When considering the amount of EVs on the road in Arizona and the likely small percentage of those that can support bidirectional charging, adoption is low. This variable will play an important role in the scenario analysis because the amount of EVs that support bidirectional charging greatly impacts the resilience of the grid.

Regulations, Public Awareness, and Battery Capacity

The three variables mentioned in the previous sections have the most impact on the possible scenarios that will be analyzed. However, a few smaller variables such as regulations surrounding EVs, public awareness regarding bidirectional charging, and battery capacity of an EV all have an impact on the future of V2G technology and grid resilience. The battery capacity of an EV plays an important role in how much power the vehicle can provide in a blackout and how efficiently it can transfer energy back to the grid. Policies and regulations are also important because they can impact EV adoption, grid reliability, and funding. The public awareness surrounding V2G technology also had a significant impact because the more people that are aware of the technology the more likely they would be to invest in it and utilize it. If there isn't a focus on spreading the knowledge of EV potential and bidirectional charging, then the technology will not be utilized as much as it can be.

RESULTS

As discussed, up until this point there are a lot of variables that play an important role in V2G technology and its widespread use. These variables can now be used to develop scenarios for the potential future of V2G technology and how it can be used in the event of a blackout in Phoenix. There will be three scenarios that will be outlined in detail, the best-case scenario, the moderate-case scenario, and then the worst-case scenario. Each scenario will utilize different values for the defined variables and will outline how each will respond to a grid blackout. The first step however will be to define a system boundary. The system boundary will include only the specific area that will be analyzed and will allow for a more localized approach. The physical boundary of the system will be the City of Phoenix. All variables that will be considered are located within the system boundary, and the limits of the system are shown in *Figure 3*. The only exceptions are the entire Arizona power grid will be analyzed and the state's adoption rates as a whole will be considered. This is due to there being more data available for the entire state.

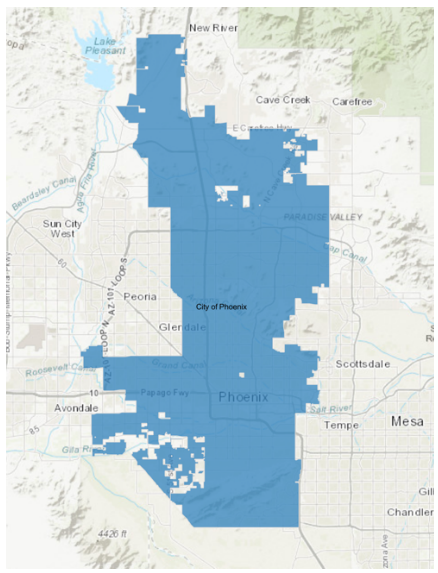

Figure 3: ArcGIS Map of Phoenix, sourced from City of Phoenix.

With the variables and system boundary being defined the scenario analysis can now begin. As mentioned, there are three scenarios that will be outlined and their potential outcomes and effects on the city will be studied. Each scenario will consider different ranges of values for the variables, which are unique to each scenario. For each of the possible scenarios the same event will take place. The event is outlined below.

> It is the month of July 2030 in Phoenix, Arizona. The hottest city in the United States is amid its hottest month of the year. Residents are staying inside due to heat warnings and high UV levels. They manage to receive some relief from the heat by turning their AC on high, utilizing fans, and drinking plenty of cold water. The power grid experiences high levels of demand from the residents, especially during the hottest parts of the day. Day after day residents struggle to withstand the high temperatures and the grid must be

able to respond to the constant demands, with no relief even in the middle of the night when temperatures sometimes don't drop below 90°F. Residents begin to worry about the impacts of the constant electricity demand especially since the high temperatures won't let up any time soon. The following scenarios outline different outcomes of this possible situation.

Scenario One: The Best-Case Scenario

Scenario One is defined as one in which all variables meet or are close to meeting their desired values. These values must be within reason and have the possibility to occur. As mentioned above the main variables to be considered are Phoenix's climate and weather conditions, Arizona's power grid reliability, EV adoption rates, as well as regulations, public awareness, and battery capacity. *Table 1* summarizes the ideal values for Scenario One.

Table 1: Scenario One Variable Summary

Variable/Driving Force	Level of Importance	Projected Results
Climate/Temperatures	High	Decreases/No Change
Power Grid Reliability	High	Increases/No Change
EV Adoption Rates	High	Increases
Regulations	Moderate	Increases
Public Awareness	Moderate	Increases
Battery Capacity	Low	Increases/No Change

To better understand the desired values for the best-case scenario a more in-depth analysis will be performed. Phoenix's climate and high temperatures are the main driving force for this study in general, resulting in this variable being a vital one to study. *Figure 4* shows the probability for future maximum temperatures in July for Phoenix. The graph utilizes data from the past 30 years to determine the probability for future highs. The same data is used in *Figure 2,* however the difference in *Figure 4* is that it considers all maximum temperatures equally instead of showing an overall trend.

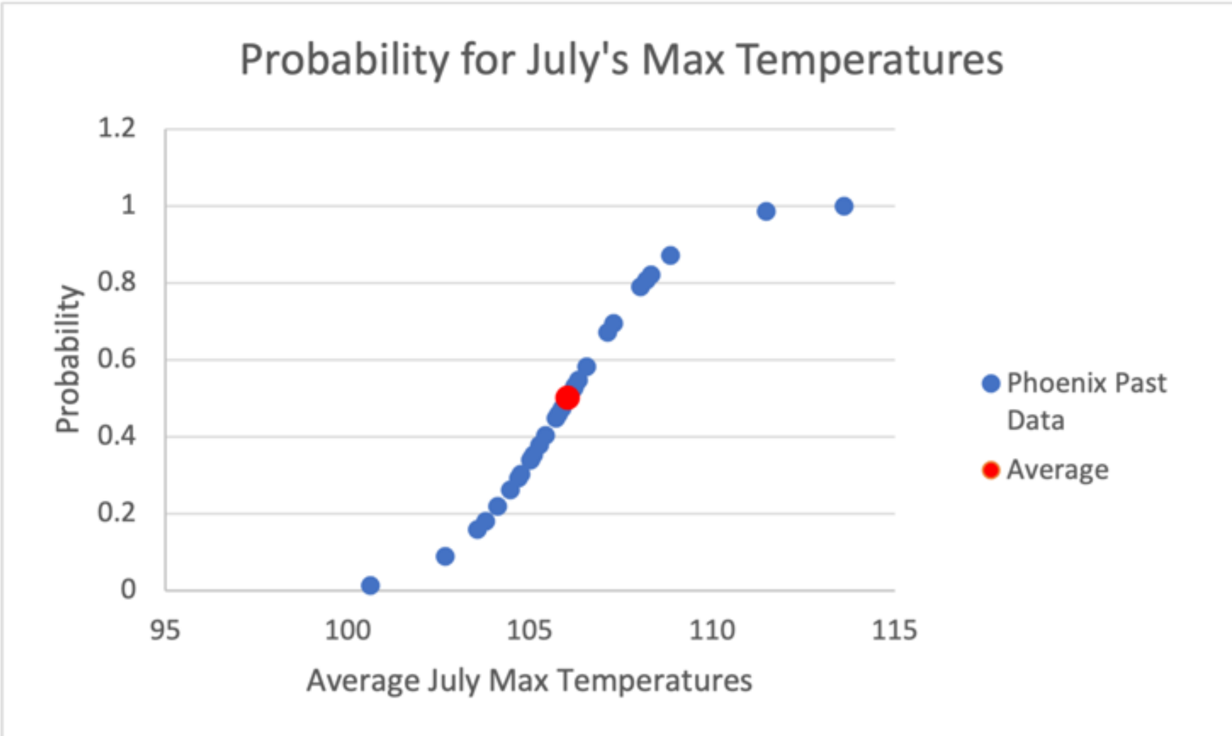

Figure 4: Probability for July's maximum temperatures using data from 1995 to 2024.

Using the data shown in *Figure 4* the average high over the last 30 years is determined to be approximately 106°F. In a perfect world the highs would decrease in a future scenario, however this is extremely unlikely. This results in the best-case scenario considering a stabilization of future high temperatures rather than a decrease. Scenario One will in turn be utilizing a future average high of 106°F in July, which would be better than the overall increasing trend shown in *Figure 2*.

The second variable to discuss is future power grid reliability. As determined earlier Arizona's power grid is one of the most reliable in the country. There are worries that as temperatures increase the reliability could go down. However, for this scenario the temperatures remain stable, which in turn would allow the power grid to also remain stable. Within the best-case scenario the power grid will continue to remain dependable.

The final highly important variable to consider is EV adoption rates. As mentioned earlier, Arizona electric vehicle numbers are the 10th in the country, with about 90,000 EVs on the road. This results in only about 1% of vehicles on the road in Arizona being fully electric. The current numbers of EVs in Phoenix, as of 2025, are estimated to be about 46,000 (City of Phoenix). The City of Phoenix's hope is that this number will greatly increase within the next 5 years. Phoenix's Transportation Electrification Action Plan (TEAP) has a goal of supporting 280,000 EVs in Phoenix by 2030. This is an increase of more than 6 times the current number. The best-case scenario will assume that this projection is met. The TEAP considers a 30% compounded annual growth rate which will be considered for this report. These growth rates will be adopted into the best-case scenario.

The two moderate variables of regulations and public awareness work together. The more regulations that are created surrounding electric vehicles not only increases public awareness, but also increases the benefit of owning an EV. According to the U.S. Department of Energy there are many different laws and incentives within Arizona that benefit those that own an EV. The laws surround license plates, parking space regulations, federal fleet regulations, and more. There are also incentives such as parking incentives, tax exemptions, HOV lane exemptions, and more. The goal of these regulations and incentives within the state are to encourage residents to purchase and drive EVs. This would help contribute to the meeting of the state's 2030 EV adoption goal. The public awareness would also increase as these incentives would encourage more consumers to consider purchasing an EV. However, for this report the public awareness surrounding bidirectional charging is what matters the most.

Within the best-case scenario there would be a state incentive that encourages consumers to utilize bidirectional charging, especially during times when the grid experiences peak demand. It would also be important for there to be a federal regulation that encourages EV manufactures to increase production of vehicles that support bidirectional charging. As mentioned earlier there is a limited amount of EVs that currently support bidirectional charging. In summary, if there are more regulations and incentives placed on EVs that allow bidirectional charging than there would be an increase in public awareness surrounding the technology and its possibilities. Using this knowledge and applying it to the best-case scenario, in Arizona, and specifically Phoenix, there would be an increase in these regulations as well as an emphasis on increasing public knowledge surrounding V2G technology and its benefits.

The final variable to consider is an EVs battery capacity. If an EV can only hold enough energy to power a home for a few minutes than it might not have much of an impact on the grid. This could also decrease the public's adoption of EVs. Fortunately, electric car batteries hold more energy than this. "Electric car batteries hold an average of 69.5 kilowatt hours (kWh) of energy, enough to provide back-up power to an average U.S. household for two days" (Metzger, 2024). This is a significant amount of time considering in 2021 the average Arizona resident only experienced 1.77 hours of power outages (U.S. Energy Information Administration). This results in the battery capacity of an EV to already meet the best-case scenario desired values. Overall, the goal for Scenario One would be either to maintain the amount of energy an EV can hold or to increase it.

Results of the Best-Case Scenario

In the previous section the variables that have the greatest impact were outlined and desired values and ranges were determined. Using these values, the result of the best-case scenario can be analyzed. Referring to the outlined event earlier this can be combined with these values to determine what could happen.

> To begin, temperatures within July of 2030 were high, but didn't overall exceed the desired average of around 106°F. The grid had in the past

remained stable under these grueling temperatures and was able to do the same for the summer. It also was able to receive some help from the increased numbers of EVs that utilized V2G technology. Phoenix was able to reach their goal of over 250,000 electric vehicles on the road by 2030 due to the increased implementation of regulations and incentives on EVs. One main factor that resulted in the increase of EV adoption in Phoenix was the push for public awareness surrounding bidirectional charging. The knowledge surrounding bidirectional charging and its ability to lower electricity bills became popular and more residents felt encouraged to purchase an EV that allowed for V2G compatibility. There was also an increase in manufacturers producing EVs that supported this capability. Residents then not only used EVs to power their homes during heat waves but more frequently in hopes of lowering their electric bills. This resulted in the grid overall not being under as much pressure to meet the extremely high levels of demand it was used to. All of this in turn resulted in no power outages during the summer and encouraged even more residents to purchase one of these vehicles in the near future.

Within the best-case scenario power outages within Phoenix remained low and EVs that supported bidirectional charging became more popular on the roads. This is the ideal scenario and requires significant effort from governments and EV manufacturers. However, without significant work this scenario is unlikely.

Scenario Two: The Moderate-Case Scenario

The goal of the moderate-case scenario is to combine likely future events while still maintaining a positive approach. The variables to be analyzed are the same as the previous scenario and the results are summarized in *Table 2*.

Table 2: Scenario Two Variable Summary

Variable/Driving Force	Level of Importance	Projected Results
Climate/Temperatures	High	Minimal Increase
Power Grid Reliability	High	Minimal Decrease
EV Adoption Rates	High	Minimal Increase
Regulations	Moderate	Minimal Increase/No Change
Public Awareness	Moderate	Minimal Increase/No Change
Battery Capacity	Low	No Change

Figure 2 shows the trend of average Phoenix temperatures in July and how they have been gradually increasing over the last 30 years. The trendline shown on the graph displays the average linear increase of the temperatures over time. The linear equation is not one that can be used to predict future temperatures and is only included to show the overall trend. Within the moderate-case scenario the hope would be that aside from the knowledge temperatures in Phoenix will increase, they will increase less than what is anticipated. In a case such as this the trendline will still be increasing, but the slope would be less than what *Figure 2* shows as data from future years is added. In response the grid would experience an increase in demand, however it wouldn't be a large spike that shocks it.

With the increase in temperatures, however minimal, an increased demand from residents is placed on the grid. Another factor to consider is that concurrently as temperatures increase over time, the grid is aging. "Looking at our present stress on the grid, you have the aging infrastructure and there is a seat to maintain that and modernize that" (Johnson, 2024). This aging of infrastructure is Arizona is especially concerning due to the already high temperatures. It would then be expected that the grid will decrease in reliability, however it wouldn't be anticipated to be significant. This more moderate increase in temperatures would allow for more time for Arizona to address grid problems before they become too serious. It is important to emphasis though, that even with a minimal decrease in grid reliability, it is dangerous in a state that requires significant power.

The third important driving force within the scenario is EV adoption rates. The previous case assumed Phoenix reached their goal of around 280,000 EVs on the road by 2030. Scenario Two assumes that there is a minimal increase of EVs on the road. As mentioned, the TEAP that Phoenix outlined assumed a 30% compounded growth rate through 2030. This scenario assumes less of an increase, around half. The result of this would be approximately 150,000 EVs on the road in Phoenix by 2030. This would in turn result in less EVs in Phoenix that support bidirectional charging. The effect of less vehicles with bidirectional charging capability is that there would be less of a decrease in demand on the overall grid. Not only would there be less vehicles to provide power during a blackout, but there would also be less homes in the city that use their EV to power their home throughout the summer. The cause of this minimal increase in EV adoption could be caused by little to no increase in public awareness and regulations.

Scenario Two assumes that there is minimal to no increase to state and federal regulations surrounding EVs. The same goes for public awareness surrounding V2G technology. This is not an unlikely scenario when considering President Donald Trump's opinions on EVs in the U.S. In an inaugural address President Trump stated, "We will revoke the electric vehicle mandate, saving our auto industry and keeping my sacred pledge to our great American auto workers" (NPR, 2025). This statement doesn't directly impact current federal or state regulations but can still have an impact on individual's opinions and choices. The President's thoughts on EVs could result in future decreases in EV regulations and incentive programs. As a result, it is plausible that incentives and regulations will increase very little, if at all, in the near future. If this does occur there would likely be an impact on public awareness surrounding V2G technology and bidirectional charging. These together are not ideal for the future of EVs, but there can still be some benefit.

The last factor to consider in this scenario is the battery capacity of an EV. As mentioned in the previous scenario the current battery capacity of an EV is good. For this scenario there will be no increase or decrease to the battery capacity and it will remain the same. With the summary of all variables being completed the overall scenario can be outlined.

Results of the Moderate-Case Scenario

Temperatures within July of 2030 were high and continued to break records. However, the overall increase in temperatures from year to year was less than expected. Even with the minimal increase in temperatures, demand on the grid increased. Residents were tired of the heat and remained indoors as much as possible and put their AC on high. The grid had to account for this increase in demand as it continued to age. There was minimal emphasis placed on EV regulations and incentives throughout the state, and they hadn't changed much within the last few years. There was a slight increase in the resident's awareness surrounding EVs and V2G technology. The numbers of EVs in Phoenix grew to around 150,000, which was greater than the number in 2025, but missed the TEAP's overall goal of 280,000. Residents that owned an EV that supported bidirectional charging utilized their vehicles during the summer heatwaves to lower their electric bills. These residents were able to slightly help alleviate the demand placed on the grid, but not by a lot. The result was that in the month of July 2030 a heat induced blackout occurred. The blackout was resolved quickly, but many of Phoenix's residents were without power during the hottest month on record. EV owners that could use bidirectional charging experienced no effect from this blackout and were able to power their home until the grid came back on. However, many residents struggled with the outage and had no relief to the heat. Once power was resorted many were fearful of what would happen if a longer blackout occurred. Only owners of EVs that utilized the bidirectional charging felt secure during the blackout. Without the residents who used V2G technology the blackout could have been worse. Higher temperatures and a less reliable grid could have also resulted in a more devastating situation. This is what the worst-case scenario outlines.

Scenario Three: The Worst-Case Scenario

The third and final scenario to be outlined is the worst-case scenario. The goal of this scenario is to analyze how EVs that utilize bidirectional charging can be helpful during a blackout. *Table 3* outlines the variables and what their projected results are.

Table 3: Scenario Three Variable Summary

Variable/Driving Force	**Level of Importance**	**Projected Results**
Climate/Temperatures	High	Increases
Power Grid Reliability	High	Decreases
EV Adoption Rates	High	No Change
Regulations	Moderate	Decreases/No Change
Public Awareness	Moderate	Decreases/No Change
Battery Capacity	Low	No Change

With the climate and temperatures in Phoenix being one of the main driving forces that impact each scenario, the overall increase shown in *Table 3* is significant. *Figure 2* shows the trend of temperatures over the last 30 years and the trendline helps visualize the notable increase overtime. For Scenario Three the same increase in temperatures will be assumed throughout the years of 2025-2030. This increase throughout the years will continue to put serious demand on the grid.

As reliable as the Phoenix power grid has been up until this point, continuous periods of high temperatures put stress on it and result in faster aging. As mentioned in Scenario Two there is worry about the aging of infrastructure in Phoenix and on the power grid. It can be difficult to predict how the grid will respond to unprecedented high temperatures, but it can be assumed it will be under constant demand. Using this knowledge, it is safe to say that the reliability of the power grid will likely decrease. This is not only due to the high temperatures but also the overall population increase of Phoenix.

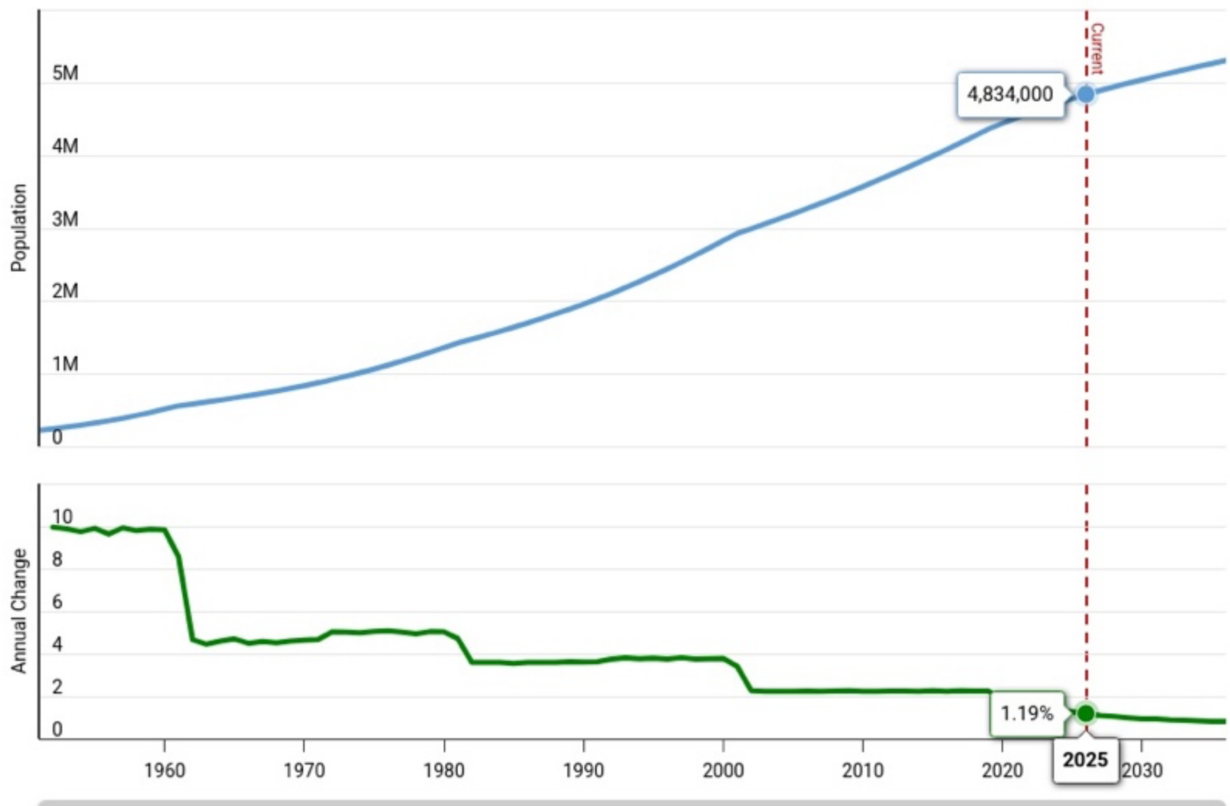

Figure 5: Phoenix Metro Area Population 1950-2025. (Image in the public domain, obtained from macrotrends.net)

Figure 5 shows the Phoenix Metro Area population over the last 75 years. The population has been increasing over this time and doesn't seem to be stopping anytime soon. The increase has slowed down but is still overall increasing. This is vital to consider because as the population grows so will demand on Phoenix infrastructure, and for this case specifically, the power grid. The combination of higher temperatures, aging infrastructure, and a growing population all result in the likelihood of a decrease in the reliability of the power grid by 2030. This can result in an increase in power outages in Phoenix.

For this case it considers that EV adoption either increases very minimally or there is no change at all. This is not unlikely to happen. "North America accounted for 1.8 million, or just over 10% of global EV sales, but saw only a modest 9% increase in 2024. In the rest of the world, EV sales grew rapidly… 27% higher than in 2023" (Nuccitelli, 2025). The problem with this slowdown in the purchasing of EVs in North America is that it can be the beginning of a new trend. This trend combined with President Trump's outspoken negative opinions on EVs, can result in a decrease in EV purchases throughout the country. If Phoenix follows suit with the rest of the country this can cause a decrease in the number of EV adoptions within the state. This concept is utilized for the worst-case scenario.

The fourth variable to consider is regulations. As mentioned, regulations can work hand-in-hand with increased EV sales. However, it is a possibility that these regulations can be taken away. For example, in an article posted by Yale Climate Connections, they state that many Congressional Republicans have called for the elimination of EV tax credits (2025). This can directly influence individual states to reconsider their regulations on EVs, especially those that lean more in favor of conservative ideals, such as Phoenix. The worst-case scenario considers this possible decrease, or no change, in regulations and incentives and shows how it can decrease EV adoption.

Another issue with the rhetoric surrounding EVs within the United States government is that it can decrease public perception of EVs and what they can be capable of. Within this scenario it is assumed that public awareness surrounding EVs, and bidirectional charging remains the same, or decreases. If there isn't explicit effort placed on expanding the public knowledge of V2G technology, then its benefit decreases. Those who are already aware of the technology will benefit from it, but without help from state and federal governments it is difficult to increase public awareness of an EVs capability. This is not ideal for the future of electric vehicles.

The battery capacity of an EV is the same as in the last two scenarios. It is included however, to show that bidirectional charging is capable of powering a home in the event of a blackout, regardless of perception surrounding EVs and their adoption rates.

Results of the Worst-Case Scenario

> It is the month of July 2030 in Phoenix, Arizona. Temperatures have been increasing at a concerning rate, and the summer of 2030 is no exception. It is the hottest summer on record within the state, surpassing the record placed by the year prior. It has been well over a month straight with highs of over 100°F, and relief is not in the near future. Residents spend more and more time indoors as to not face the sweltering heat that the outdoors bring. The air conditioning of homes and businesses throughout the city are working overtime and must work all hours of the day. This has placed a significant amount of pressure on the power grid and demand does not seem to be slowing down any time soon. EV adoption rates within the city have been nearly stagnant due to a decrease in incentives. Public perception surrounding EVs has also begun to decrease due to the government's claims surrounding the vehicles. These factors combined all

result in a grid blackout. The blackout occurred during the hottest time of the day in July. It took several hours for the power to be restored, and many were negatively impacted. Many people experienced heat-related illnesses and some residents lost their lives during the event. Most were unable to find any relief during the event and felt helpless until power was restored. However, those who has EVs that were equipped with bidirectional charging were able to power their homes during the event. In this scenario the EVs were not only able to keep their homes cooled and power on, but also keep the owners safe and alive. Even with the minimal amount of EVs in the state, there were less hospitalizations than there could have been. The effects of the blackout were detrimental and exposed the reliability of the grid.

DISCUSSION

In the previous section three different scenarios were examined. Each of the scenarios considered the same variables and driving forces, but different possible values were determined. Scenarios were outlined and the effects of each were discussed. It can be determined that when the outside variables, such as temperature increases and aging infrastructure, were impossible for the average person to have control over, they still had reliance on their EVs. In the initial scenario there was no blackout, and there are a few reasons as to why this happened. One explanation could be that the temperatures had evened out over the last few summers and stopped breaking records, however because it was Phoenix, they were still higher than anywhere else in the country. The more likely explanation was the overall increase in the city's EV adoption rates and the public awareness of V2G technology. These together allowed for less pressure to be put on the grid. The city reached their goal of increasing the number of EVs on the roads as more and more residents purchased EVs. There was also an increase in the utilization of EVs powering people's homes to decrease their energy bills. This put less pressure on the power grid throughout the whole summer, so it was able to keep up with the rest of the demand.

The initial scenario allowed for an in-depth analysis of the effect of increasing electric vehicle adoption in a city, and how V2G technology can be used to control the demand placed on a power grid. The second two scenarios outlined different levels of what could go wrong in a city that experiences extreme heat and doesn't have a way to significantly combat it. In the second scenario there were enough EVs to decrease the impacts of the blackout, but not enough to prevent it. This was due to a minimal amount effort being placed on EV regulations and incentives and expanding public awareness of V2G technology. The third scenario outlined what could happen if regulations begin to disappear and less emphasis is placed on the adoption of EVs. This was the worst-case scenario, and many people were hospitalized, and some lost their lives. The blackout not only impacted people during the event but also caused the residents to distrust the state and local governments moving forward. A blackout can cause many to feel helpless and that they must put much of their faith in the government to restore power. Scenario One was stark in contrast to this because residents had their own way to power their homes and keep their families safe. This is one of the main benefits of V2G technology.

CONCLUSION

This paper outlined Vehicle-to-Grid technology and its usefulness in the event of a power outage. The city of Phoenix, Arizona was the system that was analyzed for this report. Phoenix is one of the fastest growing cities in the United States and has one of the largest populations. One of the most notable features of the city, however, is that it experiences the highest temperatures of any major city in the country. The growing population along with the extreme temperatures made the city an ideal system to study regarding V2G technology and its ability to mitigate the impacts of a blackout. A scenario analysis was performed to determine how different values of variables such as temperature, grid reliability, and EV adoption impacted the system and if a grid blackout occurred. In the moderate and worst-case scenarios blackouts occurred, with the worst-case scenario experiencing the more prolonged event. The result of the analysis was a conclusion that there must be more emphasis placed on being proactive regarding EV policies and V2G public awareness. If there is only a small portion of the population that owns an EV that supports bidirectional charging and utilizes it, then it only benefits a small group of people. The best-case scenario was able to shine light on the idea that if a significant to moderate amount of the population uses V2G technology to power their home then that is how a blackout can be prevented. In cities that aim to increase their EV adoption there must be an increase in policies and incentives surrounding EV purchases and an increase in public awareness. Without proactive measures being taken, such as an increase in EV adoption, then climate change and extreme weather can cause cities such as Phoenix to experience extensive negative impacts.

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