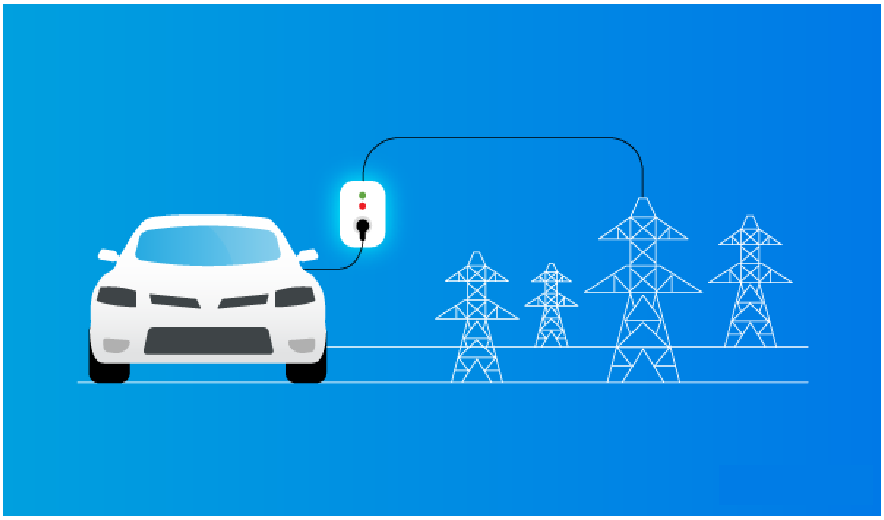
MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

VEHICLE-TO-GRID ANALYSIS TO REDUCE ELECTRICAL PEAK LOAD IN THE SAN DIEGO AREA IN 2030



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RESUME

Objective:

Presenting an innovative model that enable users to study the feasibility of Vehicle-to-Grid (V2G) scenarios in a specific distribution line in the future. To support this model an extensive analysis in San Diego, California, has been developed to study the viability of V2G in 2030. The aim of this study is to reduce evening electrical peak load by taking advantage of the energy stored in Battery Electric Vehicle (BEV).

Key Contributions:

1. **Problem Statement:**

Due to electrification of transportation and overall electrical load demand growth, California will have to face several challenges. New fast generation power plants will need to be built in order to meet peak load increases and at the same time, transmission and distribution system upgrades will be enforced.

2. **V2G as a Solution:**

The other solution to the investments of billions of dollars that utilities will have to face, is to use Electric Vehicles (EV) as a Distributed Energy Resources (DER) for storing energy when there is excess of energy generation and discharging the energy stored in the batteries whenever it is convenient. This solution is commonly known as Vehicle-to-Grid.

3. **Alignment with State Goals:**

The adoption of Electric Vehicles and Vehicle-to-Grid (V2G) technology comes from the need to achieve the goals that the state of California has for 2030, both reducing greenhouse gas emissions and increase zero-emission vehicles goals, as outlined in Executive Order B-48-18 and N -79-20.

4. **Model Development:**

Accomplished the creation of a functional V2G model capable of studying and evaluating the viability of V2G scenarios independently. This model incorporates algorithms and methodologies to provide a thorough analysis of the potential benefits and challenges associated with V2G technology. The purpose of this model is that based on the input that the user is willing to simulate, obtain the percentage of battery withdrawn from every Battery Electric Vehicles (BEV) available and the discharge rule that indicates the load factor of the bidirectional chargers.

5. **Scenario Analysis:**

To support the model, a comprehensive analysis of load profiles of distribution lines and assumed parameters for Battery Electric Vehicles (BEV) availability is presented. The data has been scaled to a hypothetical 2030 scenario for San Diego County, California. Two different cases have been simulated. In case 1, a comparative analysis of the simulated circuits has been developed. Since the distribution of residential consumers in each circuit differs from the others, the BEV availability will

vary, limiting the capacity of discharging energy and therefore increasing the load factor of chargers and the portion of BEVs battery discharged. The purpose of case 2 is to determine the limits of the simulation and peak load decreasement has been maximized in all circuits. With 22% of peak load decreasement, circuit 278 has performed the best results among all circuits.

6. Peak Load Reduction Potential:

Supported the V2G model by showcasing the potential of EVs to reduce peak load during the evening hours in 2030. Explored two simulation cases, highlighting the impact of residential consumer distribution on BEV availability. It is concluded that:

- Higher residential consumer distribution correlates with lower BEV battery depletion
- If the BEV availability in the future is higher, less energy will be withdrawn from batteries

7. Contribution to the Field:

With this model a significant contribution to the field of sustainable energy and transportation has been made by offering a versatile model that empowers users to study and evaluate the viability of V2G scenarios independently. The research outcomes contribute to the ongoing discourse on the integration of electric vehicles into the grid.

Overall, this thesis serves as a valuable resource for anyone interested in exploring the potential of V2G scenarios, emphasizing a user-friendly approach to model V2G during the evening and contributing to the advancement of knowledge in the field.

RESUMEN

Objetivo:

Presentar un modelo innovador que permita a los usuarios estudiar la viabilidad de escenarios V2G en el futuro. Para respaldar este modelo, se ha desarrollado un análisis exhaustivo en San Diego, California, para estudiar la viabilidad de V2G en 2030 y reducir la demanda eléctrica pico aprovechando la energía almacenada en los Vehículos Eléctricos.

Contribuciones Clave:

1. **Declaración del Problema:**

Debido a la electrificación del transporte y al crecimiento general de la demanda eléctrica, California se enfrentará a varios desafíos. Se necesitarán construir nuevas centrales de energía para satisfacer el aumento de la carga pico, y al mismo tiempo, la red de transmisión y distribución debería renovarse.

2. **V2G como Solución:**

Una de las posibles alternativas a las costosas inversiones que eso supondría seria utilizar los vehículos eléctricos como Distributed Energy Resources (DER) para almacenar energía cuando hay exceso de generación y descargar la energía almacenada en las baterías cuando sea conveniente. Esta solución es comúnmente conocida como V2G.

3. **Alineación con Objetivos Estatales:**

La adopción de vehículos eléctricos y la tecnología V2G surge de la necesidad de alcanzar los objetivos que el estado de California tiene para 2030, tanto en la reducción de emisiones de gases de efecto invernadero como en el aumento de vehículos de emisión cero, según lo establecido en las Executive Orders B-48-18 y N-79-20.

4. **Desarrollo del Modelo:**

Se ha desarrollado un modelo funcional de V2G capaz de estudiar y evaluar la viabilidad de escenarios V2G de manera independiente. Este modelo incorpora algoritmos y metodologías para proporcionar un análisis exhaustivo de los posibles beneficios y desafíos asociados con la tecnología V2G. El propósito de este modelo es, basándose en el input que el usuario desea simular, obtener el porcentaje de batería descargado de cada vehículo eléctrico disponible y la discharge rule que indica el factor de carga de los cargadores bidireccionales.

5. **Análisis de Escenarios:**

Se presenta un análisis exhaustivo de 5 líneas de distribución con parámetros asumidos para la disponibilidad de vehículos eléctricos en 2030. Los datos de partida se han escalado a un escenario hipotético de 2030 para el condado de San Diego. Se simularon dos casos diferentes. En el caso 1, se presenta un análisis comparativo de los circuitos simulados. Dado que la distribución de consumidores residenciales en cada circuito es diferente, la disponibilidad de vehículos eléctricos

variará, limitando la capacidad de descarga de energía y, por lo tanto, aumentando la discharge rule y la porción de las baterías descargada. El propósito del caso 2 es determinar los límites de la simulación y se ha maximizado la reducción de la carga pico en todos los circuitos.

6. **Potencial de Reducción de Carga Pico:**

Se respaldó el modelo V2G mostrando el potencial de los vehículos eléctricos para reducir la carga pico durante las horas pico en 2030. Las conclusiones más importantes del estudio son:

- Una mayor distribución de consumidores residenciales se correlaciona con un menor porcentaje de batería descargada de los vehículos eléctricos disponibles para reducir la energía pico.
- Si la penetración de vehículos eléctricos en 2030 es mayor, menor será el factor de carga de los cargadores bidireccionales V2G

7. **Contribución al desarrollo del coche eléctrico:**

Con este modelo, se ha realizado una contribución significativa al campo de la energía sostenible y el transporte, al ofrecer un modelo versátil que capacita a los usuarios para estudiar y evaluar la viabilidad de escenarios V2G de manera independiente. Los resultados de la investigación confirman que la integración de los vehículos eléctricos en la red es una solución para resolver los desafíos derivados de la electrificación del transporte y el aumento de la demanda de electricidad.

En resumen, este Trabajo Fin de Máster sirve como un recurso valioso para cualquier persona interesada en explorar el potencial de escenarios V2G, haciendo hincapié en un enfoque en escenarios V2G en líneas de distribución.

LABURPENA

Helburura:

Lan honen helburua, etorkizunean V2G egoerak distribuzio sareetan aztertzeko modelua aurkeztea da. Eredu hori babesteko, azterketa San Diegon (Kalifornia) egin da), 2030ean V2G-ren bideragarritasuna aztertzeko eta eskari elektrikoa murrizteko, ibilgailu elektrikoetan bildutako energia aprobetxatuz.

Garrantzizko ekarpenak:

1. **Problema Adierazpena:**

Garraioaren elektrifikazioa eta eskari elektrikoaren hazkunde orokorra direla eta, Kaliforniak hainbat erronka izango ditu. Energia-zentral berriak eraiki beharko dira puntako kargaren igoera asetzeko, eta, aldi berean, transmisio- eta banaketa-zirkuitu berritu egin beharko dira.

2. **V2G Aukera bezala:**

Inbertsio garestien ordezko aukeretako bat, ibilgailu elektrikoak erabiltzea litzateke, energia gehiegi sortzen denean baterietan bildu eta ala behar denean energia deskargatu. Irtenbide horri V2G esaten zaio.

3. **Estatuko helburuekin lerrokatzea**

Ibilgailu elektrikoak eta V2G teknologia Kaliforniako estatuak 2030erako dituen helburuak lortzeko beharretik sortu dira, bai berotegi-efektuko gas-isurketak murrizteari dagokionez, bai zero isurpeneko ibilgailuak handitzeari dagokionez, B-48-18 eta N-79-20 arauetan ezarritakoaren arabera.

4. **Modeloaren Garapena:**

V2G eredu funtzional bat garatu da, V2G egoeren bideragarritasuna aztertzeko. Eredu horrek algoritmoak eta metodologiak ditu V2G teknologiarekin lotutako onura eta erronka posibleen azterketa sakonagoa egiteko. Eredu honen helburua, erabiltzaileak simulatu nahi duen inputean oinarrituta, ibilgailu elektriko bakoitzetik deskargatutako bateriaren ehunekoa eta noranzko biko kargagailuen karga-faktorea lortzea dira.

5. **Eskenarioen Analisia:**

Bost zirkuitu aztertu dira, 2030ean ibilgailu elektrikoak parametroekin. Hasierako datuak 2030eko egoera hipotetiko batera igo dira San Diego konderrirako. Bi kasu desberdin simulatu ziren. Lehenengoan, zirkuitu simulatuen analisi konparatiboa aurkezten da. Zirkuitu bakoitzean etxeko kontsumitzaileen banaketa desberdina denez, ibilgailu elektrikoen erabilgarritasuna aldatu egingo da, beraz, discharge rulea eta deskargatutako baterien zatia handituko da. Bigarrenen kasu helburua simulazioaren mugak zehaztea da, zirkuitu puntako kargaren murrizketa maximizatutaz.

6. Piko-Karga Gutxitzearen Potentziala:

Desberdin V2G egoera eredua babestu da, eta ibilgailu elektrikoek 2030ean puntako orduetan karga murrizteko duten ahalmena erakutsi da. Azterlanaren ondorio garrantzitsuenak hauek dira:

- Etxebizitza-kontsumitzaileen banaketa handiagoa estu lotuta doa ibilgailu elektriko deskargatutako bateriaren ehunekoa txikiagoarekin.
- 2030ean ibilgailu elektrikoak gehiago badira, V2G kargagailuen karga-faktorea txikiagoa izango da.

7. Ibilgailu Elektrikoen Garapenera Emanaldi:

Modelo honekin, ekarpen nabarmena egin zaio energia iraunkorraren eta garraioaren sektoreri, erabiltzaileei V2G egoeren bideragarritasuna aztertzeko. Emaitzak baieztatzen dute, ibilgailu elektrikoak distribuzio zirkuitoetan integrazioa, garraioaren elektrifikazioak eta elektrizitate sare erronkak konpontzeko irtenbidea da.

Laburpen moduan, Master Amaierako Lan honek baliabide baliotsua da V2G agertokien potentziala aztertu nahi duen edonorentzat, eta arreta berezia jartzen du distribuzio sare V2G egoeretan.

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CA: California

V2G: Vehicle to Grid

V2X: Vehicle to Everything

V2H: Vehicle to home

BEV: Battery Electric Vehicle

PEV: Plugged-in Electric Vehicle

PHEV: Plugged-in Hybrid Electric Vehicle

CCE: Center for Community Energy

EV: Electric Vehicle

CPUC: California Public Utilities Commission

DER: Distributed Energy Resources

GHG: Greenhouse Gas

CAISO: California Independent System Operator

CEC: California Energy Commission

PG&E: Pacific Gas and Electric

SCE: Southern California Edison

SDG&E: San Diego Gas and Electric

ZEV: Zero emission vehicle

EVI PRO: Electrical Vehicle Infrastructure Projection Tool

NREL: National Renewable Energy Laboratory

AC: Alternating Current

DC: Direct Current

OEM: Original Equipment Manufacturer

IEPR: Integrated Energy Policy Report

GNA: Grid Needs Assessment

DOOR: Distribution Deferral Opportunity Report

BTM-PV: Behind The Meter Photovoltaic

1. INTRODUCTION

1.1. Company approach

The work here presented is an analysis on a Vehicle to Grid (V2G) simulation to reduce evening electrical peak load in the San Diego area in 2030 by taking advantage of the energy stored in Battery Electric Vehicle (BEV). This project has been carried out thanks to Center for Community Energy (CCE) which is a non-profit organization which was founded to advance the development of Community Choice Energy in the San Diego area. One of their projects is to use the EV and Vehicle-to-Everything (V2X) as a solution to reduce costly grid infrastructure upgrade to support transportation electrification in California. The idea is to present an alternative to the California Public Utilities Commission (CPUC) where vehicles are charged during the day with power from local solar arrays mounted over parking lots, bring the charge home and deliver some of it to the grid or homes. By doing so, residential consume will be reduced potentially solving a very important issue in California, the Duck Curve. A functional and useful model has been carried out in order to analyze the viability a V2G simulation where Electric Vehicles (EV) discharge energy during the evening to reduce peak load by certain percentage. To support this model the analysis of the San Diego area is presented.

The model acknowledges the use of EVs to move power from workplaces charging stations and deliver it to homes/grid whenever it is convenient. Even though, the idea of Vehicle-to-Grid V2G has been profoundly studied, the fact of using EVs as a mobile storage resource is still under research. There are several challenges that V2G has to overcome before commercial vehicle-to-grid can become widely available.

CCE is located in San Diego, California, which is the state in the US with the fastest growing EV market and sales. Therefore, CCE location is extremely advantageous to showcase the idea of V2G and mobile storage resource to the utilities. The Founder and Executive Director of the company, Jose Torre-Bueno has been the thesis advisor during the development of the thesis and Executive Director Susan Wayo has guided into looking for the right solutions and people while working for CCE.

1.2. Motivation

Right now, in California, transportation electrification and clean sustainable energy resources are topics that need to be solved urgently. CCE project can showcase the potential of EVs to solve both problems by creating a business model. It can be proved that by using EV as mobile storage resources, California Public Utilities Commission (CPUC) will focus and help develop V2G technologies. There are many challenges that need to be overcome before CPUC consider V2G as Distributed Energy Resources (DER). Public incentives, supportive policies, supporting EV charging policies and profound investigation should be promoted to develop V2G. Researching such an innovative technology, can change the way energy is distributed and the way people move around California in the future. It seems like if somewhere around the world EV and V2G were going to exponentially grow, it will be in California thanks to public incentives, supportive policies and Executive Orders to promote EV adoption (see section 2.3). If V2G in California is correctly implemented, US states and other countries will start to take part and invest in V2G technology.

1.3. Scope

In this report, the problem of the future electrical grid that California will have to face in the next recent years is intended to explain. Due to electrification of transportation and overall electrical load demand growth, new fast generation power plants will need to be built in order to meet peak load increases and at the same time, transmission and distribution system upgrade will be enforced.

The other solution to these investments of billion of dollars that utilities will have to face is to use EVs as a Distributed Energy Resources (DER) for storing energy when there is excess of energy generation and discharging energy stored in the batteries whenever it is convenient. This solution is called Vehicle-to Everything (V2X) or commonly known as Vehicle-to-Grid (V2G). Unlike V2X, smart charging or V1G does not consider delivering energy back to grid and different strategies like time of use tariffs are adopted to reduce charging cost during the day. Energy can be discharged during peak-load times to reduce the strain on the electrical grid, reducing energy provided from fossil-fuel power plants, minimizing the overloading of the distribution systems equipment and reducing the cost of electricity. This innovative young technology is now in stages of testing and developing, therefore utilities have not considered it yet as a future energy resource. CCE model consists of taking advantage of the EV adoption in the future and use its potential to store energy to avoid costly grid reinforcements. Another problem that California will have to solve is the “Duck Curve” and the ramping situation during evenings when solar generation starts to decrease.

Firstly, this work explains the overall electric vehicle trend and renewable energy situation of California, the state of the art of the V2X technology, CCE’s business model about the EV fleet of the future, benefits and challenges of V2X and a review of the main supporting papers of smart charging and V2G consideration in California. Some papers are published by public entities and some by individual research.

Secondly, an innovative **model** is presented to analyze the **viability** of V2G situation in 2030 to **reduce peak load in residential areas**. Information related to electric load profiles, percentage of EV owners and V2G EVs technical characteristics are founded in different sources. **Sensitivity scenarios** are simulated to comprehend how changing factors affect the electric charging load in the future. In the model, as only EV discharging energy is modeled, **only V2G is considered** (the charging starts whenever the car is plugged in). In the end, the approximation of how many EV owners with V2G strategies that are necessary to balance the load increase in the residential areas is going to be calculated. By knowing how many houses are connected to each distribution line, a percentage of houses with V2G can be assumed.

The simulation is based on specific load profiles of distribution lines in San Diego. The profiles show the highest load of each hour of each month in 2022. Based on this, the goal is to obtain how much discharged energy is needed to meet a certain peak load decrease and the threshold of the distribution line. The **outputs** are the load factor of chargers, the **percentage of energy discharged from EV batteries** and **how much V2G penetration per distribution line is needed** to meet the assuming load increase, also called discharge rule.

In this way, this report presents a **promising model** which showcases the potential of EVs used as Distributed Energy Resources and a justification that **V2G** could **solve** the problem of **California**. Even though power flow analysis and voltage or current regulation studies are not assessed, load increase mitigation and minimize peak valley difference by adopting V2G strategies is carried out.

With this model a significant contribution has been made to the field of sustainable energy and transportation by offering a versatile model that empowers users to study and evaluate the viability of V2G scenarios independently. The research outcomes contribute to the ongoing discourse on the integration of electric vehicles into the grid.

1.4. Limitations

The constrains of the modelling tool have limited the extension of the analysis of the work. Right now, modelling V2G in distribution networks and specially the idea of charging EV during the day and discharging energy during the evening, is not an easy task because of its early stage of development and adoption. The fact that this project has been an individual work in collaboration with CCE, where the simulation tool and all the information regarding the assumptions had to be researched, the analysis of the potential of EV used as mobile storage devices has been limited.

Before simulating the model in an Excel script, possible simulation tools research were carried out to find the appropriate EV and V2G simulators. The initial simulators found were either too simple for the scope of this project or too complex to understand the modelling due to lack of time and help from the developers. Some tools that could have been very interesting are the following: EVI-Pro 2 [1], V2G-Sim [2] or EV Simulator [3]. Despite being a Non-Profit Organization project, the developers of these simulators, on behalf of confidentiality and security constrains, didn’t authorize to use them.

2. CALIFORNIA ELECTRIC VEHICLE CURRENT SITUATION AND CCE BUSINESS IDEA PRESENTATION

The energy sector has faced two major problems over the last few decades. Firstly, there has been a huge increase in the use of fossil fuels, which are non-renewable and will eventually run out. Secondly, electric load growth and adoption of fossil-fuel power plants have resulted in an increase of greenhouse gas (GHG) emissions which contribute to global warming. Renewable energies such as wind or solar energy are producing electricity but still fossil-fuel plants capacity have a great weight in the energy mix of most countries. One major area that relies on fossil fuels is transportation. To address this issue, the Battery Electric Vehicle (BEV) was developed as an alternative to Internal Combustion Engines to reduce CO2 emissions and decrease reliance on fossil fuels.

California is a leading innovator in energy policy, with forward-thinking laws that aim to reduce energy consumption, greenhouse gas (GHG) emissions, and air pollution across the economy. Since transportation is responsible for a significant portion of GHG emissions (38%), implementing clean transportation policies is crucial to achieving these objectives. Figure 1 illustrates the state's GHG emissions by sector.

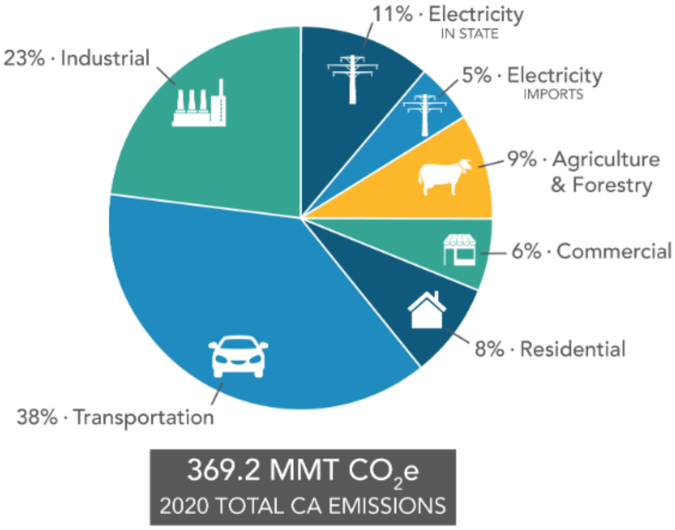


Figure 1. Greenhouse Gas Emission by sector in California [4]

2.1. EVs growing market

Shifting from gasoline powered cars to EVs is critical to reduce GHG emissions in the transportation sector. As Figure 2 shows, Californians are driving more each year, about a 17% increase from 2012 to 2016.

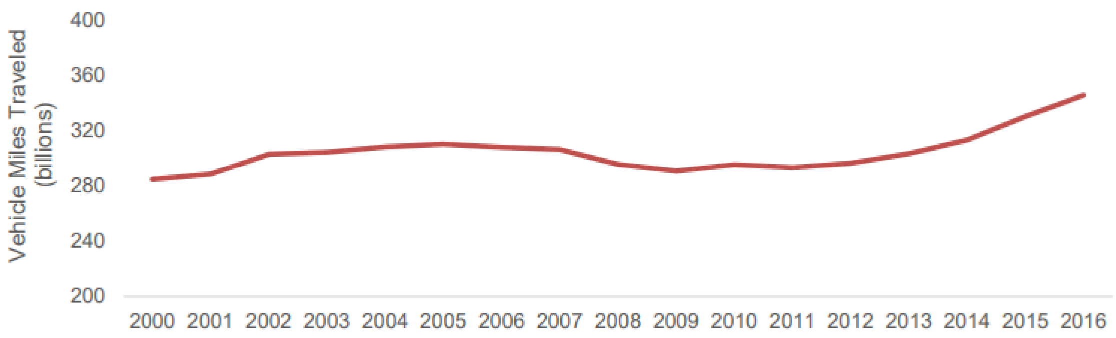


Figure 2. California Light-Duty Vehicle Miles Traveled (in billions) [5]

The Energy Commission's Transportation Fuel Supply Outlook for 2017 offers a more comprehensive view of the past trends in fuel consumption in the transportation industry. Figure 3 shows the electricity consumed in California's transportation sector. Before 2011, rail transit and trolleys were the main electricity consumers in California. However, the increasing sales of light-duty EVs have resulted in a significant increase in the electricity consumed by the transportation sector since 2011.

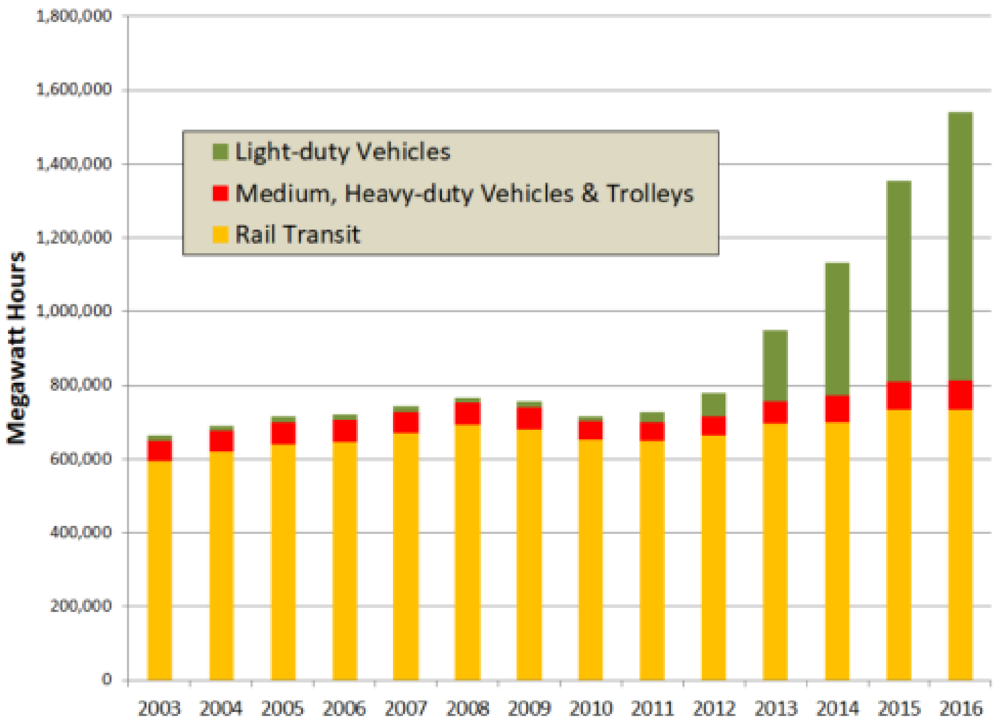


Figure 3. California Transportation Electricity Consumption [4]

Since 2013, EVs sales data indicate a change in the type of light-duty vehicles sold. This change can be attributed to two main factors: higher gasoline prices and an increasing preference for battery electric and plug-in hybrid electric vehicles [4]. Figure 4 shows a decline in the percentage of hybrid electric vehicles sold since 2013 and an increase in the Battery Electric Vehicle and Plug-in hybrid Vehicle fleet.

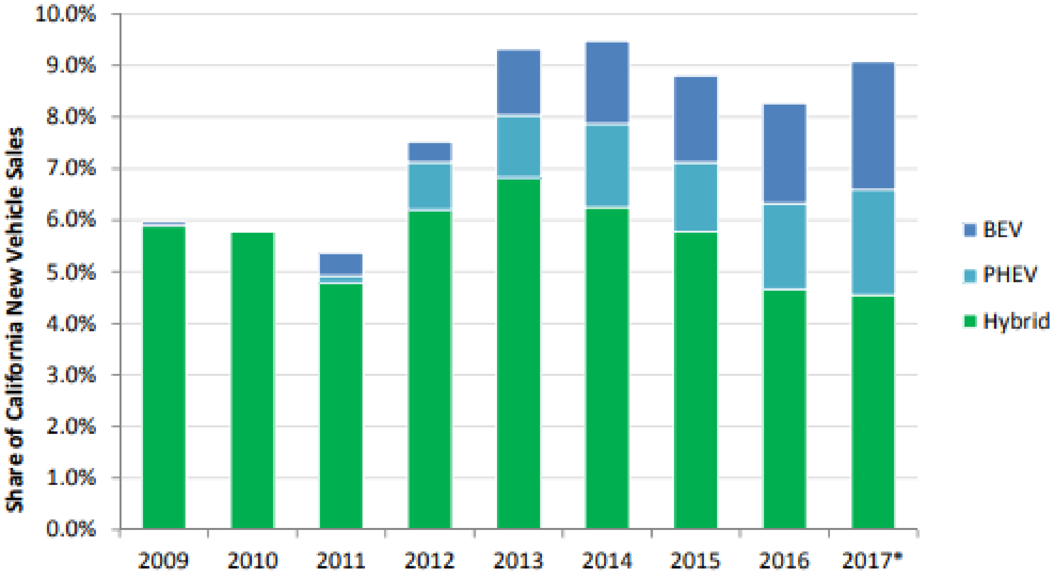


Figure 4. California Hybrid, Plug-in Hybrid Electric and Battery Electric Vehicle Sales Share [5]

Figure 5 reveals that the BEVs being sold are also evolving, with consumers opting for BEVs with a range greater than 200 miles as batteries technology is improving and efficiencies are increasing.

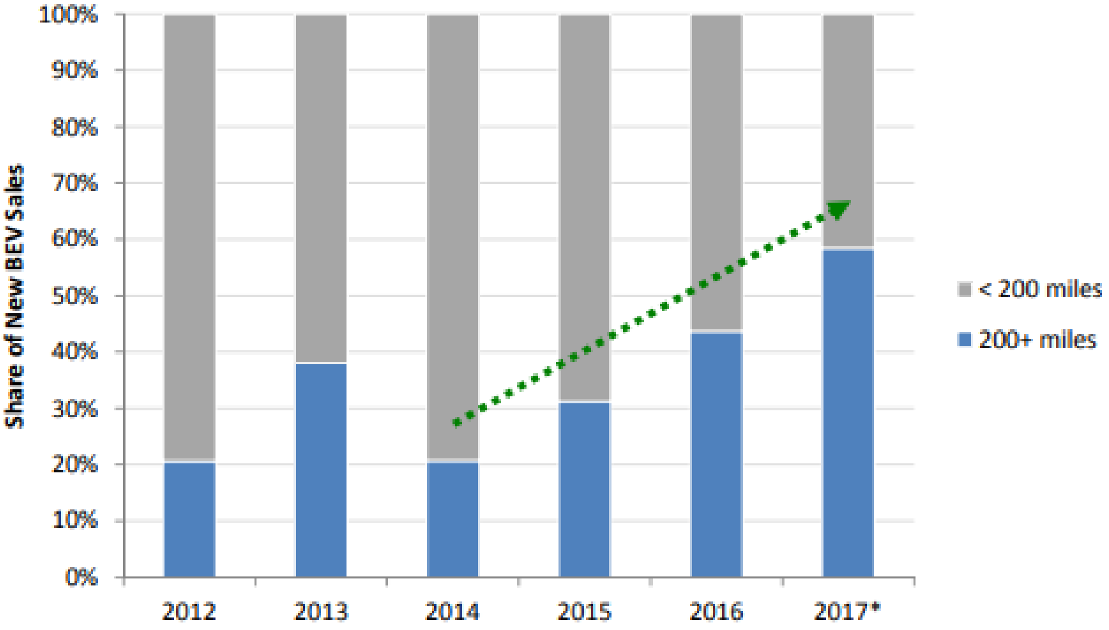


Figure 5. Share of BEV Sales in California and Range [5]

2.2. Stakeholders and System Components

Following are the description and function of the principal stakeholders that participate in the electrical system and in the Vehicle-to-Grid Integration.

- Generation. The electricity consumed by end-users is produced by baseload power plants, that operate and produce constant energy the entire year such as nuclear or coal power plants, and variable power plants that generate electricity depending on climate factors or on grid necessities. These technologies are solar, wind, natural gas and some hydropower.
- Transmission. Transmission is the highest level of the electrical system and it is used to transport electricity throughout a country or state. The transmission system uses very high voltage to reduce energy losses and transport energy efficiently. However, this high voltage energy cannot be used by consumer as it is too powerful to manage it. In order to use it, the voltage has to be reduced with step-down transformers and then energy will be moved in the distribution system.
- Distribution system. Distribution systems are designed to move power from transmission lines that reach populated areas to end users. Normally distribution systems are controlled by different utilities depending on the region (in California the following companies operate: San Diego Gas and Electric, Pacific Gas and Electric and Southern California Edison). Years ago, when distribution systems were designed, generation was not considered. Nowadays, there exist microgrids, Distributed Energy Resources, energy storage, solar arrays and other forms of energy systems. Besides, now the concept of V2G V2G is starting and means that EV are designed to act as a mobile battery that can deliver energy to the distribution systems. Due to the variable energy output, the integration of these technologies is a problem utilities have to face to ensure grid reliability and minimize energy losses.
- Feeder. Feeders are electric lines that connect different substations or connect substation with distribution transformers.
- Consumers. Related to the VGI topic there are 3 different types of consumers.
    - Customers. From the utility point of view, each consumer is an individual payer who pays for the energy used.
    - Building owners. They are responsible for the correct maintenance and reliability of their facilities. It is typically that these install Electric Vehicle Supply Equipment (EVSE) to provide electricity to EV in multi-dwelling houses. In order to reduce the electrical bill, solar arrays could be connected to reduce the energy purchased from the grid or the sell energy to operators through a net-metering agreement [6]
    - Electrical Vehicles Owners.
- California Independent System Operator (CAISO). It is an organization that coordinates, controls and operates the electrical grid of California. CAISO oversees ensuring the safe and reliable transportation of electricity on the power grid. As an impartial grid operator, it has no financial interest in any individual segment ensuring fair and transparent access to the transmission network and market transactions [7].

- California Energy Commission (CEC). It is the primary energy policy and planning agency in California. Their role is to design a clean and modern energy system that ensures the fifth largest economy in the world continues to thrive [8].
- California Utilities. In Figure 6 the operating region of each utility are shown.
    - Pacific Gas and Electric (PG&E)
    - Southern California Edison (SCE)
    - San Diego Gas and Electric (SG&E)

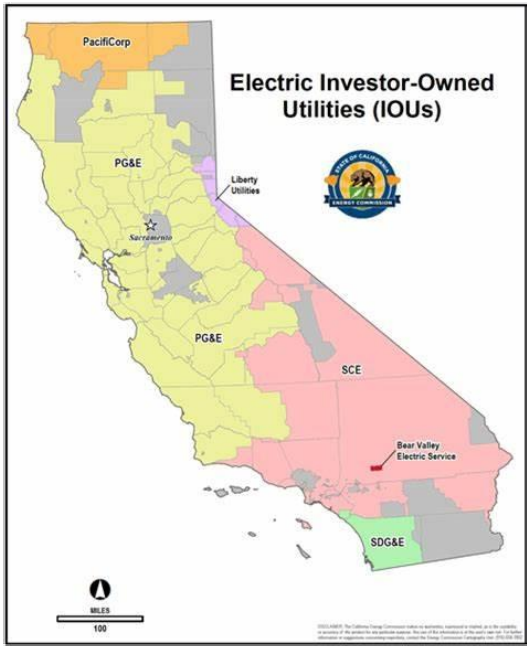


Figure 6. Electric Investor-Owned Utilities [9]

Following are definitions of grid interface interactions that must consider before any V2G Integration.

- Demand response, also known as demand management, empowers electricity users by reducing their energy consumption rather than increasing power generation to maintain balance. Technologies utilized in demand response such as smart buildings are constantly evolving, resulting in more sophisticated methods of reducing energy consumption in applications such as air-conditioners, industrial equipment, electric hot water heaters, lights or dryers. With the increasing integration of renewable energy sources like solar and wind, demand response may play a crucial role in the future of the grid by enabling the smooth integration of these variable sources.

  Energy stored in EVs can be discharged very fast [10] [11], and therefore they can compensate the reduction of variable energy resources output, so expensive natural gas plants do not participate in the electricity market [12].

The study committed by Opinion Dynamics and Extensible Energy [13] identified the following conclusions for EV participating in Automated Demand Response programs in PG&E region.

  - EV Automated Demand Response charging techniques are promising for reducing nighttime peak-load. The results showed that 601 kWh of curtailing EV charging over 4 hour period energy were successfully shifted to the period 12 am to 4 am.
  - The maximum potential of EV Automated Demand Response is 9 MW to 13 MW during evening time (4-9 pm) for 366.000 EVs in PG&E territory
  - Close to half of EV owners charge their cars during 4-9 pm or nighttime. Therefore, EV Automated Demand Response programs during that time are an effective way to reduce peak load and expensive electricity cost.

- Ramping. Ramping is related with the speed that a generator can increase or decrease energy production. The fact that most baseload technologies (nuclear, coal) can't change their output instantaneously and that the output of variable energy power plants can't be changed, means that when solar generation in California starts to decrease, natural gas plants have to be started very fast. This issue is discussed in section 3.

  Both studies [6] and [14] conclude that EVs can act as mobile storage systems and deliver power back to the grid to help reduce ramping and possible shortages due to the unavailability of instantaneously energy generation.

- Peak shaving. It consists of actively managing the total demand to eliminate sudden demand spikes that create higher peaks. This approach helps reduce and stabilize peak loads, leading to a decrease in the overall expense of demand charges. The following study made by Noor Aziz [15] analyze the current literature on how V2G could provide peak shaving benefits and conclude that there exist doable solutions that can be carried out effectively.
- Valley filling. Valley filling is given when electrical demand is placed on purpose during periods considered low demand or "valley", as the Figure 11 shows. The simulation conducted in the study [16] showed that after analyzing the outcomes, it was demonstrated that the EV model is resilient in peak shaving during high demand periods and valley filling during off-peak hours. This is accomplished by smoothing out the load curve and optimizing the utilization of microgrids.
- Time of Use. SUNRUN [17] defines Time-of-use metering as a method of measuring and charging a utility customer's energy consumption based on when the energy is used. Utility companies charge more during the time of day when consume is higher. TOU rates vary by region and utility.
- Voltage and frequency regulation. These regulation services balance power generation and demand. It's procured separately and priced as an ancillary service. The system operator schedules generators based on forecasted load, adjusting output 1 hour and every 5 minutes. Automatic generation control then fine-tunes output every 4 seconds to generate

the exact required load. Grid-tied V1G/V2G EVs can respond to these commands by changing load or generation.

2.3. Policy Background

The adoption of the EV and V2G technology comes from the need to achieve the goals that the state of California has for 2030, both reducing greenhouse gas emissions and increase zero-emission vehicles (ZEV) goals. To do so, transportation and electricity industries (supporting industries like gasoline too) need to change the way they operate to meet California's goals [18]. California goals for the transition to a cleaner, safer and electrified future are listed below. These are the most important regulations and policies that dictate California's future.

2.3.1. Executive order B-48-18 Jan 2018.

In January of 2018, Executive Order B-48-18 was signed to "boost the supply of zero-emission vehicles and charging and refueling stations in California." The Executive Order directs state government to meet a series of milestones toward a long-term target of 1.5 million ZEVs on California's roadways by 2025 and 5 million by 2030 [19].

2.3.2. Senate Bill 100 (DeLeon) 2018

"The 100 Percent Clean Energy Act of 2018," Senate Bill 100 (SB 100, De León): Sets a 2045 goal of powering all retail electricity sold in California and state agency electricity needs with renewable and zero-carbon resources — those such as solar and wind energy that do not emit climate-altering greenhouse gases. 60% of Renewable Portfolio Standard by 2030 and 100% by 2045 [20].

2.3.3. Executive order N-79-20 Sept 2020.

Newsom in September 2020 signed Executive Order N-79-20 that stipulates that 100% of in-state sales of new passenger cars and light-duty trucks will be zero-emission by 2035 and 100% of medium- and heavy-duty vehicles sales must be zero emission by 2045 where feasible [21].

On the other side, EU recent 2030 Climate Target plan has set a goal of cutting greenhouse gas emissions to 55% below 1990 levels by 2030 which is a much stronger goal than California's [22]. However Spain doesn't align with EU goals based on the target of 23% compared to 1990 levels by 2030 [23]. Based on the report about the global EV outlook 2021 [24], the International Energy Agency is expecting that according to the Sustainable Development Scenario, around 220 million electric light duty vehicles (excluding light-commercial vehicles) are expected to be in use globally by 2030, representing almost 15% of the total stock. EVs fleet are expected to be about 7% of the total road vehicle fleet by 2030.

2.4. Duck curve

Whether adding EVs will help or harm grid management depends entirely on when and where they are charged and discharged. The evening shortfall of power is already a major issue. Figure 7 shows the data from CAISO for a particularly bad day when demand almost exceeded the sum of all available power plants and caused a spike in the wholesale power market. The green line represents the total available output of all power plants that could have been turned on to meet demand. The red line represents changing demand that day (plus a 20% reserve CAISO maintains in case of an emergency).

The drop-off of the green line in the evening is due to solar power plants losing power. If the red line crosses the green line, utilities will have to buy power on the real time market. Failing that, CAISO would have to turn off power to communities to prevent a grid collapse (as they did during the heatwave of summer 2020). The shortage of power around 5:30 PM led to a spike in the wholesale cost of power that utilities buy to meet immediate shortfalls.

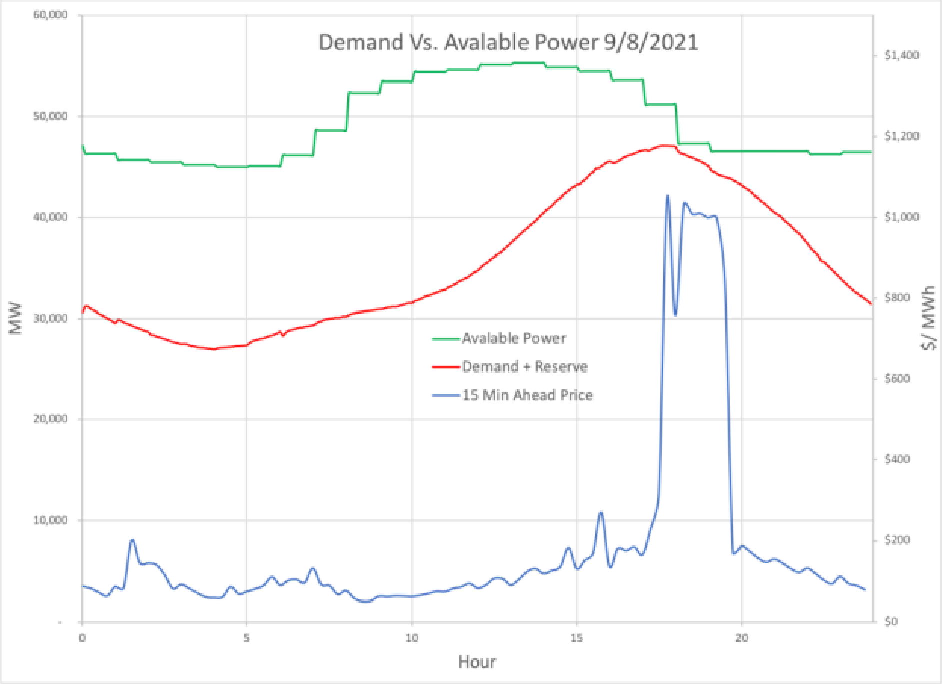


Figure 7. CAISO Electric demand, available power and 15 minutes ahead price (August 9, 2021), CCE

If all owners of EVs were to plug in their cars when they get home, it would exacerbate this problem. So far, the CPUC's solution has been to create special EV rates that give owners a major discount to wait until after midnight to charge, Figure 8. However, it is not an optimal solution from the point of view of helping the state's goal of achieving a carbon-free electricity system because natural gas power plants would be necessary to charge EVs during nighttime.

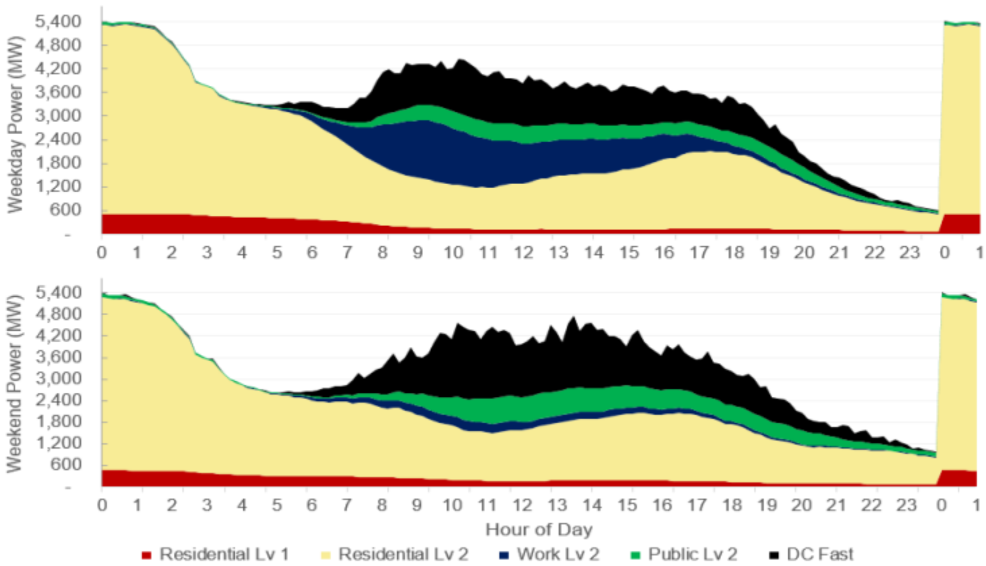


Figure 8. 2030 PEV Charging load for 8 million ZEV in EVI Pro 2 [4]

Looking at Figure 11, during mid-day, net demand (total demand minus renewable energies) decreases to 11.000 MW approximately because of solar generation in California. The "duck curve" is the net curve that shows the electricity demand and the availability of solar energy during the day. Solar production starts to increase with the sunrise, bringing net demand down. Peak solar production happens around midday, when electricity load is the lowest. As a result, energy production, mainly solar, is higher than it needs to be and net demand is decreased. The duck curve gets more pronounced each year, as solar energy is increased and therefore net demand is decreased each year, Figure 9. When peak-load happens during the evening, solar production is reduced as sun gets weaker.

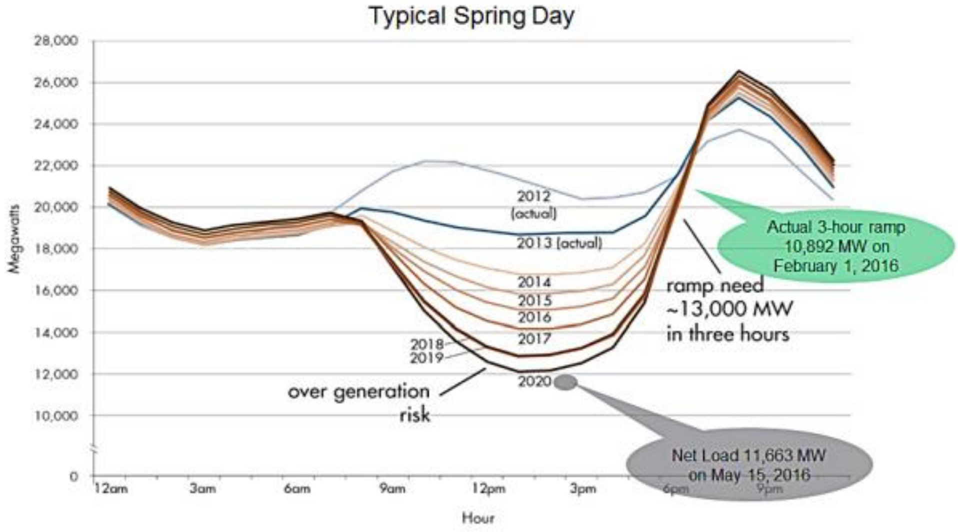


Figure 9. CAISO duck curve evolution 2012-2020, [9]

Interestingly, this late day increase in demand is due entirely to residential customers explained by the daily load profile by customer type shown in Figure 10.

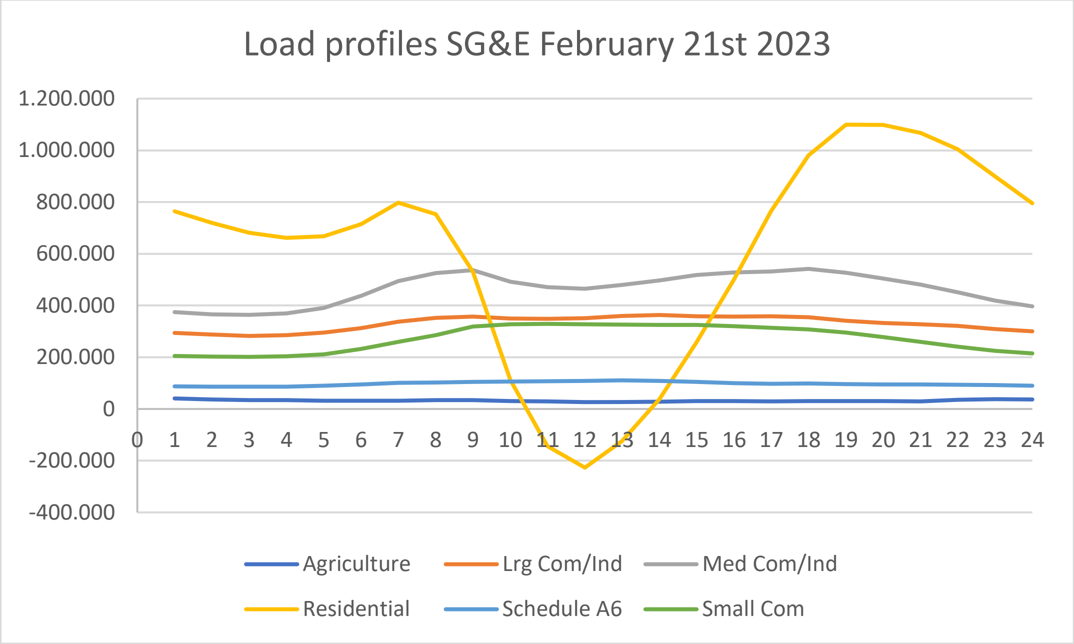


Figure 10. Electric load profiles in the San Diego area the (February 21, 2023), [25]

2.5. CPUC Future Planning & Transportation Electrification

Due to energy demand growth and electrification of transport among other things, the report made by the CPUC in February 2023: *Modeling Assumptions for the 2023-2024 Transmission Planning Process* concluded that 21,738 MW of new battery storage, 1.524 MW of long-duration storage in the form of pumped hydro storage, and 41.148 MW of new in-state renewable resource will be required by 2033 in California. Besides, in terms of the transmission system, there will be a need of 4.041 MW of partial or full transmission upgrades by 2033 [25].

To quantify this problem, the Boston Consulting Group evaluated California's new utility infrastructure needs and determined that between 11$ and 30$ billion will be necessary to maintain grid reliability [26].

As mentioned before, on September 23, 2020, Governor Gavin Newson from California, was committed to have by 2035 100% ZEV new sales for new personal vehicles and light duty trucks. Besides, he also signed the Executive order, targeting that by 2045, 100% of new sales of medium and heavy duty should be ZEV.

The CPUC presented a document in 2021 named Electric Vehicle Charging Infrastructure Assessment Analyzing Charging Needs to Support ZEVs in 2030 which is a study to assess the adoption of ZEV target in 2030 [4]. The CPUC estimates that to meet those objectives, 8 million light-duty ZEVs and 180.000 medium and heavy duty ZEVs will be needed in 2030. To estimate the number and type of charger needs for 2030 based on the 8 million ZEVs goal, the CPUC has relied on the Electrical Vehicle

Infrastructure Projection Tool (EVI PRO) developed by the National Renewable Energy Laboratory (NREL). EVI PRO determines the number of chargers needs depending on the type of charger: workplace, public, DC fast charger, residential,… This tool was first used to assess the chargers needs for 2025 (Executive Order B-48-18, 2018), to meet 1.5 million ZEV population. To do so, EVI-PRO 1 determined that 250.000 chargers were needed by 2025, 10.000 of them DC fast chargers [27].

The update of these numbers are calculated with EVI-PRO 2, the new model based on the previous one but takin into account 8 million ZEVs population. EVI-PRO 2 estimates that chargers needs will vary between 1.086.000 and 1.230.000 depending on the adoption of EVs and more factors, Table 1. Whereas in EVI-PRO 1 92% of PEV had access to home charging, EVI-PRO 2 only 67% of PEVs have access. This means that as the CPUC expects, in the near future, EVs charging will rely more on workplace charging and DC fast charging, both public and private.

Table 1. Projected chargers need for 8 million ZEVs in 2030 in California, [4]

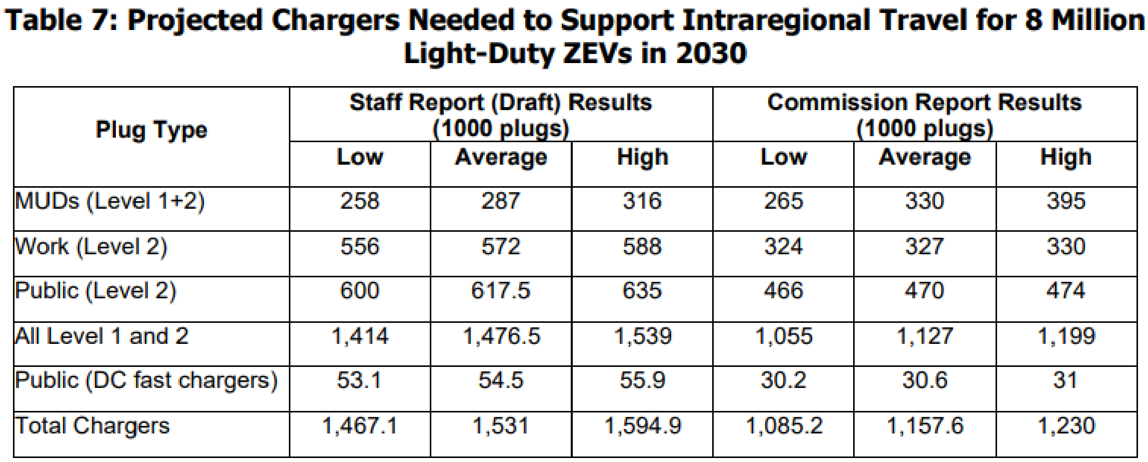


Table 7: Projected Chargers Needed to Support Intraregional Travel for 8 Million Light-Duty ZEVs in 2030

Plug Type	Staff Report (Draft) Results (1000 plugs)			Commission Report Results (1000 plugs)		
	Low	Average	High	Low	Average	High
MUDs (Level 1+2)	258	287	316	265	330	395
Work (Level 2)	556	572	588	324	327	330
Public (Level 2)	600	617.5	635	466	470	474
All Level 1 and 2	1,414	1,476.5	1,539	1,055	1,127	1,199
Public (DC fast chargers)	53.1	54.5	55.9	30.2	30.6	31
Total Chargers	1,467.1	1,531	1,594.9	1,085.2	1,157.6	1,230

The California Electric Vehicle Infrastructure Project which is funded by the CEC, assess EV charging needs by providing incentives to projects which want to adopt EVs in local areas by building Level 2 and DC fast chargers. This program is thought to help reduce the cost of installation by providing public funds. The average cost of a Level 2 charger installation is about 9250$ per charger and about 106.000$ for a DC fast charger (total cost of project divided by number of charger installed). This cost is based on 6 different incentive projects that were completed from 2017 to 2022 in California [28]. Using this average, the California Energy Commission (CEC) has projected that the state will require 1.2 million public EVSE units by 2030, with a projected total cost of 13 $ US billion - a sum that falls within the range expected by the Boston Consulting Group. However, it's worth noting that the projects only entailed the charging site cost, and not the full scope of the CEC's projected EVSE installation. A complete installation of 1.2 million EVSE units would also require transmission and distribution system upgrades, which would further increase the cost.

The projected expenses for the new system are based on the assumption that the power required to charge upcoming generations of EVs will be sourced from remote, utility-scale facilities, necessitating the creation of new transmission infrastructure. These generation resources will be based on wind farms located in remote areas. Off-shore wind technology is expected to start in California by 2026 and to have between 3200 MW installed by 2033 [29]. Nuclear power capacity in California is based on two nuclear power plants, The San Onofre nuclear power plant and Diablo Canyon nuclear power plant. The San Onofre plant was shut down in 2013 and the Diablo Canyon plants is still providing 2260 MW of power capacity. These plants were expected to shut down in 2025 but the California Energy Commission approved a staff analysis on February 28, 2023, to extend the operation of the Diablo Canyon power plant until 2030 [30]. CEC argues that the lifetime of the power plant should be increased to avoid shortages during extreme weather conditions, like it happened in summer 2020 [31].

Furthermore, CPUC has assumed that Vehicle-to-Grid technology cannot contribute to grid support during peak demand (not taken into account in RESOLVE planning model for energy capacity in the future), thus requiring significant storage capacity, 22000 MW additional battery storage will be needed in 2033, and controversially, the use of natural gas power plants is not expected to reduce dramatically by 2030 [25], which runs counter to California's goal of achieving a fossil fuel-free energy grid. In this topic, a big discussion is being held on which technology should replace conventional fossil-fuel plants. From very sophisticated and efficient renewable energies to new generation nuclear power plants or fusion power plants.

Nevertheless, the purpose of this report is to analyze how Electrical Vehicles and Vehicle-to-Grid Integration can help reduce distribution and transmission infrastructure upgrades in California by reducing peak load during the evening and by shifting charging from evening to midday when solar generation is abundant (usually exports of energy are placed during midday [32]).

Therefore, if utilities take the adoption of V2X technology seriously into account, the two main goals of the Executive Orders exposed before, can be met: the increase of the electrified, clean and zero emission transportation (passenger’s vehicles and medium-heavy duty vehicles), and having green and sustainable energy supply in California. V2G can also help flatten the duck curve and reduce energy imports from other states (every year around 30% of the energy generation is coming out-state [33]).

2.6. CCE alternative proposal

CCE state that utilities model of remote generation and upgrades in the electrical infrastructure is not the best option to ensure reliability in the grid and provide electricity to consumers in the future. CCE goal is to charge EVs in companies parking lots during the day and therefore solar arrays should built to provide clean energy to the batteries of EVs. Once this is completed, EVs can operate as mobile energy storage and deliver energy to houses and/or grid during peak load times in the evening. By doing this, EVs are a potential resource to reduce the duck curve in California.

In CCE view, this approach of mobile energy storage devices can solve three problems:

1. By building solar panels over parking lots, no need to upgrade the distribution and transmission infrastructure is needed, as energy will be directly delivered to the EVs. The savings from the upgrade will surpass the cost of the expensive carport chargers.

2. EVs fully charged during the day and connected to bidirectional chargers at houses during the evening, will deliver power to the grid and potentially reduce the duck curve during critical hours (ramping during evening) and support the grid. As mentioned in section 2.4. the duck curve is entirely caused by residential load so by implementing in V2G technology in houses chargers, this issue could be solved.
3. Nowadays the availability of EV charger in multi-unit dwelling is a problem due to the unavailability to support energy to every EVs. If chargers at workplaces are common, this problem will be solved, and EV users can use workplaces chargers instead of home charging. Besides, the cost of upgrading the distribution system to deliver energy to MUD is more expensive than provide energy directly to EVs in a combination of solar arrays and EV chargers at parking lots.

3. VEHICLE-TO-EVERYTHING TECHNOLOGY

3.1. Introduction

A frequently disregarded fact is that cars, on average, are driven for only 4 percent of their time, while they remain parked for the remaining 96 percent of the time. This means that for most of the day, cars are just sitting unused. Vehicle-to-grid technology V2G can be extremely useful in such situations. EVs have a large battery capacity that can store a considerable amount of energy, unlike internal combustion engine cars. Therefore, what if EVs' battery capacity could be utilized to store grid energy and provide additional power to balance out energy consumption fluctuations? V2G makes EV battery storage accessible by enabling bidirectional charging between a vehicle and the grid. In simple terms, V2G allows an EV to provide power back to the grid temporarily, depending on the electricity demand at a specific moment.

3.2. How does it work?

A bidirectional charger is an advanced EV charger that can perform two-way charging. It involves a complex power conversion process from alternating current (AC) -if energy is provided from the grid- to direct current (DC), unlike regular unidirectional EV chargers that charge using AC. As an example of it, the revolutionary Quasar DC bidirectional charger from Wallbox is 7,4 kW 150-500 V DC power and is used for charging or discharging [34].

Bidirectional chargers, like inverters, convert AC to DC during charging and reverse the process during discharging. As bidirectional chargers are far more advanced, they are also more expensive than regular EV chargers. This is because they incorporate sophisticated power conversion electronics to manage the flow of energy to and from the vehicle. Bidirectional chargers for homes include features to manage loads and isolate the house from the grid during power outages, which is known as islanding. This allows them to supply power to the home when an electricity shortage for example. The way a bidirectional EV charger operates is similar to bidirectional inverter-chargers that have been utilized for backup power in home battery storage systems for more than ten years [35]. The term Vehicle to Everything (V2X) is referred to any type of energy deliver from a battery of EVs. It is used to include the two possible variations: Vehicle to Grid (V2G) and Vehicle to Home (V2H).

3.2.1. V2G: Vehicle to Grid

V2G technology involves using a bidirectional EV charger to transfer electricity between an EV's battery and the grid via a DC to AC converter system. The purpose of V2G is to help balance and meet the energy demands of a particular region, locality, or nation through intelligent charging. By charging EVs during off-peak hours and returning excess energy to the grid during peak hours, EVs can effectively function as power banks, which can stabilize the electricity grids of the future. As cars remain parked for about 96% of the time, with proper planning and infrastructure, EVs can play a crucial role in ensuring that there is always enough power supply for everyone. Hence, we can consider EVs as mobile batteries, helping maintain a stable energy supply, participating in actions presented in section 2.2.

3.2.2. V2H: Vehicle to Home

V2H technology involves using a bidirectional EV charger to transfer electricity between an EV's battery and a house or building via a DC to AC converter system combined within the EV charger. Similar to V2G, V2H also could help balancing and stabilizing the local or even national supply grids. By charging an EV at night when the demand for electricity is low and then using that stored electricity to power the home during the day, grid energy demand could be reduced and hence, the pressure on the grid would be limited. Thus, V2H could ensure that homes have sufficient power when needed, while ensuring reliability in the electricity grid.

As we shift towards fully renewable energy systems, V2G and V2H could become even more significant. This is because different renewable energy sources generate variable energy depending on the time of day or season. Solar panels, for example, produce the most energy during the day, while wind turbines generate more power when it's windy. Bidirectional charging allows EV batteries to store excess solar or wind power when it's generated, making it available for use during times of high demand or low energy production. This way, EVs could contribute to the renewable load, ensuring that there is always enough power available for everyone, while also benefiting the environment.

As mentioned before, V2X can help reduce the strain in California electricity grid by charging EVs during the day when solar power is abundant and deliver that stored energy in EVs during the evening when peak load occurs due to the increase of residential load.

3.3. Electrical Vehicles as Distributed Energy Resources

The concept of using EVs as a mobile energy storage resource was proposed in 1997 by Willet Kempton [36] when he acknowledged the huge potential of batteries as storage and fuel cell and hybrid vehicles as energy generators. Willet explained that for utility-side using EVs as Distributed Energy Resources (DER) would have many advantages in terms of an easier integration of variable new renewable energies and grid reliability. Since then, V2G has widely been studied and tested. There is still a long way to go until V2G is being placed by the utilities as DER in their future energy mix plans. The following paper [37] reviews the state of research on V2G and assess the technical and economic barriers.

3.4. CCE V2G California model

To show the potential of V2G in California the following CCE approximated model of V2G is presented to show the feasibility of the use of EVs batteries during the ramping period in the evening when solar generation decreases.

First, it has to take into account that internal combustion engines and EVs batteries are overdesigned for daily travels. The big difference here is that batteries can be used as an energy resource. In California, whereas the average batteries mileage range is around 250 miles, daily usage is typically around 40 miles [8].

Figure 11 shows the net and total power demand during the 23th of February 2023 in California. As it is reflected, the 3-hour average ramping during the evening is about 11.639 MW of power which is the amount of power natural gas plants have to replace gradually during a 3 hour time period when solar generation starts to decrease and residential load starts to increase. Suppose home bidirectional chargers are Wallbox Quasar, with 7.4 kW. This very inaccurate approach means, supposing the DC energy is converted to AC and delivered to the grid without any losses, on the 23th of February, about 2,2 million EV should be plugged into the grid during 3 hours not to rely on natural gas plants power. By 2030 more than 2.2 million EV will be driving around California (3.3 million PEVs [4] are expected to be by 2030) and charging and discharging power will be increased with the development of the technology (Increase factor of 2,2 [38]).

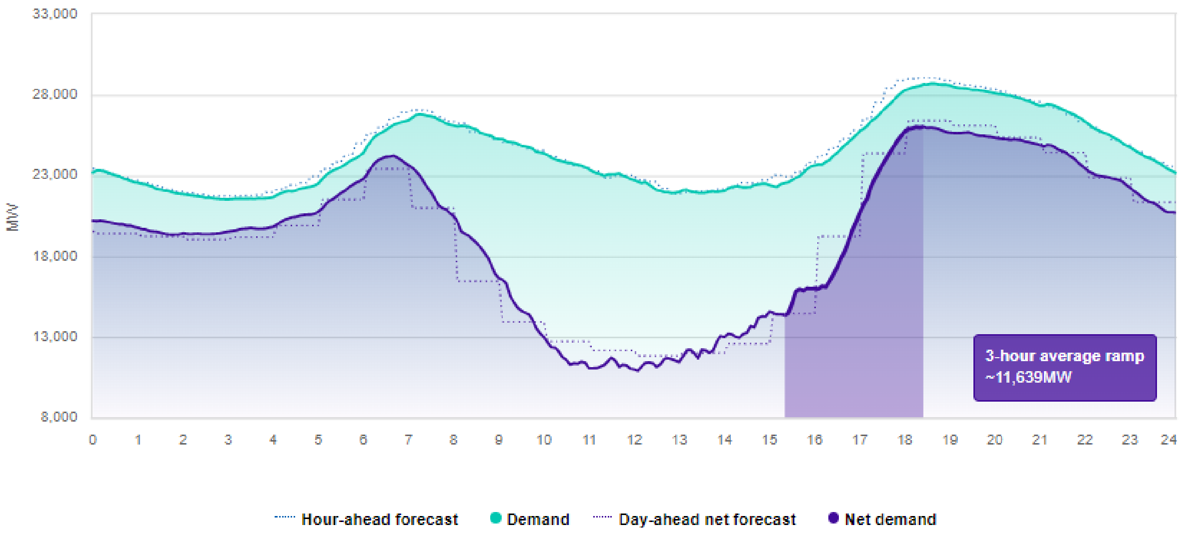


Figure 11. CAISO electric total and net demand for (February 23, 2023), [16]. Net demand (mainly fossil fuel power plants) starts to increase when solar generation starts decreasing during the evening. Ramping indicates the speed that these power plants have to increase their capacity to reach the total demand

As mentioned before in Figure 10, ramping during critical hours and therefore the duck curve, is due partly to the increase of residential consume. The average consume of a residence in February 2023 in San Diego County was 4.09 kWh during peak hours from 4-9 PM [39] and the size of a common EV in California like Tesla Model 3 is 60 kWh. It can be seen that a little energy withdraw from batteries by bidirectional chargers, can power the house during critical hours and reduce dependence from the electrical grid. This simple approximation indicates V2G could potentially help mitigate the duck curve if a large population of EVs are adopted in the future.

3.5. The Interreg project DeeldeZon

The Netherlands is also committed to develop V2G technology and their approach is very similar to the one CCE has. The project is called "The Interreg project DeeldeZon" and it consists of building solar panels on neighborhood connected to smart chargers or bidirectional EVSE linked to one or more electrical vehicles. In the article [40], it is said that their target by November 2022 was to have

80 ongoing projects in the south of Netherlands to proof the viability of this technology and demonstrate that the combination of solar power and V2G chargers is a feasible technology to eliminate the burden of the electrical grid. No recent news have been published about this.

The Netherlands seek to have 2 million EVs on the road by 2030 and expect to have a mobile storage capacity of 50 GW. Their lack of current storage capacity (20 MW [41]) and their need to upgrade energy storage (at least 29 GW, and perhaps as much as 54 GW by 2050, energy analyst said [42]) is pushing the Netherlands to take advantage of V2G technology as a future storage resource. They estimate that if 1 out of 8 cars participate in V2G, about 2.5 GW of energy storage would be available by 2030, an amount substantially higher than the 100 MW reserve capacity needed in Netherlands to ensure electricity reliability.

3.6. Services provided by EVs

The integration of EVs in the current electrical grid faces two main challenges. First, EV charging should be done without increasing peak loads, which would cost money to the utilities and could cause problems in the operation of the grid. Second, electric demand will grow in the future due to overall electrification (gas stoves and gas water heaters will be replaced by electric ones and house heating will be electric) and EVs connected at residential areas cannot overload distribution system equipment such as transformer, switches and wires.

Utilities should take advantage of the potential of EVs as mobile storage and the services that can provide and adopt smart charging to maximize grid reliability for all consumers and at the same time optimizing operational cost. The report from 2021, which is a summary and recollection of interviews to EV experts, shows the following services that EV can provide to the grid and to consumers [43].

From transmission systems point of view:

- Frequency response: quick action to keep systems frequency between limits
- Frequency regulation
- Spinning reverse: Generation capacity that is unloaded but can take part within short time to help energy outages
- Congestion management

From distribution system point of view

- Congestion management
- Load shifting
- Peak shaving
- Valley filling
- Voltage control

Besides, some studies and analyses have concluded the following:

- Plugged-in EVs can be used when parked for frequency regulation ancillary services. The potential based on [44] is around 10$/MWh.
- V2G frequency regulation and peak reduction potential value are dependent on power. In New York from 2007 to 2009 for 1,3 kW chargers, revenue was between 277 $ and 837 $ and for 10 kW chargers between 2200 and 2500 $ [45].
- V1G technology compared to V2G technology requires double amount of EVs to help balance wind generation [46].
- Sioban Powell [14], states the following related to the comparison of two different charging scenarios. *Switching from Business As Usual charging to the Low Home, High Work access charging scenario would reduce the cost of installed storage by US$0.7billion with an optimistic 143 US$ kWh−1 forecast for the cost of storage or US$1.5billion with a higher forecast cost of 299 US$ kWh−1. These savings are substantial compared with total electricity costs and grow substantially as we look at higher levels of EV adoption. In the stress stest with 100% EV adoption, the switch to Low Home, High Work access would yield savings of US$1.6billion or US$3.4billion with either cost forecast.*

To validate the value proposition of EV grid service, timely delivery of services from both the communication and EV charging infrastructure is crucial. Moreover, customers should receive remuneration for utilizing these services, while the utility company should be able to measure the impact of the services provided. This impact should provide value to the utility's operation, particularly at the distribution level where the benefits of the services will be realized.

Furthermore, to ensure successful implementation of the EV grid service, it is important to consider the scalability of the overall infrastructure. The EV grid service must be designed to accommodate a growing number of EVs and provide correct operation with various charging technologies. This will enable the utility company to effectively manage the increasing demand for EVs while providing reliable and efficient services to its customers. By doing that, utilities can unlock the full potential of the EV grid service and deliver maximum value to all stakeholders involved.

3.7. Benefits of V2G

Owning an EV combined with a bidirectional charger instead of a unidirectional charger can be a little more expensive but there are benefits that V2G technology overlap V1G smart charging. Some of these are: make money by selling electricity excess to utilities, save money with different price tariffs and become self or part sufficient.

<u>Make profit by selling electricity to utilities</u>

In the CCE model, bidirectional chargers will be used to discharge energy from the batteries to homes/grid. By delivering electricity back to the grid, money can be made. Energy that has been generated during daytime thanks to solar panels installed in parking lots of companies, can be sold to the utilities and make profit out of it. Based on [47], they estimate that the revenue from a V2G point of view of a Nissan Leaf along its 10 years lifetime and 120.000 miles could be around 4000$.

Money saving

In Spain, where energy prices vary along the day, or in the UK, where utilities offer EV owners off-peak charging tariffs, even more money can be made if energy is sold during peak-load times. Some energy companies and governments are currently providing incentives to EVs in the form of price reductions, with the aim of encouraging them to charge their EVs during off-peak hours, resulting in even more affordable electricity. This approach helps stabilize the electricity grid and ensures that not all EVs are charging simultaneously during peak demand periods. By using the stored electricity in EVs to power homes during the day, cheaper energy could be purchased instead of the normal peak-load price available for all customers, and therefore save money on the electricity bill.

Energy partly sufficient

As mentioned before, EV batteries are large enough to power houses during certain time periods. If EVs arrive home almost fully charged, whenever there are peak-load periods, batteries can release energy instantaneously and power the house. If house owners have solar panels installed in their roof, the house can be even more energy efficient. Solar excess generated by Photovoltaic (PV) panels during the day can be stored in EVs and used later whenever it is necessary. Depending on the size and power of PV panels and how charged batteries are, bidirectional charging would contribute to becoming energy self-sufficient.

V2G should be considered while designing a microgrid. Communities who look for managing their own energy generation and distribution, can use EVs as mobile storage devices to store, power houses and sell it to utilities and make profit. In this way, enabling V2G in microgrids can contribute with the development of renewable energy and distributed energy resources and at the same time support energy self-sufficient communities and multi-unit dwellings, not only single-unit houses.

3.8. Avoiding capacity investment

When EVs are connected to the grid with the purpose of charging, electricity travels from generating power plants to car's batteries. Therefore bulk, substation and distribution systems are affected. If EV charging load is increased, utilities will have to look careful at the capacity of the system not to overload system's equipment. Although the overall charging load of EVs will not affect the operation of the grid and market, EV charging during peak load times will have an impact and specially in the distribution level.

3.8.1. Bulk level

The following paper [48], identifies the insights about the different existing charging options in California that maximize the benefits on consumers and utility-side. The assumption is the following: 7% of houses in California own an EV (870.322 EVs) and all of them are charged at the same time. If the charger was Level 1 (2 kW), the charging load would suppose 3,8% of systems peak load whereas if the charger was Level 3 (40 kW) it would be 75.1%. This data assumes annual peak time.

3.8.2. Substation level

Key conclusion from the study Xcel Energy [49] are that if 5% of all residential customers were to charge their EV at the same time in Colorado, the load on the transformer would increase 4% in the worst case and 4% of all distribution transformers could be overloaded if charging during peak time. Besides, the impact of EV charging on distribution transformers will start to be significant 10 years from now.

3.8.3. Distribution level

The distribution level is the focus of this work. The distribution system starts in the substation transformer and ends in local residential transformers which power individual houses and multi-unit dwellings.

A recent 18-month pilot project called My Electric Avenue was conducted in the UK to demonstrate a control system capable of managing clusters of Nissan Leaf EVs. The project managed ten clusters comprising more than 200 vehicles on real distribution feeders using power line carrier signals. The main objective of the project was to showcase a management system that could mitigate the potential impact of EV clusters in high-penetration neighborhoods. The study estimated that if 40% to 70% of customers owned EVs, 32% of low-voltage feeders would require upgrading. The use of the project's "Esprit" control technology could avoid more than $3 billion in distribution system costs between now and 2050 [50].

3.9. Challenges

The reason V2G is not widely implemented is because of its many difficulties and challenges that need to be solved before VGI can become widely available. In order to benefit from V2G, both public-side and private-side actions need to be done. Following, in [43] Original Equipment Manufacturers (OEMs) and experts in the field discuss technical, social and regulatory challenges from the adoption of EVs as a source for grid integration.

3.9.1. Technical challenges

Grid services provided by EVs, temperature and driving behavior are parameters that will determine EV battery life and degradation. Charging strategies that support State of Charge of batteries around 50% will help increase battery lifetime. In the future, battery aging cost should be taken into account while analysing the revenue of V2G. To do so, long-term data such as different EV user profile or number of charging cycles should be considered. Even though some EV companies have battery warranty based on specific charging cycle numbers and EV driving profiles, more information about unmanaged, managed charging, V2G and revenue of grid services that EV can provide needs to be collected, to obtain real battery lifetime implications and warranty propositions. “Even if battery degradation doesn’t exist, the user has the perception of battery degradation, which means that it has to be compensated financially otherwise they will not participate” stated an expert in [43].

3.9.2. Social challenges

Due to the impact of the new EV load on the grid experts on the V2G field concluded that decentralized charging might be a challenge in the future. Whereas workplace and home charging do not increase enormously the strain on the grid, because of long time charging period and smaller power capacity needs, public direct current fast charging is not beneficial for grid requirement and V2X, due to shorter charging time and higher power requirements.

Another social challenge is that the use of EVs in the future will radically change, there will be more car sharing and autonomous EVs will be driving in the roads. This means that the use of EVs will be increased and therefore the time EVs are parked will be reduced, affecting negatively to V2G strategies.

The most important issue is knowing if EV users will agree in participating in V2G. Experts acknowledged that they don’t really know if users want to charge or discharge their vehicles following certain strategies. Before V2G is implemented, the question if people want to participate in V2G has to be answered, given the fact that right now V2G has not been researched profoundly and it might not be suitable in the future. The implementation of V2G will begin with trials where the energy charging cost at workplaces will be free of charge or with free charging stations for example. Financial incentives will be necessary for the acceptance of V2G technology. This will happen in early stages of V2G so people can take advantage of the technology but once V2G is widely accepted in the near future, free chargers won’t be justified.

3.9.3. Regulatory challenges

The most regulatory challenge is the double taxation of charging and discharging EVs battery. Another issue stands for the cost of measuring decentralized charging providers. Given that there exist many types of vehicles with different battery lifetime, charging equipment standards and communication protocols should be enforced in the near future [43]. Some experts agree that implementation of standards can stop innovation in the field because standardization costs can increase the overall investment and some users or companies won’t be able to afford it. On the other hand, standardization of processes can encourage investors to seek new business opportunities, and at the same time, it can show the value of the actors involved in the process of the design, construction and operation of V2G. It is very uncertain what role standards will play in the future.

Besides these challenges, in [51] the following problems are diagnosed for the implementation of V2G.

- Car OEMs need to incorporate V2G characteristics in their EVs. Few cars such as Lucid Air, Ford F-150 Lightning, and Rivian R1S and R1T include these characteristics.
- Auto industry should change batteries warranty to allow bidirectional charging and discharging, so they can act as grid resources.
- Hardware and software to enable V2G is needed, communication protocols, net metering processes and interfaces between grid and EV owners.

- Real potential of V2G is not been shown and therefore car owners don't know the scope of bidirectional charging. Education and general awareness are key.

3.9.4. Problem of EV load increase

Due to the fast-growing market sales of EVs, utilities should consider that EV load can overpass the reserve margin comfort zone and therefore it could be a problem of grid reliability and operation. Both evening peak and evening diversified load will be increased due to EV penetration. Figure 12 represent the model for the potential impact of EV charging in 2030 in New England electrical grid. V2G is not considered in this model. It can be seen that, whereas annual energy in 2030 compared to 2020 may increase 2.5%, evening concentrated load is expected to grow 15.5%, which is an increase New England utilities should take into account while planning and designing the future electrical grid. Generation, distribution and transmission upgrades will be required [52].

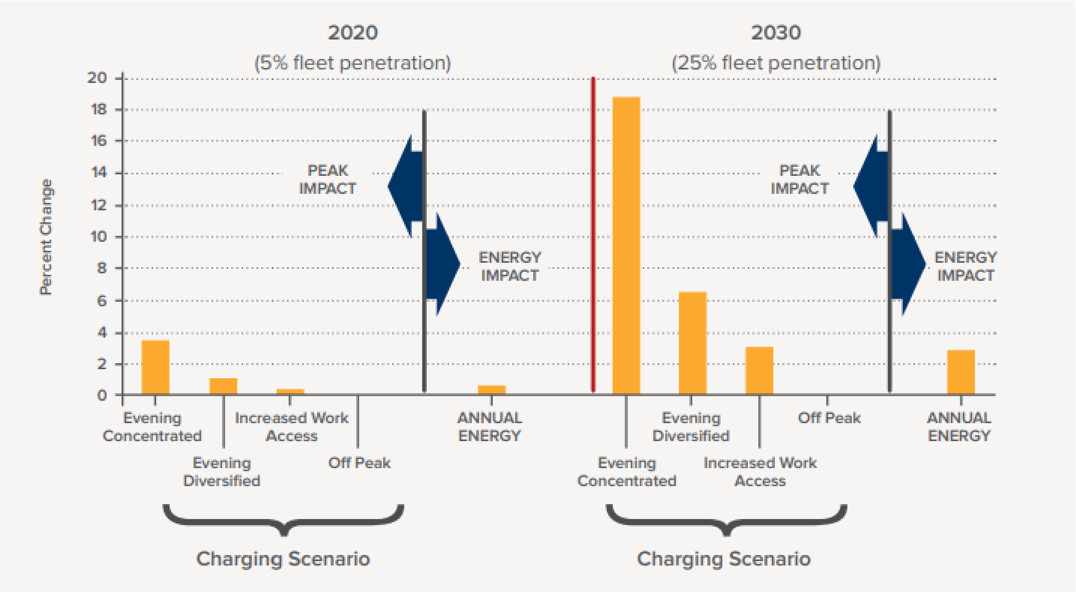


Figure 12. Potential impact of plug-in hybrids on New England system demand, [52]

Utilities have to consider develop Vehicle-to-Grid Integration scenarios and new charging tariffs, that will encourage EV owners to follow smart charging or V2G charging strategies, before it is too late to upgrade transmission & distribution systems and build new generation power plants to meet power capacity increase. In California for example, Senate Bill 350 was signed by Governor Newsom in June 2020, which dictates that utilities will be required to develop detail plans on how to achieve customer's resource needs, reduce emissions and increase the use of clean energy resources. These plans are called Integrated Resource Plans (IRPs) and also incorporate guidelines and recommendations on how to plan EV penetration in California [9]. Its goal is "to file applications for programs and investments to accelerate widespread transportation electrification to reduce dependence on petroleum, meet air quality standards, achieve the goals set forth in the Charge Ahead California Initiative, and reduce emissions of greenhouse gases" [53].

4. PREVIOUS RESEARCH

All the studies shown below are being presented to support the idea that EVs should be charged during the day. Then, energy can be discharged during peak-load times and help reduce the energy load from homes and therefore, less distribution and transmission infrastructure will be required. The following studies simulate EVs integration in 2020-2030. Whereas the main idea of most of the studies is not both charging during the day and discharging during the evening, all studies have done research and sensitivity analysis about the increase of workplace charging and how it affects the daily load profile. Benefits and conclusion about V2G are being widespread.

4.1. Modeling the Future California Electricity Grid and Renewable Energy Integration with EVs

The study [38] analyzed the potential for future fleets of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), collectively referred to as PEVs, to provide flexible load (V1G) and bi-directional grid storage resources for California in 2030. The study used modeling capabilities from SWITCH, V2G-Sim, and GridSim tools to estimate the market development of different types of PEVs, charging infrastructure development, and renewable electricity generation progress in California by 2030.

It was found that with V1G capability alone, 3.3 million PEVs in 2030 could replace $15.77 billion in stationary storage investments, providing 7500 MW of power capacity with 30,000 MWh of energy storage potential. The value of V2G services in California would be approximately double, replacing $26.28 billion worth of stationary storage investment costs in the same scenario. This indicates that the value of enabling vehicle-grid services would be immense in California, and PEVs could help substantially integrate renewable energy resources in 2030. Additionally, investment costs for dedicated stationary storage facilities could be significantly avoided in the future by utilizing vehicle-grid services.

The results from the simulation indicate that the addition of unmanaged vehicle charging demand to the system demand profiles leads to a rise in curtailment by 0.45 TWh in 2030. This trend is observed across all demand scenarios, Figure 13. However, managed charging has a positive impact in mitigating curtailment in the California system. In comparison to unmanaged charging, uni-directional controlled charging of 3.3 million PEVs can reduce curtailment by 3.66 TWh annually. By including V2G-capable charging stations in the mix, curtailment can be further reduced by 4.64 TWh, resulting in a total curtailment of 2.45 TWh in 2030 compared to 7.09 TWh in the unmanaged charging scenario.

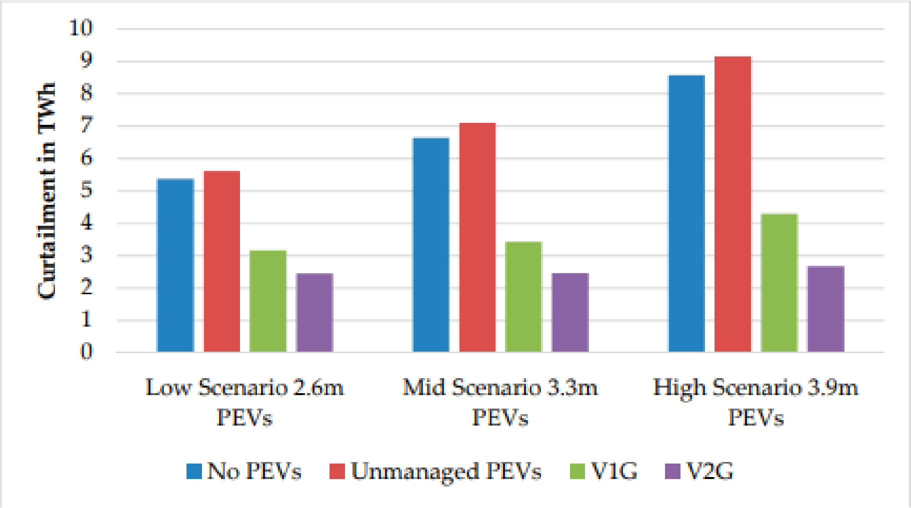


Figure 13. Curtailment required for different simulations and charging trends in 2030, [38]

4.2. Charging infrastructure access and operation to reduce the grid impacts of deep electric vehicle adoption

A study by Siobhan Powell and colleagues at Stanford University in California [14], modeled the charging demand for electric cars in 11 Western US states in 2035 and found that if more than 50% of the region's cars were electric and charged at home overnight, the demand for electricity would surpass grid capacity. They also found that if drivers charged their vehicles during the day, at work or using public chargers, the increase in peak net electricity demand would be less than 10%. The study also found that if half of the cars in use were electric, the peak demand for electricity from fossil fuels would increase by up to 25% and more than 5.4 GW of energy storage would be required, Figure 14.

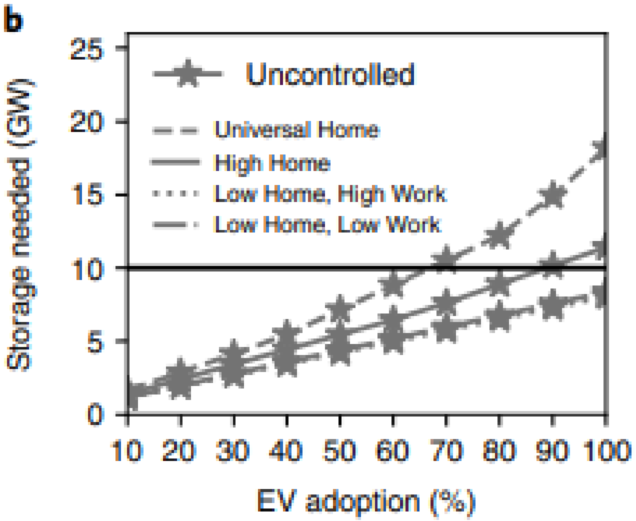
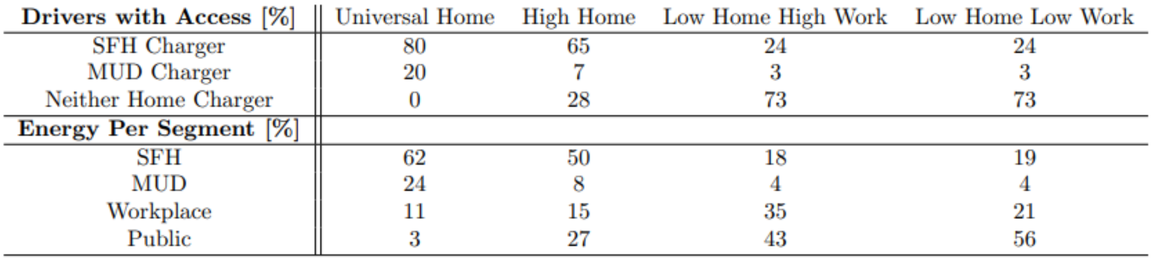


Figure 14. Energy storage needed to support specific EV adoption in 11 Western US states in 2035, [13]

Besides, they support the idea of Low Home, High Work charging scenario since the storage needed in 2030 would decrease by a factor of 1.7 if compared to Universal Home (35% of battery energy charged at work for Low Home High Work while 11% of energy charged at work for Univ. Home, see Table 2). The study concluded that if charging profiles do not change by 2030, EVs could put a strain on the electrical grid, resulting in shortages and power cuts.

Table 2. Driver Access and Energy Charged in Each Segment for each scenario, [13]



Drivers with Access [%]	Universal Home	High Home	Low Home High Work	Low Home Low Work
SFH Charger	80	65	24	24
MUD Charger	20	7	3	3
Neither Home Charger	0	28	73	73
Energy Per Segment [%]				
SFH	62	50	18	19
MUD	24	8	4	4
Workplace	11	15	35	21
Public	3	27	43	56

The authors concluded that in order to limit the upgrade of new generation, transmission, distribution and storing energy capacity, utilities should encourage to shift to daytime charging at workplaces and public sites. This has to be done carefully, as CPUC in California decided in August 2022 to ban sales of fossil-fuel powered cars by 2035.

4.3. Charging Electric Vehicles in Smart Cities: An EVI-Pro Analysis of Columbus, Ohio

This study was conducted to analyze Plug in Electric Vehicles (PEV) charging requirements in Columbus, Ohio, for the U.S. Department of Transportation's Smart City Challenge and Smart Columbus Initiative [54]. The study assessed early PEV adoption trends in the region and proposed a spatially resolved scenario for future PEV adoption in Columbus through 2019. A large GPS travel data set was used to estimate travel behavior, which was then used with NREL's EVI-Pro model to determine charging requirements and identify potential charging "hot spots." The study found that approximately 400 Level 2 plugs at multi-unit dwellings and 350 Level 2 plugs at non-residential locations are required to support the primary Columbus PEV goal of 5,300 PEVs on the road by the end of 2019. Additionally, a minimum level of fast charging coverage is recommended to ease consumer range anxiety concerns. The study's results can be used by other U.S. cities to accelerate PEV adoption in the LDV market.

Moreover, they conducted a workplace charging scenario sensitivity analysis where free workplace charging was offered. The results obtained compared to the baseline scenario (Figure 15), where home charging is dominant, indicate that a large amount of charging events are moved from early evenings to the morning hours when EVs are parked at workplaces. This resulted in a decrease of 30% of the peak-load during the evening into two smaller peaks, in the morning and in the evening as Figure 16 shows. This idea is also followed by CCE, and the work presented here researches this possibility.

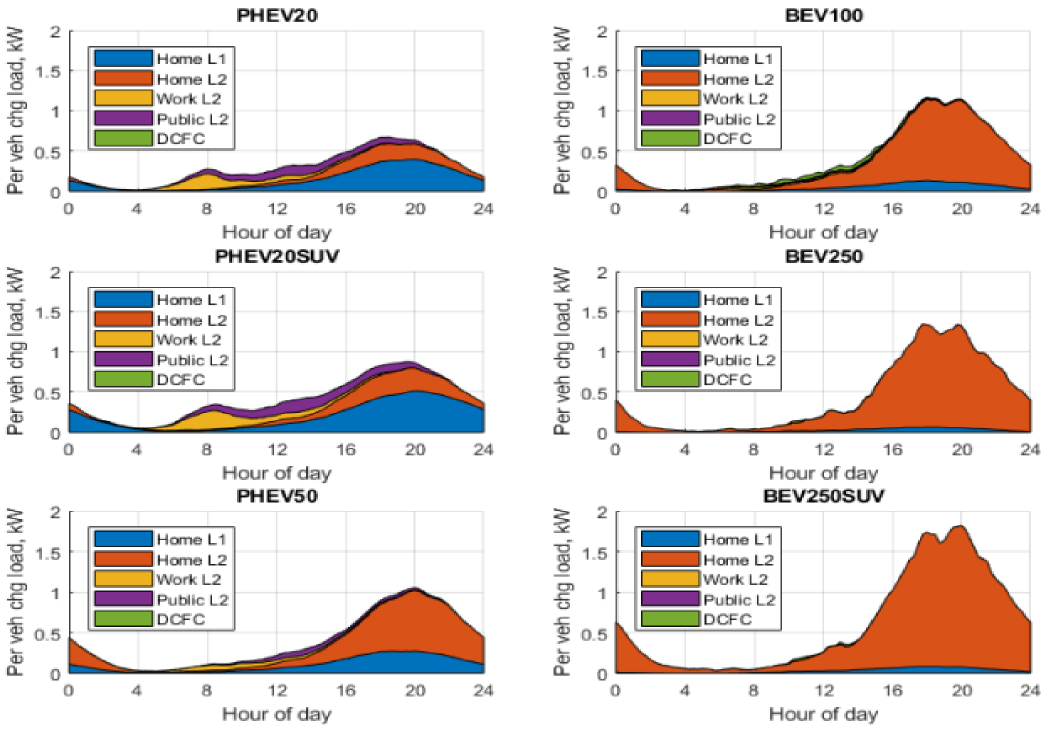


Figure 15. Simulated charging load profiles by station type and vehicle type based assuming residential charging, [54]

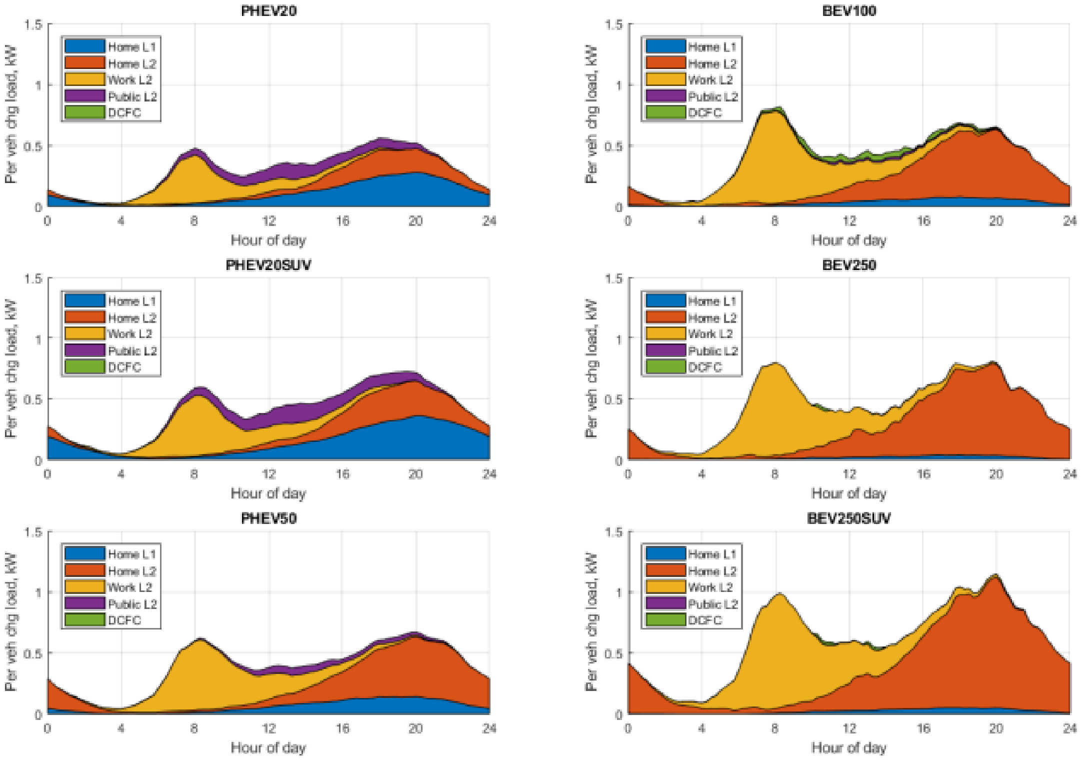


Figure 16. Simulated charging load profiles by station type and vehicle type based assuming free workplace charging, [54]

4.4. Electric Vehicle Charging Infrastructure Assessment

This report by the California Energy Commission, assesses the charging infrastructure needs to meet California Zero-Emission Vehicles (ZEV) penetration and RE generation goals by 2030, [4]. First, the contributors analyze the existing charging infrastructure and the current transportation trend to model California charger's needs in the future. The study is based on the Assembly Bill 2127, which is the roadmap for utilities, car OEMs and all actors involved in the adoption of the EV. After modelling charging needs, the report also outlines suggestions and plannings to achieve California charging infrastructure needs goals. It is expressed that vehicle-grid integration will reduce charging cost, align with renewable energy generation and power houses or even communities. Not only the concept of smart charging (V1G) it is expressed, but also bidirectional charging V2G.

Figure 17 shows the ZEV adoption trend by 2030. Two different trajectories can be seen. The red prediction is based on the California Air Resources Board's Draft 2020 Mobile Source Strategy which takes into account the air quality and climate goals for 2030 set on the Executive Orders mentioned in section 2.3. and anticipates 8 million light duty ZEV by 2030 (Executive Order N-79.20). Blue line shows the California Energy Commission's Integrated Energy Policy Report where assumptions are based on ZEV market growth and transportation demand. It is expected to reach a population of 3.3 million light duty ZEV by 2030 in its mid case. On the other hand, the black triangles set the 2025 and 2030 California ZEV adoption goals.

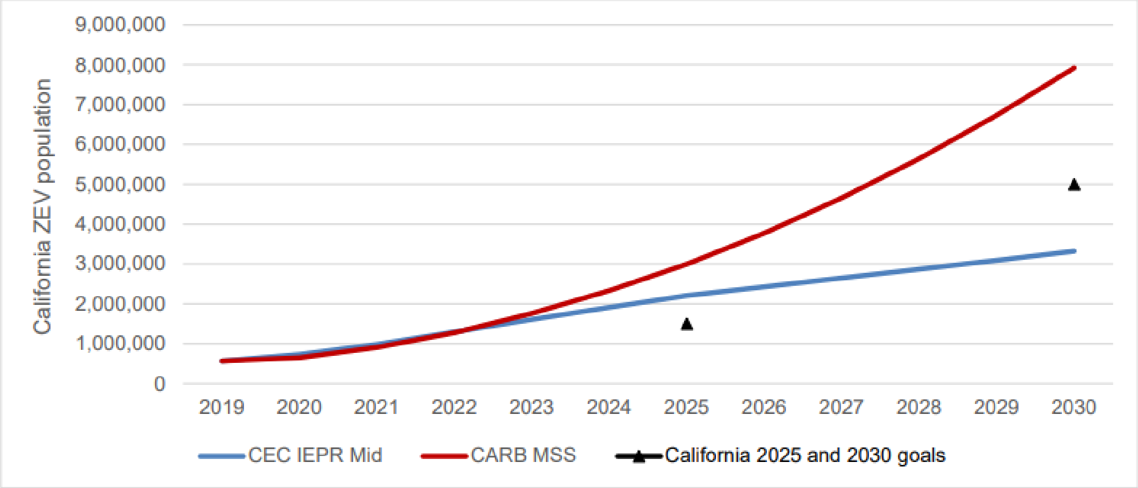


Figure 17. 2018 ZEV Adoption Trajectories in California, [4]

In the Integrated Energy Policy Report approved in February 2023 [55], different ZEV adoption trajectories are supported. Figure 17 shows that California Energy Commission predicts different ZEV population by 2030 compared to Figure 18. In the new prediction the baseline forecast is 5.4 million light-duty ZEVs for 2030 when last Integrated Energy Policy Report (IEPR) was accounting for 3.3 million. It can be seen that besides the baseline scenario, new alternatives with higher ZEV penetration have been simulated.

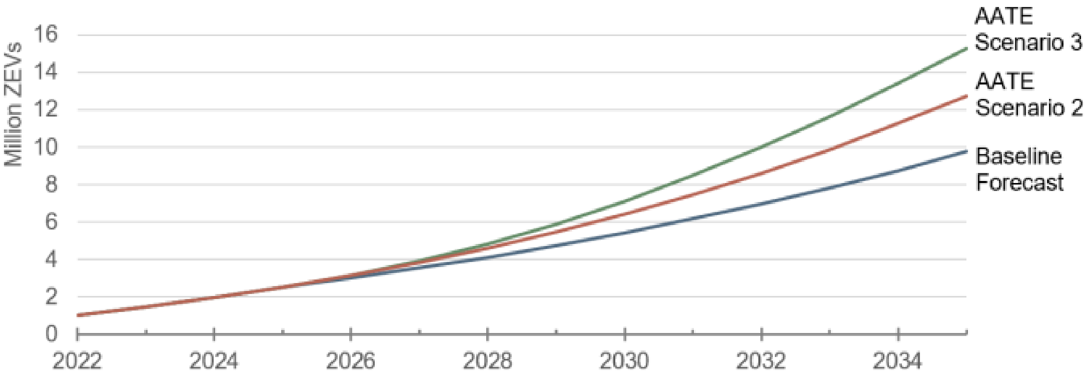


Figure 18. 2023 ZEV Adoption Trajectories in California, [55]

California is about to surpass its goal of 1.5 million ZEV driving in California by 2025, with 1.4 million ZEV population cumulative sales until 2022 [56]. However, charging infrastructure is insufficient to support this high penetration. By 2025, charging infrastructure goals are 250.000 public and shared charging stations. Throughout 2023, a new EV Charging Infrastructure Assessments report will be published with data about the existing infrastructure. In the report it is expressed that, the adoption of ZEV by new users will depend on the confidence of the availability of charging infrastructure in the future.

4.4.1. Modelling results

EVI-Pro 2 is the tool used by the CEC to simulate charging infrastructure needs by 2030. It is based on the EVI-Pro 1 used for 2025 predictions which analyzed that 250.000 chargers were needed to support the 1.5 million ZEV adoption in 2025. EVI-Pro 2 models the charging infrastructure to support 8 million ZEV in 2030. The differences between both tools are shown in Table 3. The average projection obtained with EVI-Pro 2 is that by 2030, 1.157.000 chargers will be needed, both public and private. In these simulations only smart charging (V1G) has considered. V2G is still not being considered as a way to manage ZEV charging load because the technology is still under investigation and it is being tested with pilot programs [51]. Right now, V1G or smart charging is the way utilities are considering ZEV batteries charging. The CEC concluded that there are expected to be 193.000 chargers in California in 2025 meaning that almost 1 million chargers should be installed during the following 5 years. This means that 500 chargers a day starting in 2025 should be installed to meet charging infrastructure goals by 2030.

Table 3. Comparison of Primary Input Parameters for EVI-Pro 1 and 2, [4]

Input	EVI-Pro 1	EVI-Pro 2
ZEV Population	1.5 million in 2025	7.9 million in 2030
PEV / Hydrogen Fuel Cell Electric Vehicle Split	87%/13% in 2025	95%/5% in 2030
Within PEVs, PHEV / BEV Split	45%/55% in 2025	30%/70% in 2030
Charging Behavior Objective	Maximize electric vehicle miles traveled	Mirror observed behavior
PEVs w/ Home Charging	92%	67%
Time-of-Use Rate Participation	Not included	67% in 2030
Infrastructure Utilization	Assumed	Observed

Figure 19 shows the average 24 hour charging load profile for 2030. During weekdays and weekends, the peak load is 5.4 GW, (it could represent an increase of 25% of the total electric load), and during midday, due to workplace and DC fast charging the load is expected to be about 4.2 GW. The spike during midnight could overload distribution systems equipment and affect grid reliability.

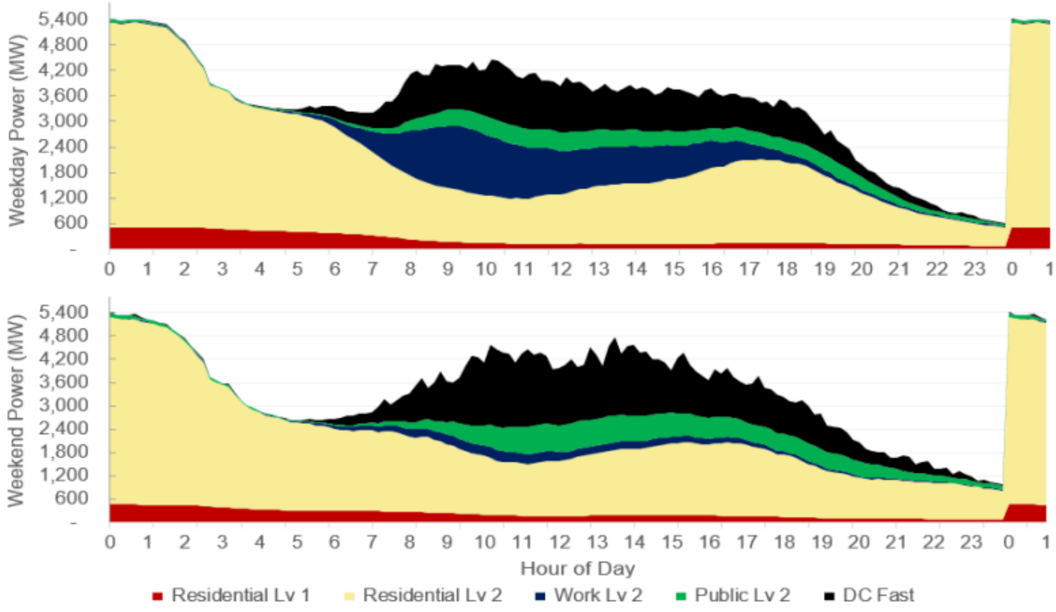


Figure 19. 2030 California charging load for 8 million ZEV in EVI-Pro 2, [4]

4.4.2. EV Happy Hour

Besides the baseline scenario, CEC has simulated 11 more ZEV charging alternative scenarios on behalf of the uncertainty of the growth and deployment of ZEV and charging infrastructure in the future. The scenario that is the most concern of this thesis is the EV Happy Hour scenario, where EV owners opt for charging their cars at workplace during the day instead of at home during the night thanks to ideal electricity tariffs at workplaces that reduce the cost of charging. In this case, 486.000 more chargers compared to the baseline scenario would be required to meet EV Happy Hour scenario assumptions. Figure 20 shows the daily charging load of the alternative scenario and it can be appreciated that midnight load has decreased to 3.5 GW (a reduction of 35% compared to baseline scenario), because the load has been shifted to workplace charging during midday. The midday peak load has increased to 6.5 GW (an increase of 54%) but the fact that solar energy will be the main energy resource has to take into account.

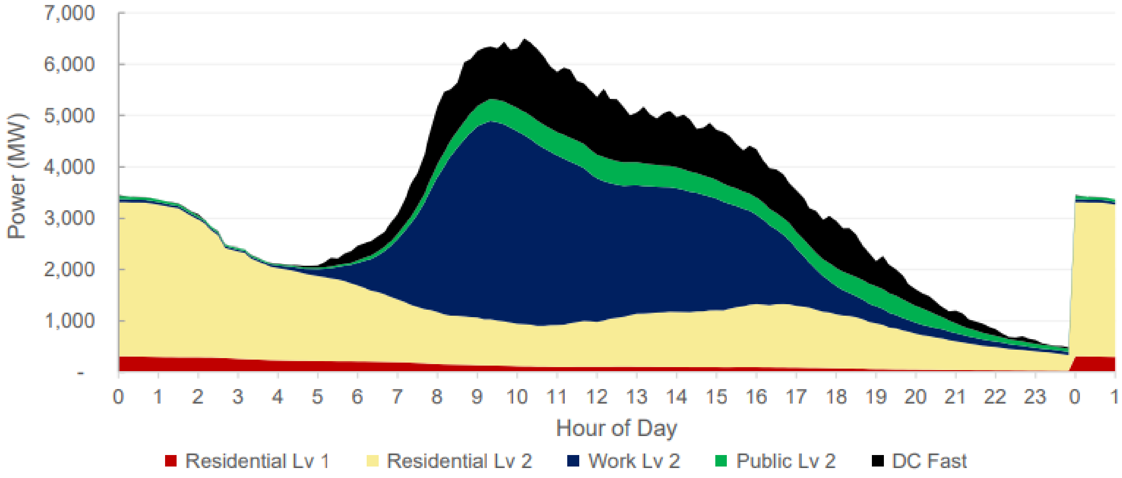


Figure 20. 2030 California charging load for 8 million ZEV in EVI-Pro 2, EV Happy Hour scenario, [4]

Fossil fuel generation resources and imports during midnight could be reduced if ZEV are charged with the surplus of energy that is generated during midday with PV power plants. As Figure 21 from CAISO shows, the 16th March 2023 in California, during daytime hours from 8 am until 5 pm, there existed exports of electricity and at the same time, batteries are being charged. This “trend events” occurs very often during the entire year.

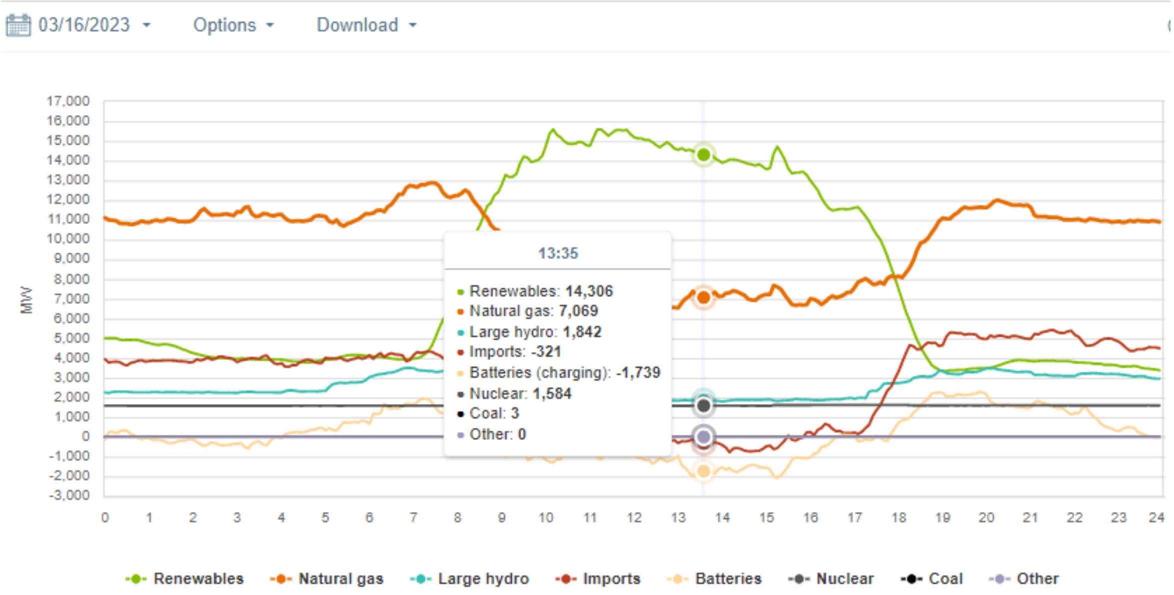


Figure 21. Supply tren broken by energy resources during the (March 16,2023), CAISO

Once again, utilities seem to have in mind that the way EVs should be charged, will be during midday, so midnight spikes are reduced and fossil fuel resources are minimized. The issue with distribution and transmission upgrades is still very uncertain. It is true that the previous scenario increases the load considerably but if more charging stations powered with local solar generation are installed, distribution upgrades could be minimized. This is the idea that CCE is willing to present to the utilities as a way to solve the electricity derived problems.

4.5. Electric vehicles as distributed energy resources

In this paper, the Rocky Mountain Institute chose 5 states with regulations supporting clean energy generation and incentives/programs for EV adoption, [51]. These states are California, Hawaii, Texas, New York and Minnesota. A baseline scenario for 2015 is compared with a 23% EV penetration scenario. Unmanaged and optimized charging has been modelled. In Figure 22, the baseline scenario with unmanaged charging can be seen in blue columns. Orange columns are plausible workplace and public charging patterns. For the modelling of the managed charging profile, the portion of home charging is 81% and 19% for public and workplace charging. Besides, to optimize the charging profile it is assumed that 90% of the charging is done during off-peak periods.

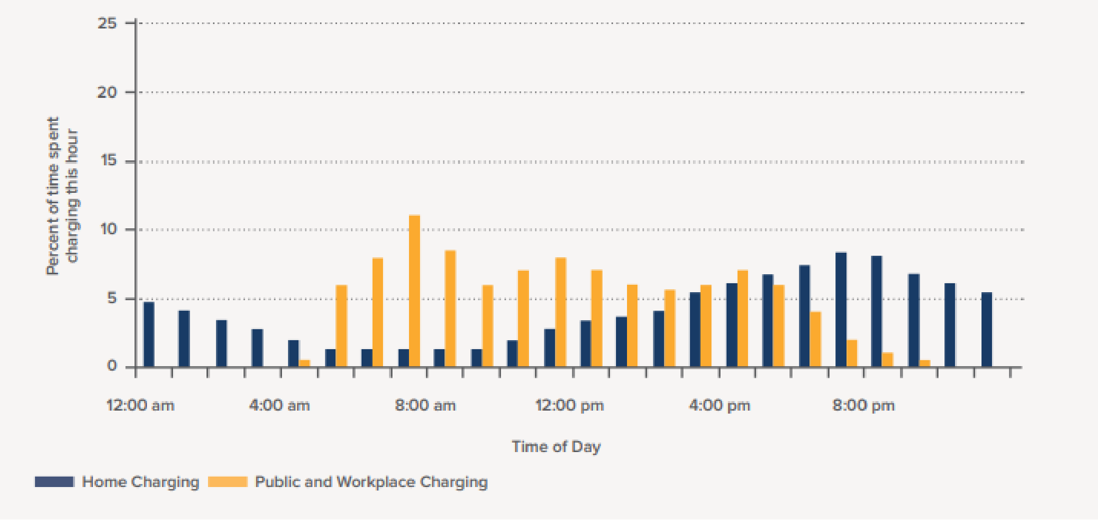


Figure 22. Uncontrolled and public/workplace charging load profile assumptions, [50]

California is the most advanced state in the US in terms of RE generation (most solar generation capacity and 3rd state in wind generation capacity) and EV adoption (currently highest EV adoption state). The Executive Orders mentioned in section 2.3., are the most ambitious goals in the US. Therefore, as California is in the forefront of RE and EV market, near future results will help other states adopt same or different strategies.

In Figure 23 and Figure 24, the CAISO 24 hour load profile with unmanaged and managed EV charging can be observed. When comparing both graphics, it can be seen that there is a big difference in the peak-load time with a 9.81% increase which means about 8 TW of power. The EV load during valley period for managed charging is higher than the EV load from 7-9 pm for unmanaged charging. The difference is that in the managed charging case, EV load during daytime is aligned with solar generation, which is cheaper than the energy produced in natural gas power plants during nighttime. Besides reducing peak load at 8 pm, managed charging helps flatten the duck curve and reduce ramping scenarios when solar generation starts to decrease.

The results from the other 4 states models align with the California scenario. The authors concluded that managed charging could avoid the investment of peak generation power plants like natural gas plants and avoid the upgrade of transmission and distribution systems.

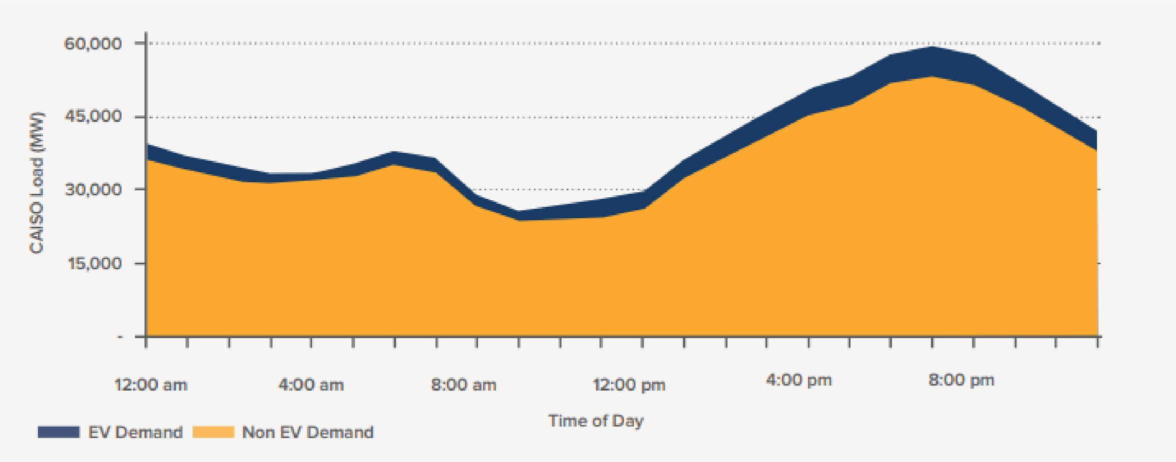


Figure 23. 2030 CAISO demand with 23% EV penetration and uncontrolled EV charging, [50]

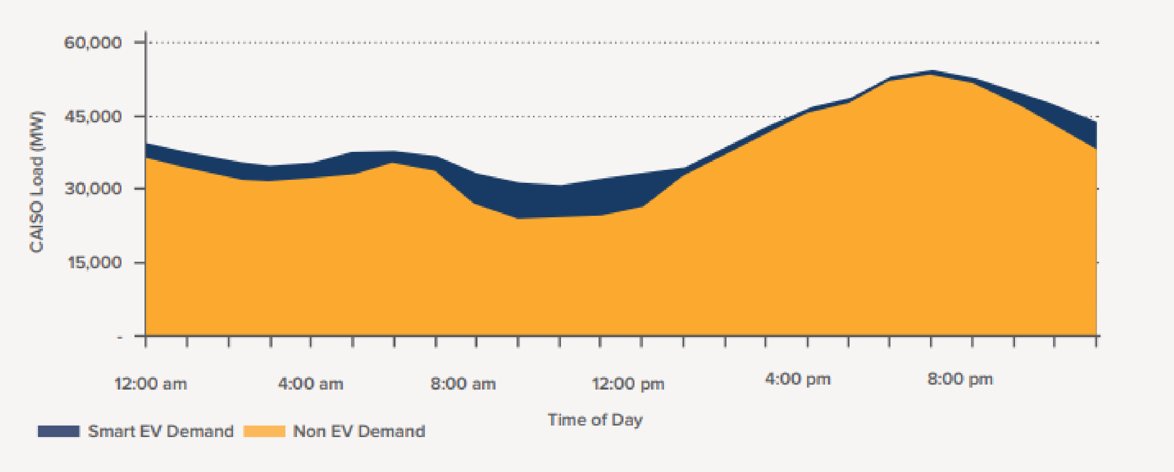


Figure 24. 2030 CAISO demand with 23% EV penetration and optimized EV charging, [50]

5. METHODOLOGY

In this section, the methodology employed for modeling CCE's concept of electric vehicle (EV) charging utilizing solar energy during the day and EV discharging at home in the evening is presented. The objective of this project has been the **accomplishment of a functional model capable of simulating V2G activities during the evening hour**s. To support the model, a specific **analysis** to the **San Diego** area is provided, which concerns 5 actual distribution lines. The core components of the model include input data, the equations utilized for simulation modeling, and the resultant outputs. Following, a scheme on the methodology followed is presented.

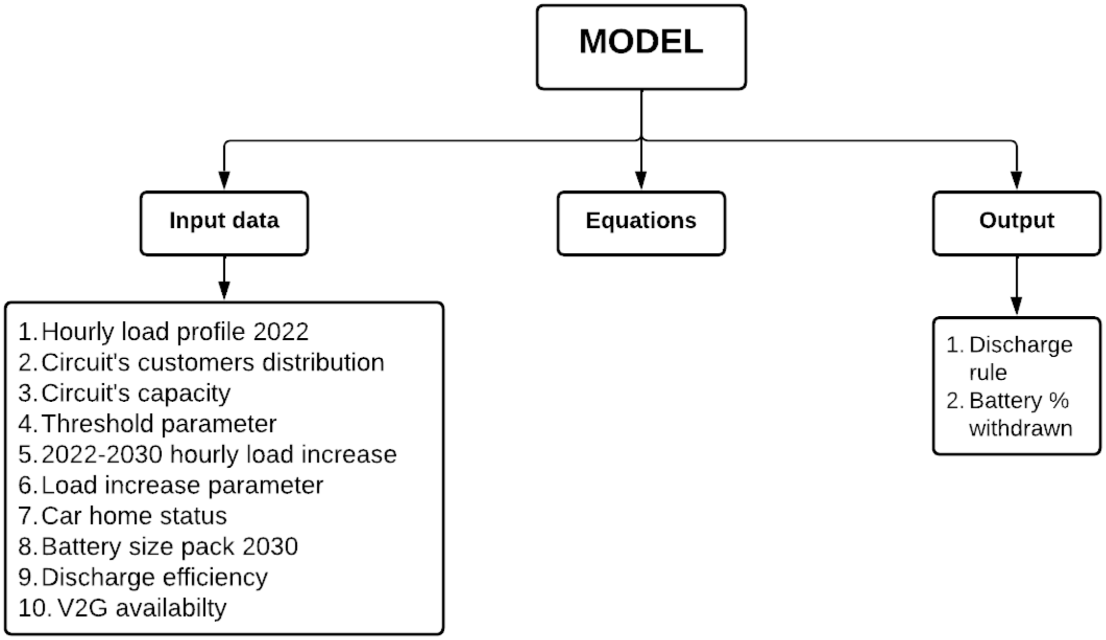


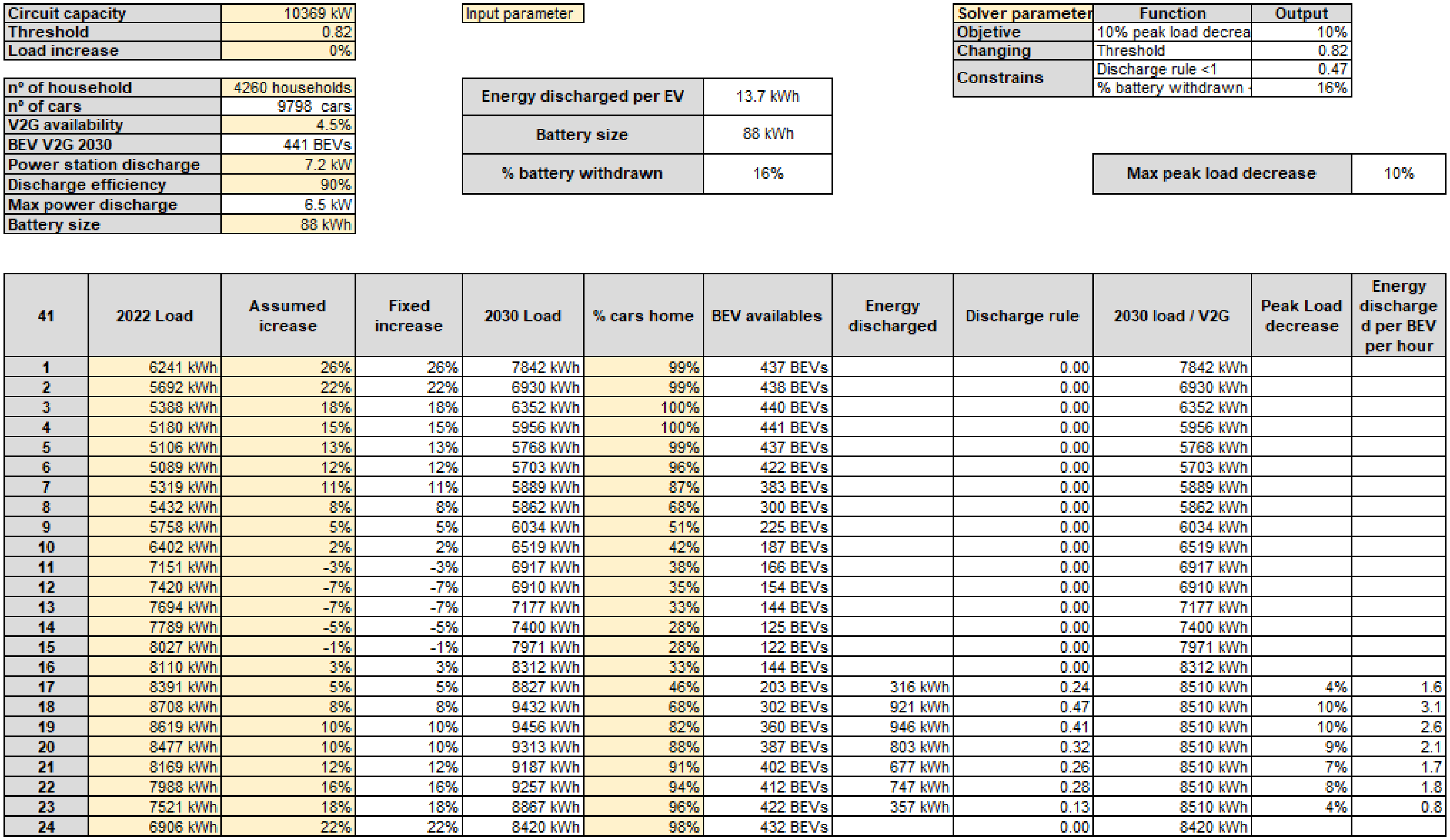
Figure 25. Methodology of the analysis

5.1. Model

The model's aim is to shave the peak load of the circuit below the threshold assumed for each circuit by discharging a little amount of energy from every BEV available at specific hours of the day. To do so, equations, modelling constrains and relationship between variables will be presented. Input parameters will be used to obtain the number of BEV that will be available to discharge the energy required to meet the threshold of the modelling circuit. The model for circuit 41 is presented in Table 4 and the result is shown in Figure 26.

The **purpose** of this model is that based on the input that the user is willing to simulate, obtain the **percentage of battery withdrawn** from every BEV available and the **discharge rule** that indicates how much energy is hourly being discharged from all BEV. These outputs will be explained in section 5.3. Firstly, the information regarding the load profile and the assumed parameters of EVs in 2022 are presented. Subsequently, this data is escalated to a hypothetical scenario in 2030 for San Diego County. Next, the calculation of the parameters used in the simulation (equations) and the output of the model is explained. Lastly, the optimization of the outputs is detailed and how the sensitivity analysis are constructed is interpreted.

Table 4. Circuit 41 Model, 10% peak load decrease



Circuit capacity	10369 kW
Threshold	0.82
Load increase	0%

nº of household	4260 households
nº of cars	9798 cars
V2G availability	4.5%
BEV V2G 2030	441 BEVs
Power station discharge	7.2 kW
Discharge efficiency	90%
Max power discharge	6.5 kW
Battery size	88 kWh

Input parameter

Energy discharged per EV	13.7 kWh
Battery size	88 kWh
% battery withdrawn	16%

Solver parameter	**Function**	**Output**
Objetive	10% peak load decrea	10%
Changing	Threshold	0.82
Constrains	Discharge rule <1	0.47
	% battery withdrawn -	16%

Max peak load decrease	10%

41	**2022 Load**	**Assumed icrease**	**Fixed increase**	**2030 Load**	**% cars home**	**BEV availables**	**Energy discharged**	**Discharge rule**	**2030 load / V2G**	**Peak Load decrease**	**Energy discharged per BEV per hour**
1	6241 kWh	26%	26%	7842 kWh	99%	437 BEVs		0.00	7842 kWh		
2	5692 kWh	22%	22%	6930 kWh	99%	438 BEVs		0.00	6930 kWh		
3	5388 kWh	18%	18%	6352 kWh	100%	440 BEVs		0.00	6352 kWh		
4	5180 kWh	15%	15%	5956 kWh	100%	441 BEVs		0.00	5956 kWh		
5	5106 kWh	13%	13%	5768 kWh	99%	437 BEVs		0.00	5768 kWh		
6	5089 kWh	12%	12%	5703 kWh	96%	422 BEVs		0.00	5703 kWh		
7	5319 kWh	11%	11%	5889 kWh	87%	383 BEVs		0.00	5889 kWh		
8	5432 kWh	8%	8%	5862 kWh	68%	300 BEVs		0.00	5862 kWh		
9	5758 kWh	5%	5%	6034 kWh	51%	225 BEVs		0.00	6034 kWh		
10	6402 kWh	2%	2%	6519 kWh	42%	187 BEVs		0.00	6519 kWh		
11	7151 kWh	-3%	-3%	6917 kWh	38%	166 BEVs		0.00	6917 kWh		
12	7420 kWh	-7%	-7%	6910 kWh	35%	154 BEVs		0.00	6910 kWh		
13	7694 kWh	-7%	-7%	7177 kWh	33%	144 BEVs		0.00	7177 kWh		
14	7789 kWh	-5%	-5%	7400 kWh	28%	125 BEVs		0.00	7400 kWh		
15	8027 kWh	-1%	-1%	7971 kWh	28%	122 BEVs		0.00	7971 kWh		
16	8110 kWh	3%	3%	8312 kWh	33%	144 BEVs		0.00	8312 kWh		
17	8391 kWh	5%	5%	8827 kWh	46%	203 BEVs	316 kWh	0.24	8510 kWh	4%	1.6
18	8708 kWh	8%	8%	9432 kWh	68%	302 BEVs	921 kWh	0.47	8510 kWh	10%	3.1
19	8619 kWh	10%	10%	9456 kWh	82%	360 BEVs	946 kWh	0.41	8510 kWh	10%	2.6
20	8477 kWh	10%	10%	9313 kWh	88%	387 BEVs	803 kWh	0.32	8510 kWh	9%	2.1
21	8169 kWh	12%	12%	9187 kWh	91%	402 BEVs	677 kWh	0.26	8510 kWh	7%	1.7
22	7988 kWh	16%	16%	9257 kWh	94%	412 BEVs	747 kWh	0.28	8510 kWh	8%	1.8
23	7521 kWh	18%	18%	8867 kWh	96%	422 BEVs	357 kWh	0.13	8510 kWh	4%	0.8
24	6906 kWh	22%	22%	8420 kWh	98%	432 BEVs		0.00	8420 kWh		

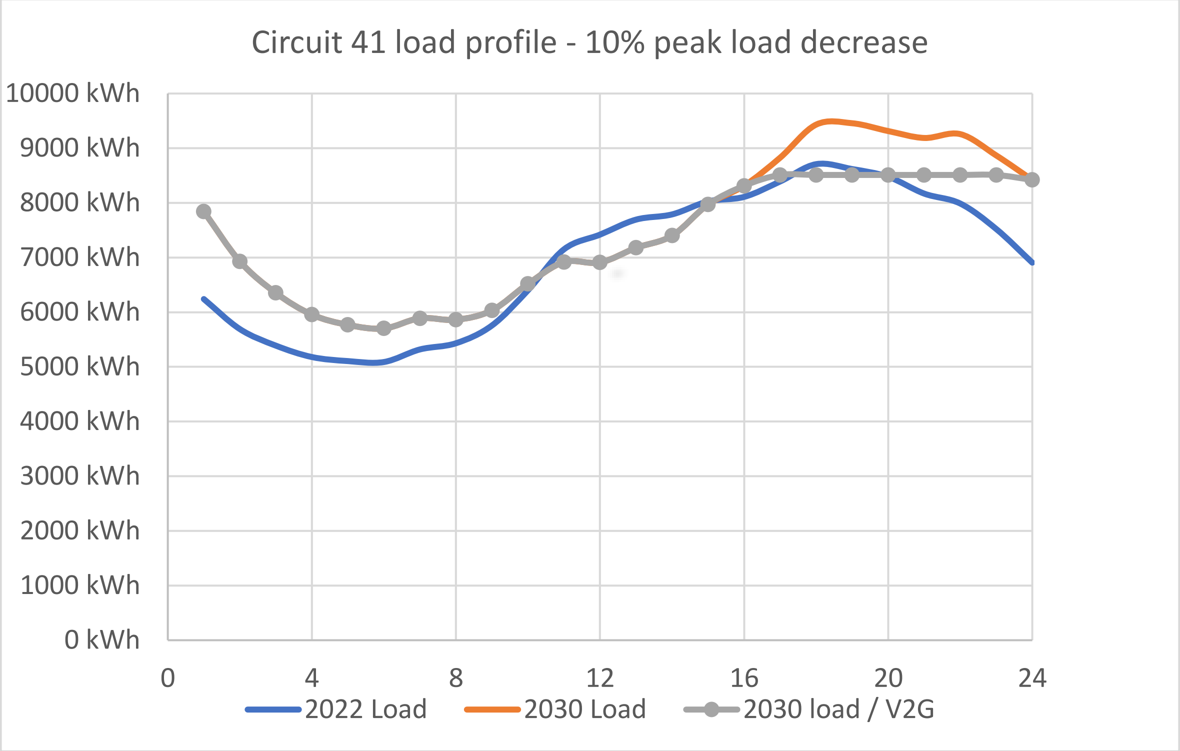


Figure 26. Circuit 41 load profile, 10 % peak load decrease scenario

5.2. Input parameters

5.2.1. Hourly load profile 2022

The simulation is based on hourly load profiles from distribution lines in San Diego County, where residential, commercial and industrial consumers are considered. These hourly load profiles have been found in the SDG&E Interconnection Map [57], where all transmission and distribution lines in the San Diego area are shown. For each distribution line/circuit, the load profile from 2022 can be downloaded. For the simulation, the maximum load values from each hour throughout 2022 from circuits 41, 445, 278, 1266 and 320 have been simulated to reflect the differences in the mix of consumers in distribution lines (see Table 5).

Table 5. 2022 simulated circuits hourly maximum values

Hour	Circuit 41 Load 2022	Circuit 445 Load 2022	Circuit 278 Load 2022	Circuit 1266 Load 2022	Circuit 320 Load 2022
1	6241 kWh	2200 kWh	4641 kWh	3727 kWh	4864 kWh
2	5692 kWh	2094 kWh	4070 kWh	3254 kWh	4471 kWh
3	5388 kWh	2047 kWh	3785 kWh	2930 kWh	4068 kWh
4	5180 kWh	2004 kWh	3451 kWh	2643 kWh	3716 kWh
5	5106 kWh	2016 kWh	3320 kWh	2485 kWh	3482 kWh
6	5089 kWh	2060 kWh	3235 kWh	2424 kWh	3341 kWh
7	5319 kWh	2125 kWh	3563 kWh	2410 kWh	3261 kWh
8	5432 kWh	2303 kWh	3999 kWh	2853 kWh	3444 kWh
9	5758 kWh	2127 kWh	3978 kWh	3007 kWh	3345 kWh
10	6402 kWh	2027 kWh	3599 kWh	2802 kWh	3279 kWh
11	7151 kWh	1884 kWh	3510 kWh	2809 kWh	3290 kWh
12	7420 kWh	2013 kWh	3429 kWh	2808 kWh	3256 kWh
13	7694 kWh	2178 kWh	3764 kWh	2981 kWh	3546 kWh
14	7789 kWh	2379 kWh	3918 kWh	3417 kWh	3871 kWh
15	8027 kWh	2471 kWh	4460 kWh	3960 kWh	4145 kWh
16	8110 kWh	2501 kWh	5054 kWh	4605 kWh	4623 kWh
17	8391 kWh	2710 kWh	5313 kWh	4923 kWh	4958 kWh
18	8708 kWh	2753 kWh	5634 kWh	5245 kWh	5430 kWh
19	8619 kWh	2781 kWh	6070 kWh	5604 kWh	5943 kWh
20	8477 kWh	2890 kWh	6217 kWh	5582 kWh	5914 kWh
21	8169 kWh	2845 kWh	5988 kWh	5352 kWh	6095 kWh
22	7988 kWh	2830 kWh	5822 kWh	5116 kWh	6037 kWh
23	7521 kWh	2656 kWh	5435 kWh	4620 kWh	5808 kWh
24	6906 kWh	2403 kWh	5096 kWh	4151 kWh	5402 kWh

The maximum load values represent the worst-case scenario throughout 2022. Highest load happens between August and September, when air conditioning load is increased due to the heat in summer. Obviously, the load is not the same in spring, summer, autumn and winter when different house loads are used depending on the climate (air conditioning, heating, lights consume, …). By modelling the highest possible load, the V2G penetration that is necessary is calculated to reduce peak load by a certain percentage. This accounts for the goal of V2G adoption in the future. By having this as a reference, if less penetration is met in the future, still peak shaving and minimization throughout the year could be achieved. If average load modelling was simulated, high peak loads wouldn't be taken into consideration and therefore the results obtained wouldn't be useful.

Figure 27 shows the 2022 daily load profiles of the circuits that are being simulated. As circuits 278 and 1266 have a larger distribution of residential consumer than the rest of the lines (Table 6), the graph exhibits a pronounced peak early in the morning.

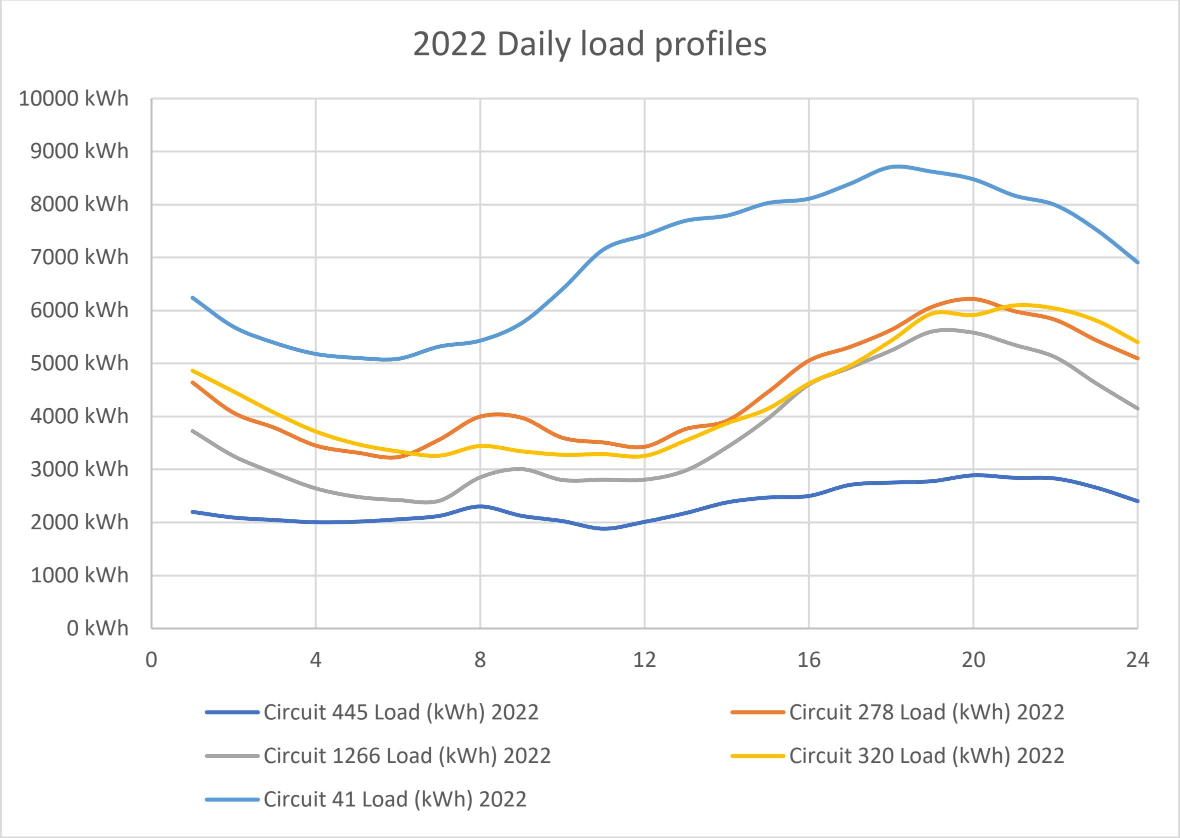


Figure 27. 2022 simulated circuits hourly maximum values load profile

5.2.2. Ciruits customers distribution

In order to know how many BEVs can be plugged in and how much energy can be discharged from the batteries, the number of residential customers in each circuit has to be known. In the SDG&E Interconnection Map [57], 2 excel spreadsheets accounting for the Grid Needs Assessment (GNA) and Distribution Deferral Opportunity Report (DOOR) have been downloaded. GNA is a list of grid needs identified from the distribution forecast and DDOR is a list of analyzed grid needs that would result in an investment requirement. Both in DDOR and GNA list, circuits 41, 445, 278, 1266 and 320 are listed as grid needs and the anticipated upgrade date is shown. Besides, in DDOR table, the number of consumers for each circuit is listed, see Table 6.

Table 6. Circuits customers distribution

	Circuit 41		**Circuit 445**		**Circuit 278**		**Circuit 1266**		**Circuit 320**	
Residential customers	4260	87%	787	83%	3772	97%	1879	96%	3199	98%
Commercial customers	624	13%	165	17%	80	2%	81	4%	67	2%
Industrial customers	1	0%	1	0%	25	1%	5	0%	7	0%
Total customers	**4885**	**100%**	**953**	**100%**	**3877**	**100%**	**1965**	**100%**	**3273**	**100%**

Table 7 indicates the maximun load per residential consumer in 2022 in each circuit. Comparing to the average residential customer load in the August 15 2019 CAISO system peak load in Figure 28 (orange line), the values are slightly similar, which contributes to verify that the values obtained from the SDG&E Interconnection map are correct.

Each residential consumer will be assumed to be a single household. This will be critical to determine the number of cars and BEV penetration in each distribution line.

Table 7. Peak consumption per customer

	Circuit 41	**Circuit 445**	**Circuit 278**	**Circuit 1266**	**Circuit 320**
Peak consumption per customer	2.0 kWh	3.7 kWh	1.6 kWh	3.0 kWh	1.9 kWh

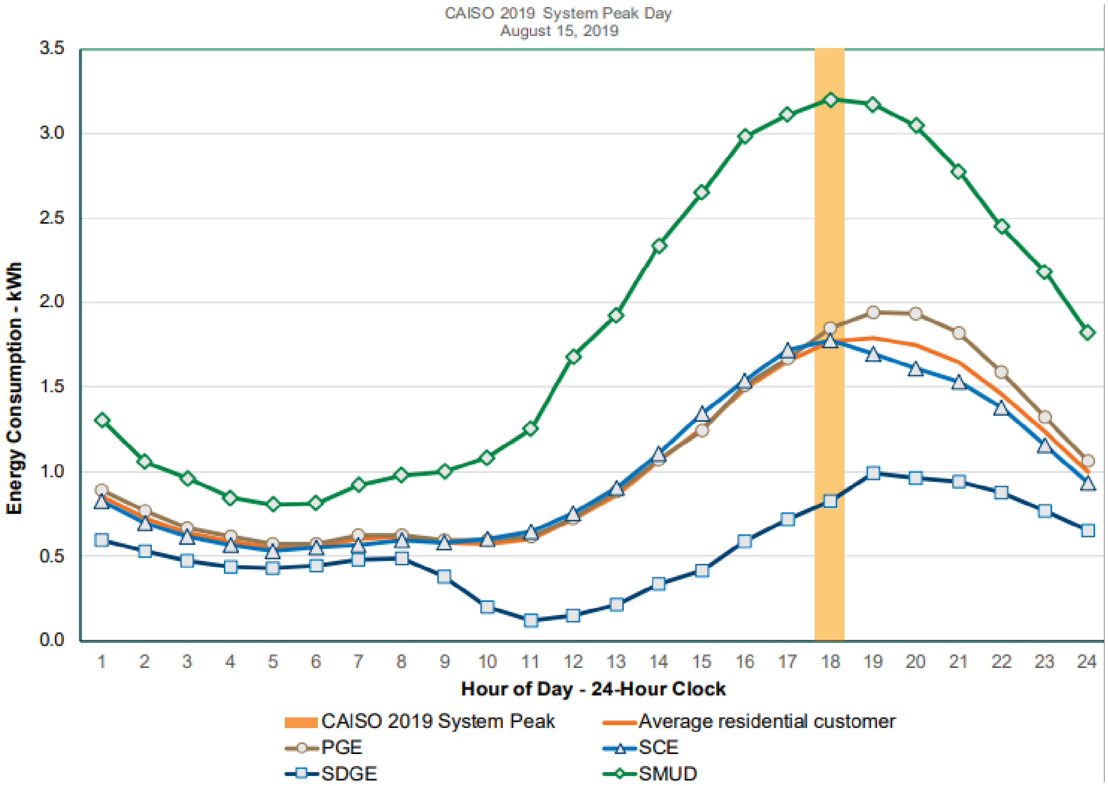


Figure 28. Electric load profiles by utility (August 15,2019), [58]

5.2.3. Circuits capacity

Following, Table 8 shows the load capacity of every modelling circuit. Based on the GNA excel sheet provided by the SDG&E Interconnection Map, the 2022 forecasted demand and facility loading factor for every circuit has been considered to obtain the circuit capacity. Big differences are observed in the facility loading of the circuits. For the **simulation** purpose, a very **important parameter called threshold** will be used in each circuit to obtain a **complete comparison** between circuits. The **threshold will be different in each circuit**.

Table 8. Circuits forecast demand, facility loading and capacity

	Circuit 41	Circuit 445	Circuit 278	Circuit 1266	Circuit 320
Forecast demand	8708 kW	2890 kWh	6217 kWh	5604 kWh	6095 kWh
Facility loading	84%	26%	50%	45%	49%
Circuit capacity	10369 kW	11115 kW	12434 kW	12454 kW	12439 kW

5.2.4. Threshold parameter

The threshold parameter is calculated with the Solver tool. This is explained in section 5.6 in detail.

As the data found in the SDG&E Interconnection map is confusing concerning the circuit capacity and circuit loading, the **threshold parameter** has been added **to reflect a realistic overloading limit of distribution circuits in the San Diego area**. An equal threshold for all circuits has not been used due to the significant difference in the facility loading of the circuits (from 26% to 84%, see Table 8). The threshold parameter will be used in **two different ways** (two cases).

In case 1, the **threshold** for each circuit will **vary based on a specific peak load decrease** in 2030. To enable a **comparison of the percentage of battery withdrawn** from each vehicle and the discharge rule between circuits, it has been decided to have an **identical maximum peak load decrease** for **all circuits**. This approach ensures consistency and facilitates the evaluation of the battery withdrawal and discharge patterns across different circuits.

In case 2, by **computing the threshold value with the Solver**, the objective is to **maximize** the peak load decrease by **constraining the % of battery withdrawn to 30% and the discharge rule to 1**. This is computed to acknowledge the potential of BEV to minimize peak load and to compare the output between circuits with different number of households.

5.2.5. 2022-2030 hourly assumed increase

In this section the 2022-2030 load increase parameter is calculated. The resulted factor is an hourly assumed increase used to scale the 2022 hourly load profile to 2030. First, four distinct scenarios predicting energy demand have been delineated, and the corresponding anticipated increases for each scenario have been computed. Subsequent to a comprehensive evaluation of the outcomes, the DRAFT scenario has been adopted as the load increase factor for the period 2022 to 2030.

To illustrate the imminent challenges facing California in the absence of concrete solutions, it is demonstrated ahead, that the 2030 Duck Curve will get worse, leading to a higher reliance on fast fossil-fuel power plants to meet evening demand.

The process followed to obtain the DRAFT load increase factor is shown in Figure 29.

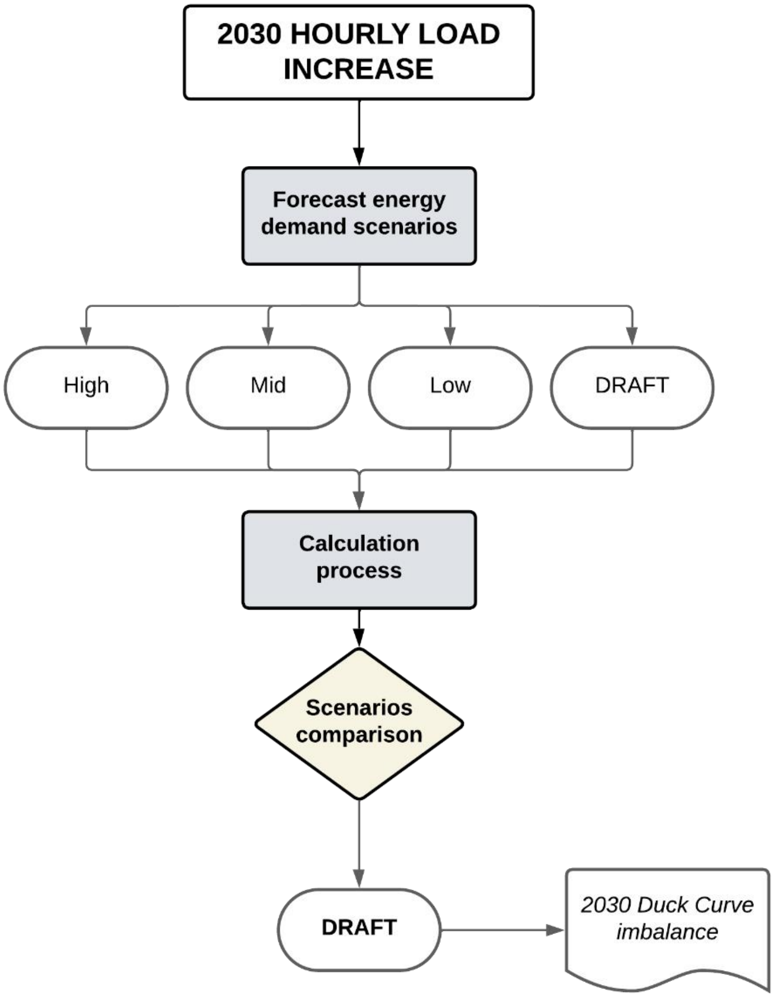


Figure 29. DRAFT load increase factor calculation

5.2.5.1. Forecast energy demand scenarios

The 2030 EV simulation for the San Diego area is modelled in alignment with the transportation electrification and clean energy generation goals set by the State of California for 2030. To do so, 2022 load profiles have been scaled according to the **CEC 2021 Integrated Energy Policy Report (IEPR) [62]**. The 2021 IEPR is a comprehensive report released by the California Energy Commission (CEC) that assesses the state's energy policies and provides recommendations for future energy policy direction. It covers a wide range of energy-related topics, including renewable energy increase adoption, greenhouse gas reduction targets, energy infrastructure, and energy resilience. The report includes policy recommendations for promoting a clean, reliable, and affordable energy future for California, such as increasing investment in EV charging infrastructure and supporting the development of offshore wind energy.

The forecast made includes **four** energy demand scenarios [62],

- **High-energy demand** case incorporates relatively high economic/demographic growth, relatively low energy rates, higher adoption of zero-emission vehicles (ZEVs), lower self-generation, and climate change impacts.
- **Low-energy demand** case includes lower economic/demographic growth, higher assumed rates, low adoption of ZEVs, higher self-generation impacts.
- **Mid-energy demand** case uses input assumptions at levels between the high and low cases.
- Besides these 3 scenarios, the report covers the **DRAFT 2021 IEPR**, which follows the California Air Resources Board goal of 8 million ZEV in 2030 to meet air quality restrictions and climate goals for 2030 set on the Executive Orders mentioned in section 2.3.

The IEPR-Volume IV [62], assess the California Energy Demand Forecast based on baseline demand forecasts and hourly demand forecast files. In both cases, an analysis of the state load (CAISO) and California utilities load (PGE, SCE and SDGE) has been concluded. For the purpose of this work, **only the SDGE hourly demand** forecast files have been taken into **consideration**. Nevertheless, the IEPR provides useful hourly demand forecast information for the rest of California.

The CEC predicts how much electricity people will use in the next 10 years. They also look at adoption forecast for Behind-The-Meter photovoltaic systems (BTM PV), electric cars, and energy-efficient technology. They incorporate new information about the economy and people's habits, and also updated their predictions for energy storage and photovoltaic systems.

Although the forecast includes **Additional Achievable Energy Efficiency and Additional Achievable Fuel Savings** which reduce final load thanks to improvement in future infrastructure efficiency, for the simulation purpose it has been **neglected** in order to assume a higher increase in the forecast and obtain more **conservative results**.

5.2.5.2. Calculation process

The procedure here explained has been used to obtain the assumed increase in the **4 possible scenarios**. Data exported from the **CEC 2021 IEPR** start in **January 2022 and ends in December 2035** and is **hourly distributed**. The Baseline Net Load from 2022 to 2030 is computed as "UNADJUSTED_CONSUMPTION + PUMPING + CLIMATE_CHANGE + LIGHT_EV + MEDIUM_HEAVY_EV + TOU_IMPACTS + OTHER_ADJUSTMENTS + BTM_PV + BTM_STORAGE_RES + BTM_STORAGE_NONRES".

In this section the **DRAFT** scenario forecast is **explained**. The process is identical for the other 3 scenarios. In Table 9, the **maximum values** from 2022 to 2030 at every hour of the day have been calculated by using Excel formula "**MAX.IFS**", using hour and year as criteria selection. Yearly increase has been calculated at every hour of the day in Table 9. Total increase at each hour has been obtained by multiplying all increases unities. Upon analysis, it is evident that the **peak load** occurs at **19h** in the San Diego area, highlighted in yellow.

Table 9. SDG&E Hourly peak values forecast in MW by CEC

Hour	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	2554	2643	2732	2818	2896	2973	3050	3123	3210
2	2411	2480	2549	2616	2682	2745	2807	2867	2936
3	2310	2361	2415	2466	2518	2569	2618	2669	2724
4	2304	2344	2387	2428	2474	2519	2560	2604	2650
5	2433	2468	2505	2542	2583	2626	2666	2705	2748
6	2664	2698	2738	2774	2815	2859	2897	2939	2985
7	2763	2796	2834	2863	2899	2942	2979	3021	3060
8	2809	2836	2856	2885	2912	2944	2978	3005	3031
9	2835	2840	2858	2879	2907	2921	2929	2949	2972
10	2900	2891	2908	2916	2946	2943	2922	2930	2953
11	2966	2939	2926	2917	2907	2899	2887	2877	2869
12	3088	3046	3019	2995	2972	2949	2923	2899	2875
13	3328	3284	3257	3231	3206	3183	3155	3129	3104
14	3495	3458	3437	3416	3397	3380	3359	3339	3321
15	3961	3943	3940	3936	3935	3936	3935	3933	3933
16	4041	4042	4055	4065	4080	4097	4112	4127	4142
17	4191	4209	4237	4260	4288	4321	4350	4379	4408
18	4257	4295	4341	4379	4424	4473	4519	4564	4611
19	4372	4421	4476	4523	4576	4633	4688	4742	4797
20	4206	4254	4308	4355	4407	4462	4516	4567	4621
21	3876	3929	4002	4058	4136	4180	4225	4284	4359
22	3518	3588	3658	3734	3804	3870	3938	4003	4077
23	3113	3188	3263	3325	3391	3461	3530	3601	3670
24	2836	2918	3005	3084	3159	3234	3305	3377	3458

Table 10 indicates a non-uniform hourly distribution of load increase throughout the years. This is explained by looking at BTM-PV and Light EV load increases from 2022 to 2030 in

Table 11 and Table 12 respectively. BTM-PV shows an increase only during daytime, whereas light EV load pattern follows another distribution, greater increase during the daytime than during the nighttime, aligning with solar energy generation.

Table 10. SDG&E yearly and total load increase in %

Hour	2023	2024	2025	2026	2027	2028	2029	2030	Total increase
1	3.5%	3.4%	3.1%	2.8%	2.7%	2.6%	2.4%	2.8%	**25.66%**
2	2.8%	2.8%	2.6%	2.5%	2.3%	2.3%	2.1%	2.4%	**21.76%**
3	2.2%	2.3%	2.1%	2.1%	2.0%	1.9%	2.0%	2.0%	**17.88%**
4	1.7%	1.8%	1.7%	1.9%	1.8%	1.6%	1.7%	1.7%	**14.98%**
5	1.5%	1.5%	1.5%	1.6%	1.7%	1.5%	1.4%	1.6%	**12.97%**
6	1.3%	1.5%	1.3%	1.5%	1.6%	1.3%	1.5%	1.5%	**12.06%**
7	1.2%	1.4%	1.0%	1.3%	1.5%	1.2%	1.4%	1.3%	**10.72%**
8	1.0%	0.7%	1.0%	0.9%	1.1%	1.1%	0.9%	0.9%	**7.91%**
9	0.2%	0.6%	0.7%	1.0%	0.5%	0.3%	0.7%	0.8%	**4.81%**
10	-0.3%	0.6%	0.2%	1.0%	-0.1%	-0.7%	0.3%	0.8%	**1.83%**
11	-0.9%	-0.4%	-0.3%	-0.3%	-0.3%	-0.4%	-0.3%	-0.3%	**-3.27%**
12	-1.4%	-0.9%	-0.8%	-0.8%	-0.7%	-0.9%	-0.8%	-0.8%	**-6.87%**
13	-1.3%	-0.8%	-0.8%	-0.8%	-0.7%	-0.9%	-0.8%	-0.8%	**-6.71%**
14	-1.1%	-0.6%	-0.6%	-0.6%	-0.5%	-0.6%	-0.6%	-0.6%	**-5.00%**
15	-0.5%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	**-0.70%**
16	0.0%	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%	0.4%	**2.50%**
17	0.4%	0.7%	0.5%	0.7%	0.8%	0.7%	0.7%	0.7%	**5.19%**
18	0.9%	1.1%	0.9%	1.0%	1.1%	1.0%	1.0%	1.0%	**8.31%**
19	1.1%	1.3%	1.1%	1.2%	1.2%	1.2%	1.1%	1.2%	**9.72%**
20	1.1%	1.3%	1.1%	1.2%	1.3%	1.2%	1.1%	1.2%	**9.87%**
21	1.4%	1.8%	1.4%	1.9%	1.1%	1.1%	1.4%	1.7%	**12.46%**
22	2.0%	2.0%	2.1%	1.9%	1.7%	1.8%	1.6%	1.9%	**15.89%**
23	2.4%	2.4%	1.9%	2.0%	2.1%	2.0%	2.0%	1.9%	**17.89%**
24	2.9%	3.0%	2.6%	2.4%	2.4%	2.2%	2.2%	2.4%	**21.92%**

Table 11. SDG&E Behind the Meter Photovoltaic hourly load forecast in MW

Hour	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	-89	-97	-105	-112	-120	-127	-135	-143	-150
9	-378	-411	-444	-475	-507	-536	-566	-597	-628
10	-627	-677	-723	-766	-811	-859	-907	-956	-1005
11	-723	-780	-833	-883	-935	-990	-1046	-1102	-1159
12	-778	-840	-896	-950	-1006	-1065	-1125	-1185	-1246
13	-779	-840	-897	-950	-1007	-1065	-1126	-1186	-1247
14	-695	-750	-801	-848	-899	-951	-1005	-1059	-1113
15	-513	-553	-591	-626	-663	-702	-741	-781	-821
16	-265	-286	-305	-323	-343	-362	-383	-403	-424
17	-13	-14	-15	-16	-17	-18	-18	-19	-20
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0

Table 12. SDG&E Hourly Light EV load forecast in MW

Hour	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	85	143	202	256	299	335	377	415	459
2	66	110	155	197	231	258	290	320	354
3	44	74	105	133	155	174	196	216	239
4	28	47	66	85	99	111	125	138	153
5	18	30	42	54	63	71	80	88	98
6	10	18	25	32	38	43	48	54	60
7	13	23	34	45	55	65	74	85	95
8	25	44	64	87	106	125	144	165	186
9	36	64	93	126	154	182	211	243	275
10	40	70	103	139	171	202	234	269	305
11	38	68	99	134	165	195	225	259	294
12	34	61	89	121	148	175	203	234	265
13	33	58	86	115	141	166	192	221	251
14	30	54	78	106	130	153	177	204	231
15	29	52	76	102	125	147	169	195	221
16	26	46	67	89	109	128	147	168	191
17	26	45	65	87	105	123	141	161	182
18	28	48	69	91	110	127	145	164	185
19	33	57	82	107	128	146	166	187	210
20	35	59	85	110	130	148	168	188	210
21	37	62	88	113	133	151	170	189	210
22	44	74	105	135	158	178	201	222	247
23	48	81	114	145	170	190	214	235	261
24	74	123	173	219	255	283	316	347	382

Scenarios comparison

In APPENDIX, a comparison of the scenarios is presented. Appendix I reflect the differences from 2022 to 2030 in terms of the light EV load, and BTM-PV load in Appendix II. These tables provide a comprehensive overview of the percentage increases from 2022 to 2030, allowing for a comparison across all four scenarios. Main conclusions from these tables are shown in Table 13.

Table 13. BTM-PV and light duty EV peak values percentage increase from 2022-2030, DRAFT, low, mid and high load scenarios

Increase % for peak values 2022-2030	DRAFT	LOW	MID	HIGH
BTM-PV load at 13	60%	78%	60%	25%
Light duty EV load at 19	629%	339%	500%	678%

Following, Figure 30 shows SDG&E load for 2030 for the 4 different possible scenarios. It is evident from the figure that low scenario exhibits a load decrease during mid-day due to a higher increase in PV generation compared to the other scenarios. On the other hand, high demand scenario shows a higher load on behalf of a lower BTM-PV energy generation. As mentioned before, differences in scenarios are mainly due to the variation of BTM-PV load and light duty EV load across the scenarios.

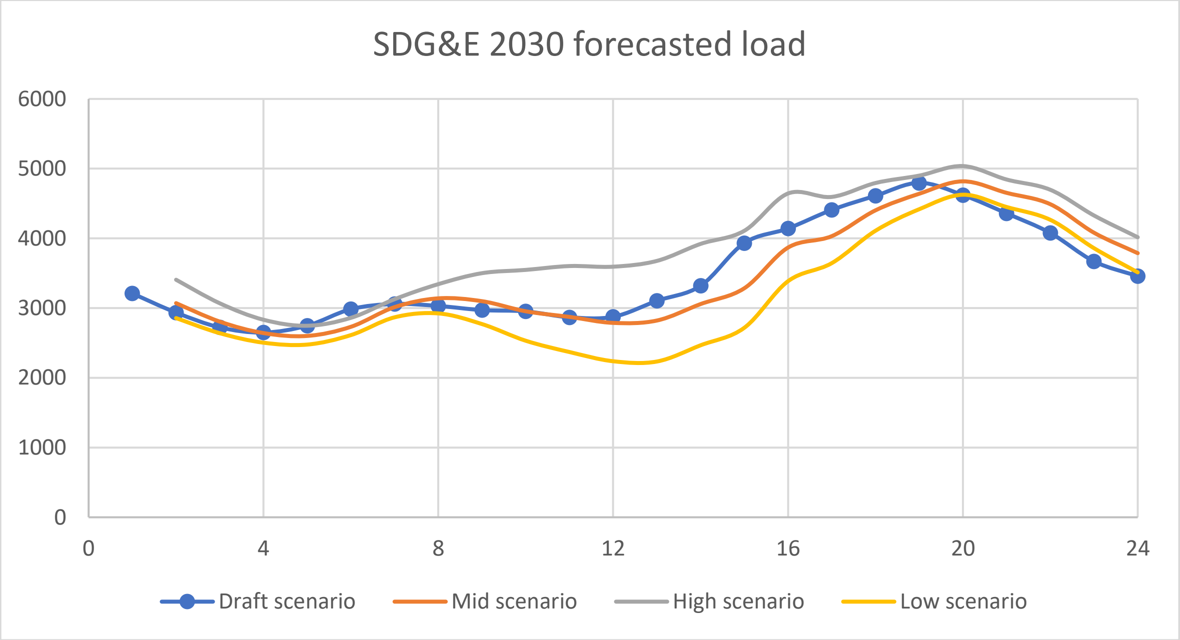


Figure 30. SDG&E 2030 hourly forecasted peak load, DRAFT, low, mid and high load scenarios

5.2.5.3. DRAFT assumed increase 2030

Despite MID and DRAFT scenarios follow a similar assumed increase distribution from 2022 to 2030, DRAFT scenario has been chosen as the modelling assumed increase for each circuit in SDGE area as an average distribution. Because DRAFT scenario was carried out by the CEC in collaboration with the CARB [63], which follows the goal of 8 million ZEV driving in California by 2030 (see section 2.3), DRAFT scenario seems a more accurate scenario than the mid scenario. DRAFT scenario is the most conservative and accurate scenario among all four scenarios.

In conclusion, the hourly assumed increase that will be taken into consideration to approximate the load in 2030 of the simulation circuits is presented in Table 14. Comparing the data from 2022 to 2030, there is a total increase of 9.72% in the peak load at 19h.

Table 14. 2022-2030 hourly load increase used in the simulation

Hour	2022-2030 increase %
1	25.66%
2	21.76%
3	17.88%
4	14.98%
5	12.97%
6	12.06%
7	10.72%
8	7.91%
9	4.81%
10	1.83%
11	-3.27%
12	-6.87%
13	-6.71%
14	-5.00%
15	-0.70%
16	2.50%
17	5.19%
18	8.31%
19	9.72%
20	9.87%
21	12.46%
22	15.89%
23	17.89%
24	21.92%

Duck Curve 2030

Figure 31 displays the load profile for DRAFT scenario in SDGE area. Interestingly, load decreases during the day (from 10h to 15h) due to the increase in PV generation (see

Table 11). This indicates that the issue of the Duck Curve, which represents the imbalance between electricity supply and demand, will worsen in the future. In particular, a steeper ramp is observed starting around 16h-17h hours, as depicted in the figure. Additionally, the increase in load during nighttime can be attributed to building electrification. During this period, the usage of heating systems, air conditioning units, and electric stoves/ovens is more prevalent, leading to a higher demand for electricity.

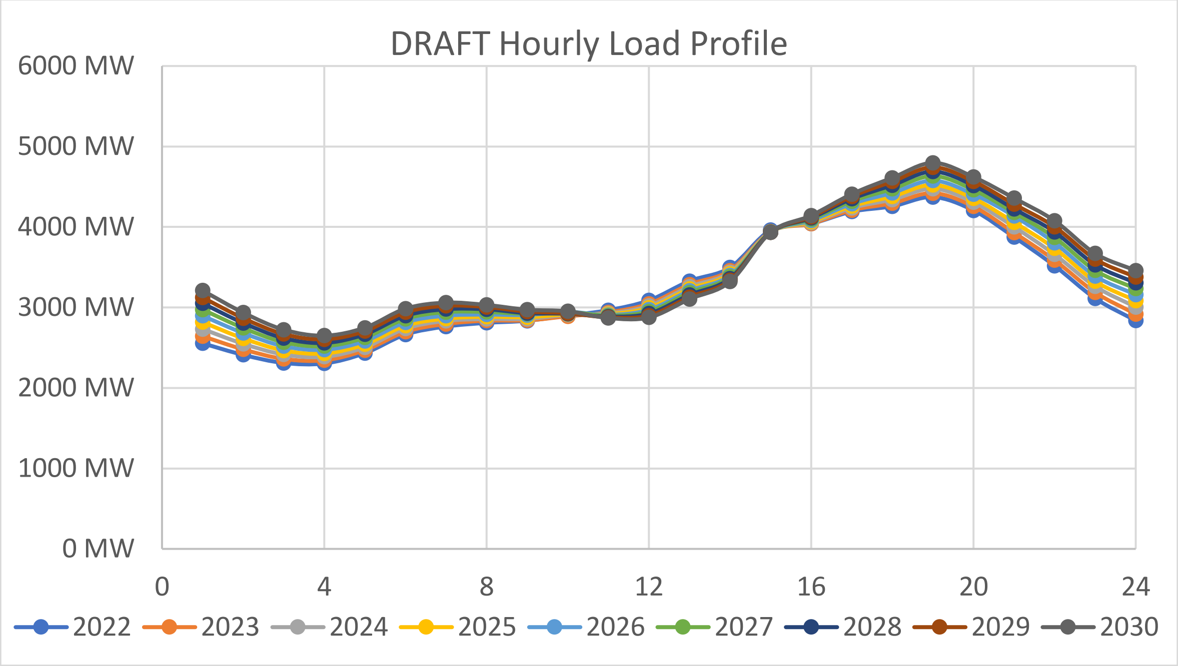


Figure 31. DRAFT SDG&E hourly peak values forecast profile

5.2.6. Load increase parameter

The load increase value accounts for the **increase** that the user wants to **add** to the modelling **2030 DRAFT assumed increase** by the CPUC. To simplify the simulation, a 0% value has been assumed.

5.2.7. Car home status

Besides knowing the penetration of BEV, the fact that not all BEVs will arrive home at the same time has to be taken into consideration. **Cars home status in San Diego** has been assumed to be the **same** distribution as for the entire **US**. According to the **National Household Travel Survey** conducted by the Federal Highway Administration [65], two different surveys have been used, **Trip End Time for Work trip purposes and Trip End Time for Home trip purposes**, see APENDIX V.

Work customers and home customer arrival time are shown in Figure 32 and Figure 33. Whereas Figure 32 indicates that most employers arrive work by 7-8, Figure 33 displays that most workers arrive home between 16 and 18, 8-9 hours later approximately.

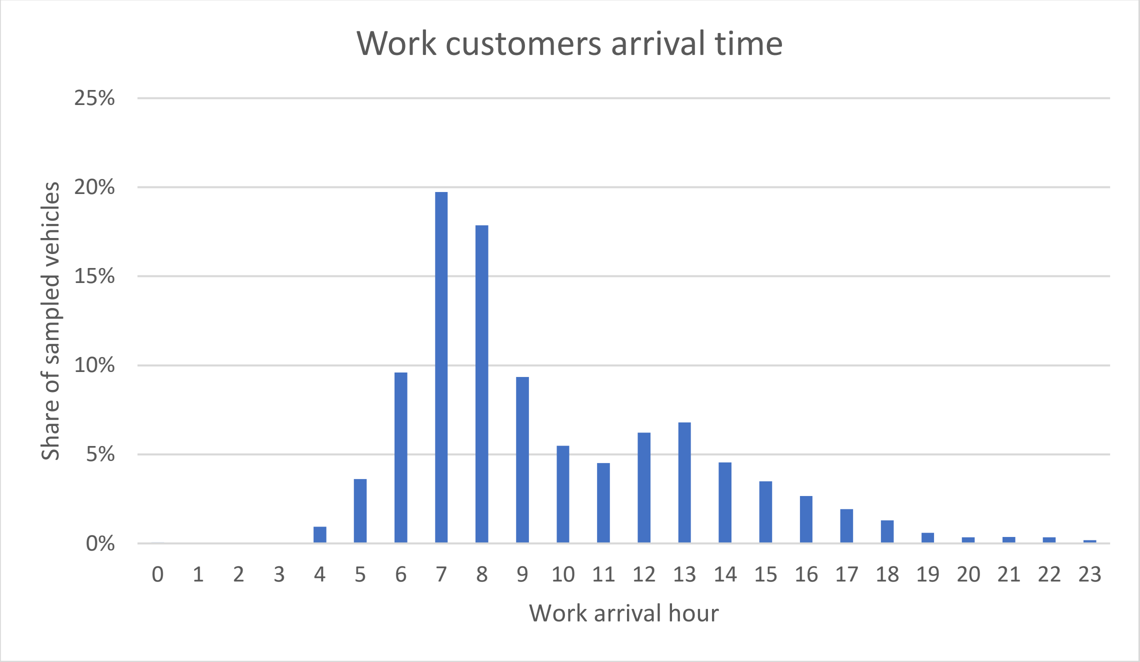


Figure 32. Work customers arrival time

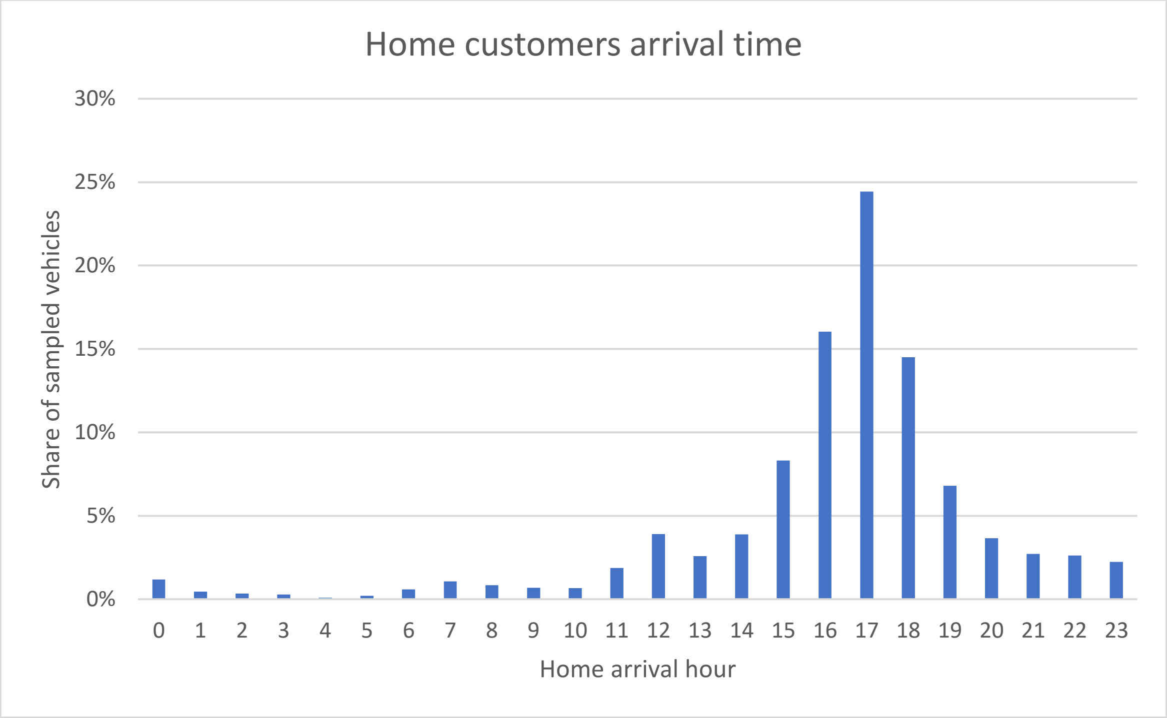


Figure 33. Home customers arrival time

To obtain the final vehicles home status, a **combination of both distributions** has been considered. First, the **net change in car percentage at home** is obtained, see Figure 34. From 15h to 3h net change is positive which means that cars are arriving home between this time frame, but after 4h, net starts to be negative which implies that cars are leaving home.

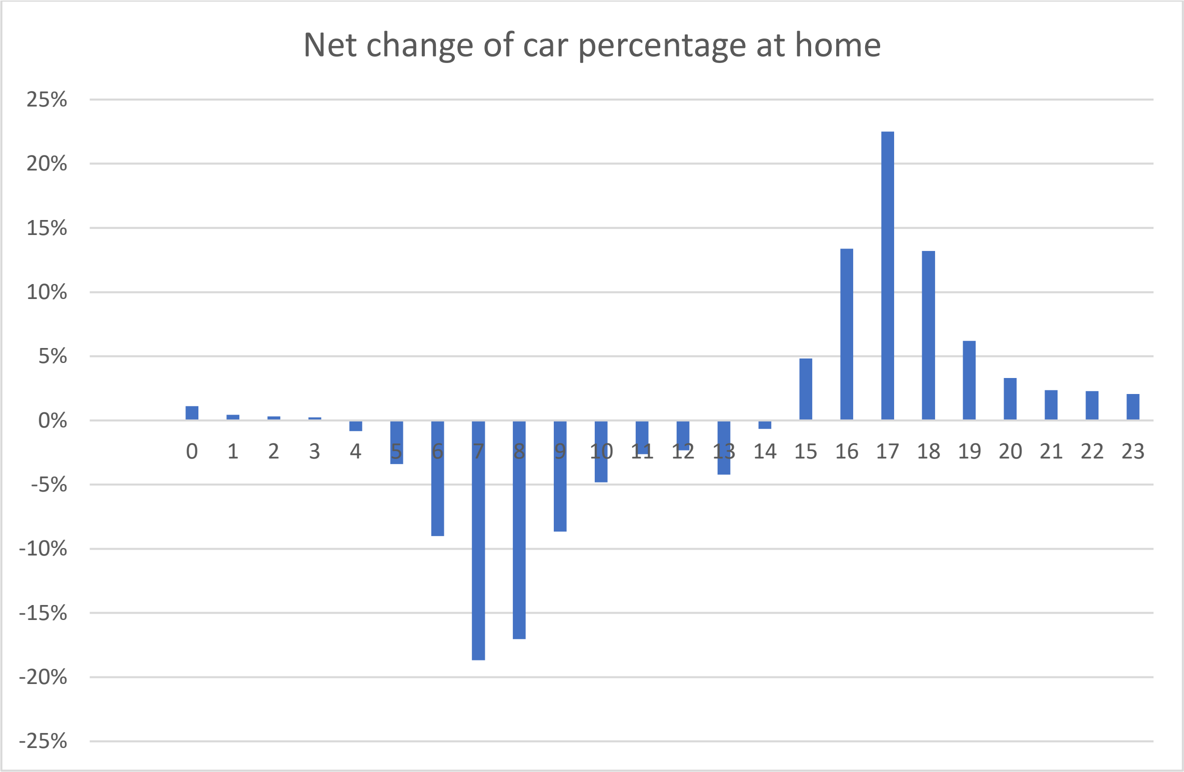


Figure 34. Net change of car percentage at home

Therefore, the final home status is based on the fact that at 3h, 100% of cars will be staying at home. Then, the **final distribution is estimated** by adding the net change in every hour based on **100% of cars at home at 3h in red color**, see Table 15 (Ex. home status at 4h, will be the home status at 3h plus the net change at 4h / 100% minus 1% is 99%).

Table 15. Final home status calculation

Trip End Time (HHMM)	Home work status	Work home status	Net change in car % home	Home Status
24	0%	1%	1%	99%
1	0%	0%	0%	99%
2	0%	0%	0%	100%
3	0%	0%	0%	100%
4	1%	0%	-1%	99%
5	4%	0%	-3%	96%
6	10%	1%	-9%	87%
7	20%	1%	-19%	68%
8	18%	1%	-17%	51%
9	9%	1%	-9%	42%
10	5%	1%	-5%	38%
11	5%	2%	-3%	35%
12	6%	4%	-2%	33%
13	7%	3%	-4%	28%
14	5%	4%	-1%	28%
15	3%	8%	5%	33%
16	3%	16%	13%	46%
17	2%	24%	23%	68%
18	1%	15%	13%	82%
19	1%	7%	6%	88%
20	0%	4%	3%	91%
21	0%	3%	2%	94%
22	0%	3%	2%	96%
23	0%	2%	2%	98%

Figure 35 shows the car home status that will be used in the simulation (weekdays). The model doesn’t discriminate between weekdays and weekends due to lack of weekend data. Assuming this distribution refers to EV population, interestingly, 30% of EVs will stay at home and won't be driven during the day.

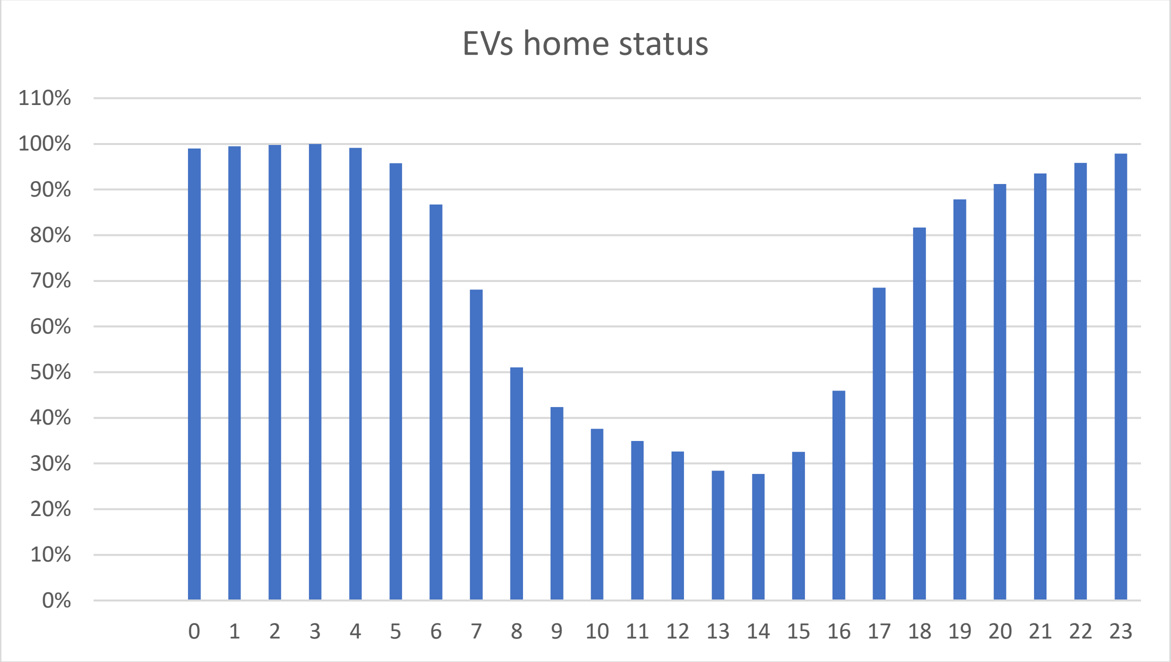


Figure 35. EVs home status percentage

5.2.8. Battery size pack 2030

The assumptions made on the EV characteristics for 2030 are also based on simulation parameters from [38]. Compared to 2022, it can be appreciated that the size of BEV batteries has increased by a factor of 2.2.

Table 16. BEV battery size assumptions for 2030

	Battery size
Battery Electric Vehicle	88 kWh

5.2.9. Discharge efficiency

The simulation relies on the assumption that the discharge efficiency is 90%, based on [3].

5.2.10. V2G availability

In this section, the assumption on the maximum amount of BEV with V2G capabilities that are available is computed. This is a **fixed** parameters accounting for the **maximum V2G availability in each circuit**. The **assumed V2G availability** value has been calculated with the following **process**:

Nº cars per household

Based on [61], California is the 5th state in the US with the highest percentage of households with at least one vehicle (93%) and the **average number of vehicles per household is 2.3 vehicles**.

2030 California BEV population

For the modelling purpose, the evolution of the number of motor vehicles registered in **California** in 2030 is **based on the overall evolution in the US** from 1990 to 2021 [64]. Based on the increase of vehicles since 1990 of 1.5% annually, 35.4 million vehicles are assumed to be driving around California by 2030. Figure 36 shows the light duty vehicle stock forecast of California and indicates a similar value for the mid demand scenario.

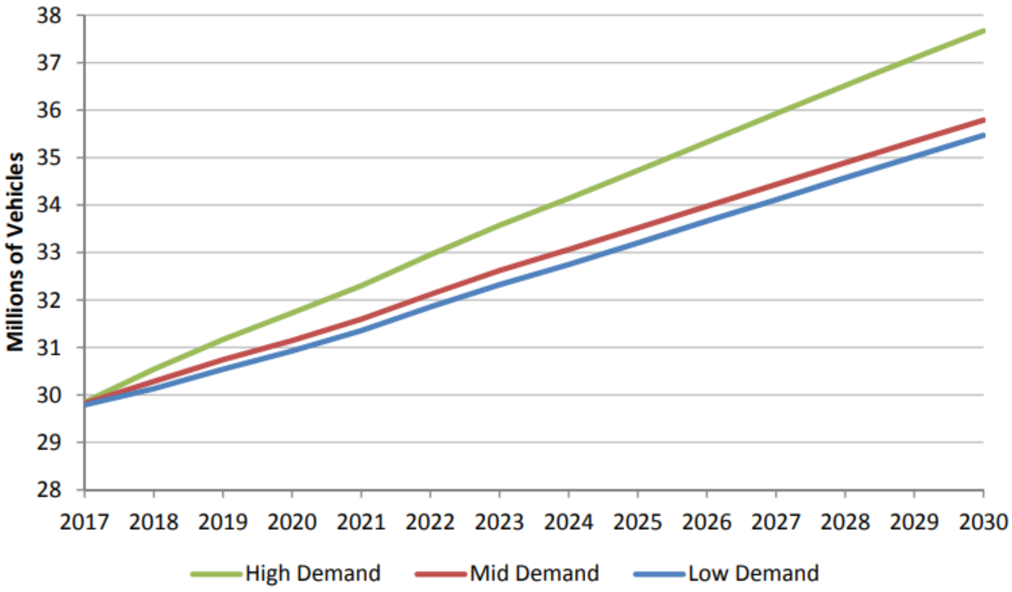


Figure 36. Light duty stock forecast of California, [5]

The CEC Integrated Energy Policy Report mid case estimations for 2030 have been used for the modelling of V2G in San Diego area [4], see Table 17, and It is assumed that based on [4], in 2030 5.3 million BEVs will be driving in California. It indicates a 400% increase in the BEV fleet in California since 2022, which will represent a BEV penetration of 14.9 % of total motor vehicles in California.

Table 17. Integrated Energy Policy Report EV estimations for 2030

ZEV population 2030	PEV / HFCEV	PHEV / BEV	BEV population 2030
7.9 millions ZEV	95% / 5%	30% / 70%	**5.3 millions BEV**

Assuming the values mentioned above for 2030, in circuit 41 there will be a fleet of 1460 BEVs out of 9798 cars, Table 18.

Table 18. Number of BEVs in circuit 41 in 2030

Number of households in circuit 41	Average number of cars per household in California	Number of cars in circuit 41 2030	Percentage of BEVs in California 2030	Number of Evs in circuit 41 2030
4260	2.3	9798 cars	14.9%	**1460 BEVs**

It has to be mentioned that the number of cars in 2030 doesn't increase, due to the fact that, concerning the distribution line 41, it can't be assured that more households or meters will be placed in the future.

V2G availability

As far as V2G availability in 2030, the assumption on home charging infrastructure in California displayed in

Table 19, will be used to calculate how many bidirectional chargers will be available in each circuit and to obtain the maximum discharge power of the bidirectional charger [38]. The bidirectional charger will limit the rate of energy discharge from the battery. Although the maximum power capacity of the battery was higher than the power of the charger, the discharge power will be limited to the charger.

Table 19. 2030 California home charging infrastructure distribution

No charger	10%
AC Level 1-1.4 kW	20%
AC Level 2-7.2 kW (uncontrolled)	10%
AC Level 2-7.2 kW (V1G)	30%
AC Level 2-7.2 kW V2G	20%
DC-24 kW V2G	10%
V2G availability 2030	**30%**
Chargers discharge power	**7.2 kW**

V2G availability in 2030 is the sum of V2G chargers availability in 2030 which is **30%**. Although, the maximum power of the bidirectional chargers should be calculated according to a 20% of 7.2 kW chargers and 10% of 24 kW, the power station discharge has been assumed to be 7.2 kW, so a more conservative approach is being simulated. As a close approximation to it, The Quasar bidirectional charger from Wallbox is 7.4 kW AC and is already commercially available [34].

<u>**Assumed V2G availability**</u>

The assumed V2G availability in California in 2030 is supposed to be the percentage of BEVs in California 2030 (14.9%) times the V2G chargers availability (30%) which **results in 4.5%.**

Table 20 shows the maximum amount of BEVs that can participate in V2G strategies in circuit 41 in 2030.

Table 20. Number of BEVs with V2G capabilities in circuit 41 in 2030

Number of BEVs in circuit 41 2030	V2G availability 2030	Number of BEVs with V2G capabilities 2030	% V2G 2030
1460 BEVs	30%	**441 BEVs**	4.5%

5.3. Equations

In this section, the equations used in the Model are presented.

Equation 1. Fixed increase

$$Fixed\ increase_t = Assumed\ increase_t * (1 + Load\ increase)$$

Equation 2. 2030 load

$$2030\ Load_t = 2022\ Load_t * (1 + Fixed\ increase)$$

The number of BEV availables to discharge energy follows the equation:

Equation 3. BEVs availability

$$BEV\ available_t = BEV\ V2G\ 2030 * \%\ cars\ home\ status_t$$

The 2030 Load V2G, equals to the 2030 Load but takes into consideration the circuit's threshold. This means that, the final load will be always lower than the circuit's capacity times the threshold.

Equation 4. 2030 load with V2G characteristics

$$2030\ load\ V2G_t = 2030\ load_t \qquad if\ 2030\ load_t < Circuit\ capacity * Threshold$$

$$2030\ load\ V2G_t = Circuit\ capacity * Threshold \qquad if\ 2030\ load_t > Circuit\ capacity * Threshold$$

The difference between the 2030 Load and the 2030 Load / V2G is the energy to be discharged from all BEVs.

Equation 5. Energy to be discharged from BEV to meet the threshold

$$Energy\ discharged_t = 2030\ Load_t - 2030\ Load\ V2G_t$$

Peak load decrease is calculated:

Equation 6. Peak load decrease based on the initial 2030 load

$$Peak\ load\ decrease_t = \frac{2030\ Load_t - 2030\ Load\ V2G_t}{2030\ Load_t}$$

Ultimately, based on a fixed number of residential consumers/households (4260), % V2G (4.5%), power station discharge (7.2 kW), 2022 circuit load and a 2022-2030 load assumed increase from the CPUC in the San Diego area, the Model computes the maximum discharge rule to meet the threshold (*case 1: 10% peak load decrease / case 2: MAX peak load decrease*) and the percentage of each BEV battery that is withdrawn in the worst case scenario in 2030 in a distribution line in San Diego.

Following the two outputs of the model are explained.

5.4. Outputs

5.4.1. Discharge rule

One of the most important outputs of the model is the hourly discharge rule. Once how many BEV are available to inject energy back to the grid is calculated, the discharge rule will indicate how much energy per BEV has to be withdrawn in one hour depending on the total energy that is needed to meet the threshold. In the equation below, the maximum power discharge is the bidirectional charger power taking the discharge efficiency into consideration. The maximum power discharge is the maximum amount of energy that a BEV can discharge within 1 hour.

Equation 7. Discharge rule calculation

$$Discharge\ rule_t = \frac{Energy\ discharged_t}{BEV\ availables_t * Max\ power\ discharge}$$

If the computed discharge rule is greater than 1, it indicates that more energy is being withdrawn from the batteries than the maximum possible energy that can be discharged, which is determined by the maximum power discharge capability. In such a scenario, it is not possible for the batteries to deliver such a level of discharge. To highlight this impossibility, the corresponding cells in the table will be marked in red, indicating an invalid condition.

Then the energy discharged per BEV per hour is calculated by multiplying the max power discharge and the discharge rule. This simple calculation takes into account that all BEV will be plugged into the grid and whenever the discharge rule allows it, BEV will start delivering energy into the grid.

Equation 8. Energy discharged per BEV based on the discharge rule and the chargers real discharge power

$$Energy\ discharged\ per\ BEV_t = Max\ power\ discharge * discharge\ rule_t$$

5.4.2. Battery % withdrawn

Another key output of the simulation is the percentage of each BEV battery that is withdrawn.

Equation 9. Percentage of battery discharged according to the assumed battery size for 2030

$$\%\ battery\ withdrawn = \frac{\sum_{t=1}^{24} Energy\ discharged\ per\ BEV\ per\ hour}{Battery\ size}$$

Following CCE’s business idea (see section 2.7) of discharging a little amount of energy from BEV to reduce peak load and minimize investments for distribution & transmission lines upgrades due to line overloading in the future, a maximum of 30% battery discharged value has been decided to follow CCE proposal.

5.5. Assumptions

The modelling is based on three important assumptions.

- The **first one** is that cars arrive home fully charged (100 %) thanks to the charge provided in parking lots during the day with solar energy. Although it is true that because of the trip from work to home, the State of Charge of batteries when they arrive home is not possible to be 100%, an approximate calculation of the percentage of the battery withdrawn from each EV has been calculated for all scenarios. In this model only the discharge of batteries is being simulated to prove the potential of EVs as mobile storage devices to reduce peak load during critical times and therefore reduce the strain in the electrical grid and reduce expected distribution and transmission upgrades (see section 2.5) in the following years in California.

- The **second assumption** is that the area used for the simulation will be San Diego County. This is so, because reliable data has been found regarding hourly load profiles and residential population in distribution lines.

- The **third one** is that for the modelling purpose, only BEVs have been taken into consideration due to their ability to discharge energy from their batteries thanks to a greater battery size than Plug-in Hybrid Electric Vehicles. PHEV are not considered to withdraw energy from batteries.

5.6. Scenarios and Solver tool

As mentioned in section 5.2.4, the threshold parameter will be used in two different ways. Firstly, the threshold for each circuit with be computed based on an equal 10% peak load decrease for all circuits in 2030. Secondly, by adjusting the threshold value, the objective is to maximize the peak load decrease while constraining the percentage of battery withdrawal to 30% and maintaining a discharge rule of 1.

As the 2030 load / V2G depends on the circuit's capacity and the according threshold, the final peak load decrease will vary with the threshold chosen.

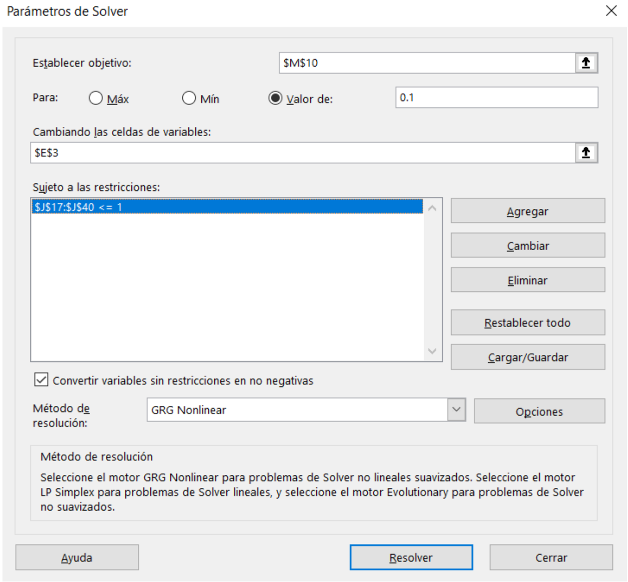
5.6.1. Case 1: Equal peak load decrease for all circuits

Based on the fixed values for all circuits presented in Table 21, the Excel tool "Solver" has been used to obtain the required threshold, the maximum discharge rule and the percentage of batteries withdrawn in each circuit according to the equations presented in section 5.3 and 5.4.

Table 21. Equal peak load decrease scenario: Fixed values used for the Excel's Solver

Load increase	0%
V2G availability	4.5%
Power station discharge	7.2 kW
Objective value: Peak load decrease	10%

The objective value of 10% maximum peak load decrease for all circuits is obtained by changing the value of the threshold required with the Solver calculation, see Figure 37. In this calculation the discharge rule has been constrained to be less than 1.


Parámetros de Solver

Establecer objetivo: $M$10

Para: ○ Máx ○ Mín ● Valor de: 0.1

Cambiando las celdas de variables: $E$3

Sujeto a las restricciones:
$J$17:$J$40 <= 1

☑ Convertir variables sin restricciones en no negativas

Método de resolución: GRG Nonlinear

Método de resolución

Seleccione el motor GRG Nonlinear para problemas de Solver no lineales suavizados. Seleccione el motor LP Simplex para problemas de Solver lineales, y seleccione el motor Evolutionary para problemas de Solver no suavizados.

Figure 37. Equal peak load decrease scenario: Solver parameters

Table 22. Circuit 41 Model, 10% peak load decrease

Circuit 41	2022 Load	Assumed increase	Fixed increase	2030 Load	% cars home	BEV available	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	6241 kWh	26%	26%	7842 kWh	99%	437 BEVs		0.00	7842 kWh		
2	5692 kWh	22%	22%	6930 kWh	99%	438 BEVs		0.00	6930 kWh		
3	5388 kWh	18%	18%	6352 kWh	100%	440 BEVs		0.00	6352 kWh		
4	5180 kWh	15%	15%	5956 kWh	100%	441 BEVs		0.00	5956 kWh		
5	5106 kWh	13%	13%	5768 kWh	99%	437 BEVs		0.00	5768 kWh		
6	5089 kWh	12%	12%	5702 kWh	96%	422 BEVs		0.00	5703 kWh		
7	5319 kWh	11%	11%	5890 kWh	87%	383 BEVs		0.00	5889 kWh		
8	5432 kWh	8%	8%	5862 kWh	68%	300 BEVs		0.00	5862 kWh		
9	5758 kWh	5%	5%	6034 kWh	51%	225 BEVs		0.00	6034 kWh		
10	6402 kWh	2%	2%	6519 kWh	42%	187 BEVs		0.00	6519 kWh		
11	7151 kWh	-3%	-3%	6917 kWh	38%	166 BEVs		0.00	6917 kWh		
12	7420 kWh	-7%	-7%	6910 kWh	35%	154 BEVs		0.00	6910 kWh		
13	7694 kWh	-7%	-7%	7177 kWh	33%	144 BEVs		0.00	7177 kWh		
14	7789 kWh	-5%	-5%	7400 kWh	28%	125 BEVs		0.00	7400 kWh		
15	8027 kWh	-1%	-1%	7971 kWh	28%	122 BEVs		0.00	7971 kWh		
16	8110 kWh	3%	3%	8313 kWh	33%	144 BEVs		0.00	8312 kWh		
17	8391 kWh	5%	5%	8827 kWh	46%	203 BEVs	316 kWh	0.24	8510 kWh	4%	1.6 kWh
18	8708 kWh	8%	8%	9432 kWh	68%	302 BEVs	921 kWh	0.47	8510 kWh	10%	3.1 kWh
19	8619 kWh	10%	10%	9456 kWh	82%	360 BEVs	946 kWh	0.41	8510 kWh	10%	2.6 kWh
20	8477 kWh	10%	10%	9313 kWh	88%	387 BEVs	803 kWh	0.32	8510 kWh	9%	2.1 kWh
21	8169 kWh	12%	12%	9187 kWh	91%	402 BEVs	677 kWh	0.26	8510 kWh	7%	1.7 kWh
22	7988 kWh	16%	16%	9257 kWh	94%	412 BEVs	747 kWh	0.28	8510 kWh	8%	1.8 kWh
23	7521 kWh	18%	18%	8867 kWh	96%	422 BEVs	357 kWh	0.13	8510 kWh	4%	0.8 kWh
24	6906 kWh	22%	22%	8420 kWh	98%	432 BEVs		0.00	8420 kWh		

In Table 23, the results of the simulation of circuit 41 with a 10% peak load decrease are presented. The maximum discharge rule obtained is 0.47 which indicates that the charger can work at 47% of its capacity, delivering a maximum rate of 3.1 kWh of energy in one hour, which is advantageous, as the smaller the discharge rule is, the more beneficial it is for the battery lifetime.

Table 23. Equal peak load decrease scenario: Solver output

Solver parameter	Function	Output
Objetive	10% peak load decrease	10%
Changing	Threshold	0.82
Constrains	Max discharge rule <1	0.47
	% battery withdrawn < 30%	16%

Figure 38 shows the load profile for circuit 41 when a 10% peak load decrease is required and Table 22 represent Circuit 41 Excel spreadsheet model. As the threshold obtained with the Solver tool is 0.82 (see Table 23), the maximum 2030 load with V2G will be 8510 kWh. Discharging energy during the evening has contributed to shave the peak load.

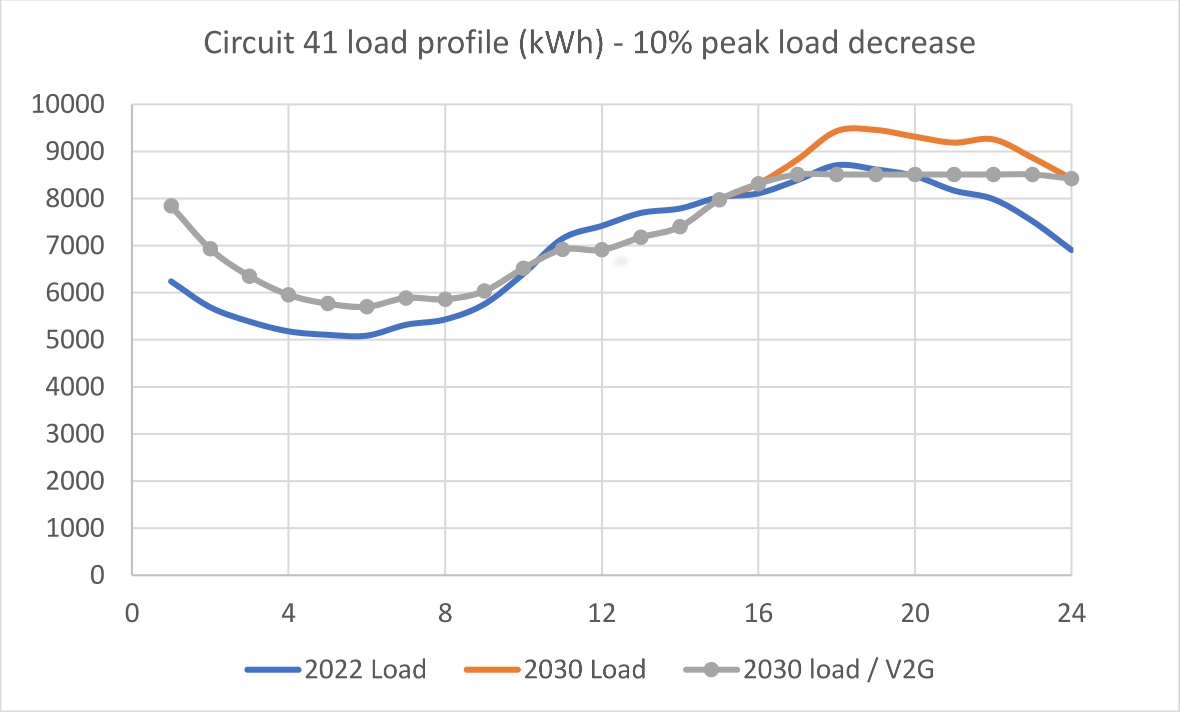


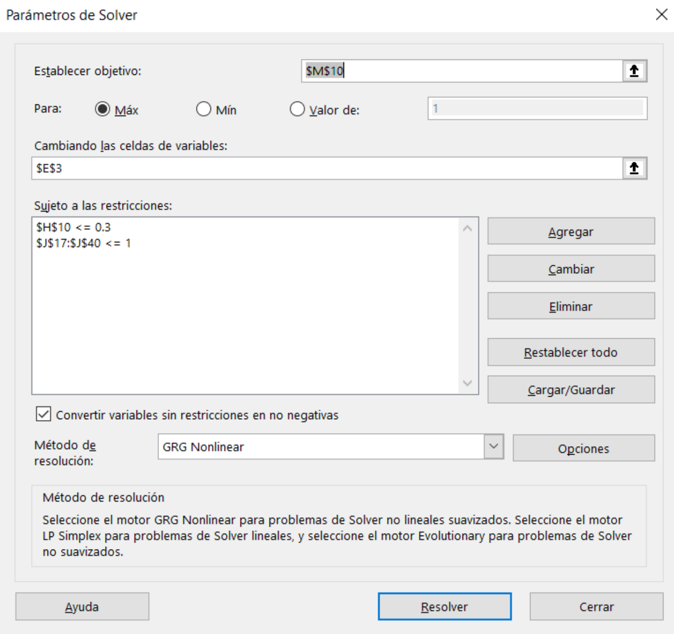
Figure 38. Equal peak load decrease scenario: Circuit 41 load profile (kWh)

5.6.2. Case 2: Maximize peak load decrease

In this case, the Solver objective is to maximize the circuit's peak load decreasement by changing the circuit's capacity threshold. First constrain is that the battery percentage withdrawn can't be over 30% and the second constrain limits the discharge rule to 1, see Figure 39. Table 24 display the fixed values used in the simulation.

Table 24. Maximize peak load decrease scenario: Fixed values used for the Excel's Solver

Load increase	0%
V2G availability	4.5%
Power station discharge	7.2 kW
Objetive value: Peak load decrease	**MAXIMIZE**



Establecer objetivo: $M$10

Para: ● Máx ○ Mín ○ Valor de: 1

Cambiando las celdas de variables: $E$3

Sujeto a las restricciones:
$H$10 <= 0.3
$J$17:$J$40 <= 1

☑ Convertir variables sin restricciones en no negativas

Método de resolución: GRG Nonlinear

Método de resolución

Seleccione el motor GRG Nonlinear para problemas de Solver no lineales suavizados. Seleccione el motor LP Simplex para problemas de Solver lineales, y seleccione el motor Evolutionary para problemas de Solver no suavizados.

Figure 39. Maximize peak load decrease scenario: Solver parameters

Table 25 presents results from the maximization problem. The **maximized** value is obtained with the Solver tool is **15% peak load decrease** when the **30% battery withdrawn** constrain has been reached.

Table 25. Maximize peak load decrease scenario: Solver output

Solver parameter	Function	Output
Objetive	Maximize peak load decrease	15%
Changing	Threshold	0.77
Constrains	Discharge rule <1	0.71
	% battery withdrawn < 30%	30%

As the threshold obtained with the Solver tool is 0.77 (see Table 25), the maximum 2030 load with V2G will be 8035 kWh (grey line in Figure 40). In this case, as the peak load has decreased in greater way than case 1, the threshold becomes lower than the previous case (0.82 in Case 1) and due to a greater energy delivery, battery % withdrawn has increased, reaching solvers constrain. Figure 40 shows the load profile for circuit 41 when a 15% peak load decrease is required. Discharging energy during the evening has contributed to shave the peak load in a greater way than in case 1.

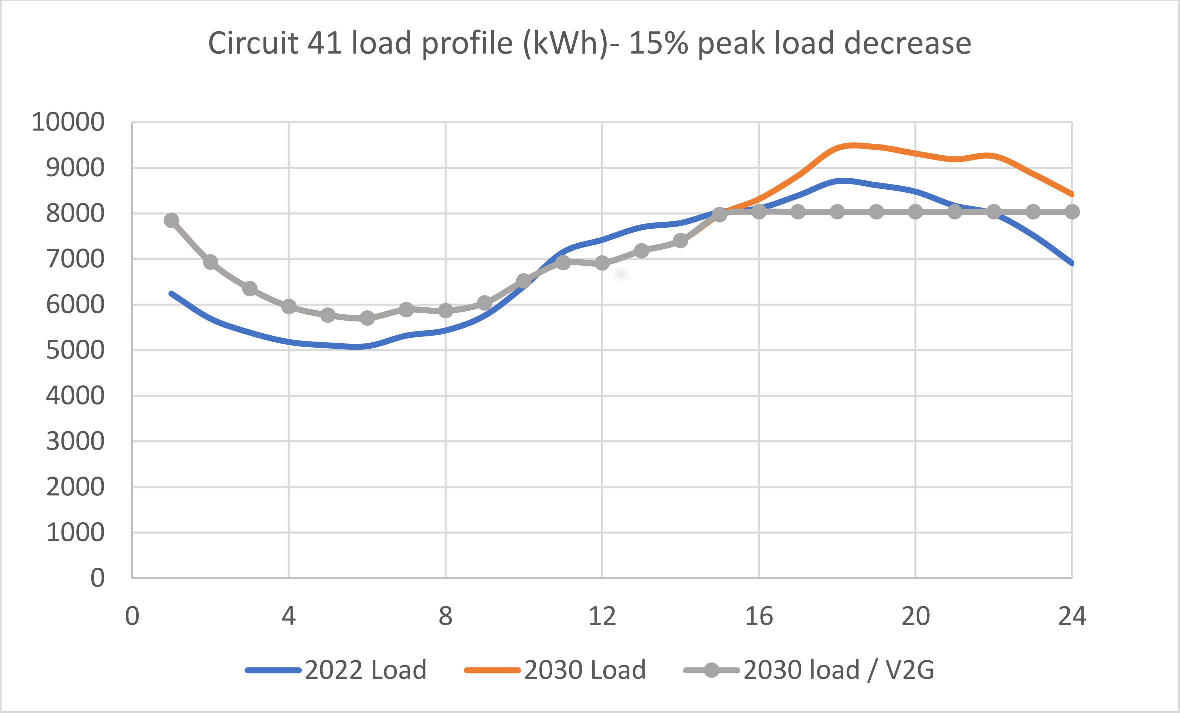


Figure 40. Maximize peak load decrease scenario: Circuit 41 load profile (kWh)

5.7. Sensitivity analysis

Thanks to the "Hypothesis analysis" Excel tool, sensitivity analysis on the **maximum discharge rule** and the **percentage of each BEV battery discharged** have been completed. These analyses are explained in section 6. The following parameters are analysed; **V2G availability, Load increase and the chargers discharge power**. An example of it is the sensitivity analysis for the output percentage battery withdrawn for circuit 41 shown in Table 26, where the load increase parameter (user % increase vs DRAFT scenario) and V2G availability are analyzed, when the threshold parameter is 0.82 and peak load decrease required is 10%.

Table 26. Circuit 41 sensitivity analysis of the percentage of battery withdrawn, equal peak load decrease scenario

		Sensitivity analysis - % Battery withdrawn								
	Initial	**Change in load increase**								
	16%	0%	5%	10%	15%	20%	25%	30%	35%	40%
Change in V2G %	0.5%	140%	149%	159%	170%	181%	192%	203%	214%	225%
	1.5%	47%	50%	53%	57%	60%	64%	68%	71%	75%
	2.5%	28%	30%	32%	34%	36%	38%	41%	43%	45%
	3.5%	20%	21%	23%	24%	26%	27%	29%	31%	32%
	4.5%	16%	17%	18%	19%	20%	21%	23%	24%	25%
	5.5%	13%	14%	14%	15%	16%	17%	18%	19%	20%
	6.5%	11%	11%	12%	13%	14%	15%	16%	16%	17%
	7.5%	9%	10%	11%	11%	12%	13%	14%	14%	15%
	8.5%	8%	9%	9%	10%	11%	11%	12%	13%	13%

6. CASES OF STUDY

The simulation of BEVs as mobile energy storage devices to deliver energy during evenings peak load is reflected with the following studies of the distribution lines in the San Diego area in 2030. Although in this section only the circuit 41 is analyzed, the same study has been completed with the remaining circuits. In this section, the **analysis** of the outputs **percentage of battery withdrawn and maximum discharge rule of circuit 41 are detailed**. These parameters are discussed in **two different cases**: 10 % peak load decrease (6.1.) and peak load decrease maximized (6.2.), which showcases the potential of BEV delivering energy back to the grid.

These two cases have been considered appropriate for the analysis of V2G in the distribution grid in San Diego because the following:

- After studying different cases, the possibility and the validity of the technology of discharging energy is concluded with case 1, which is carried out to enable the comparison of the discharge process between circuits where the discharge rule and the battery percentage are calculated, and valid values are obtained.
- The purpose of case 2 is to determine the limits of the technology, where a problem of maximization is solved.
- In the process of discharging energy from batteries, the biggest concerns are how much energy is being withdrawn and the power capacity of the bidirectional charger. Therefore, these cases of study analyze the **battery percentage and the discharge rule**.
- In **Case 1** a **10% peak load decrease has been simulated** as it is a reasonable value given the fact that the assumed increase by the CPUC for SDGE peak load is 9.72% for DRAFT scenario (section 5.3.2.2.).
- In **Case 2** (6.2.), a **30% battery withdrawn** has been assumed as the constrain of the simulation, following CCE idea of delivering little amount of energy from vehicles.

In section 6.3. a comparison of all circuits for Case 1 is presented and in section 6.4. a comparison of all circuits for Case 2 is detailed. **Table 22 is the Model for the simulation of circuit 41**. The Excel model of the rest of circuits is presented in Appendix III for Case 1 and in Appendix IV for Case 2.

6.1. Case 1. Circuit 41 analysis – 10% peak load decrease

Beyond the analysis made in section 5.6.1, **sensitivity analysis** of the maximum discharge rule and the percentage of battery withdrawn has been done. Following, the outcomes are presented in tables that depict **variations** in parameters such as **load increase, percentage of V2G availability, and changes in discharge power**. Maximum discharge rule values over 1 and percentage of battery withdrawn over 30% have been highlighted in red to emphasize this impossibility.

6.1.1. Discharge rule analysis

The following tables analyze the influence of the future V2G availability combined with the change in load increase on one side and the charger discharge power on the other side. Load increase estimates the increase of the demand by adding the percentage to hourly load increase factor (page 44). For example, if the load increase parameter is 40%, the hourly load increase factor at 19h will be of 14%

instead of 9.7%. Below, Table 27 shows the **sensitivity analysis** of the **maximum discharge rule** for a 10% peak load decrease in circuit 41. In this case, the value in blue, 0.47, is the value of the discharge rule at 18h, which is being analyzed.

Table 27. Circuit 41 sensitivity analysis of maximum discharge rule (load increase and V2G %), equal peak load decrease scenario

		Sensitivity analysis - Max discharge rule								
	Initial	**Change in load increase**								
	0.47	0%	5%	10%	15%	20%	25%	30%	35%	40%
Change in V2G %	0.5%	4.24	4.40	4.57	4.74	4.90	5.07	5.24	5.40	5.57
	1.5%	1.41	1.47	1.52	1.58	1.63	1.69	1.75	1.80	1.86
	2.5%	0.85	0.88	0.91	0.95	0.98	1.01	1.05	1.08	1.11
	3.5%	0.61	0.63	0.65	0.68	0.70	0.72	0.75	0.77	0.80
	4.5%	**0.47**	0.49	0.51	0.53	0.54	0.56	0.58	0.60	0.62
	5.5%	0.39	0.40	0.42	0.43	0.45	0.46	0.48	0.49	0.51
	6.5%	0.33	0.34	0.35	0.36	0.38	0.39	0.40	0.42	0.43
	7.5%	0.28	0.29	0.30	0.32	0.33	0.34	0.35	0.36	0.37
	8.5%	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33

In circuit 41, with **4.5% V2G penetration and for whatever change in power discharge and load increase the discharge rule stays lower than 1**. If decreasing the power discharge, a steep increase in the discharge value is promoted (see Table 28) reaching 1.41 when V2G availability is 1.5%. On the other hand, increasing the load increase to 40%, which means that peak load at 19h is increased by 14%, a smaller increase of the discharge rule is obtained - 0,62.

Table 28. Circuit 41 sensitivity analysis of maximum discharge rule (power discharge and V2G %), equal peak load decrease scenario

		Sensitivity analysis - Max discharge rule								
	Initial	**Change in power discharge**								
	0.47	4 kW	5 kW	6 kW	7 kW	8 kW	9 kW	10 kW	11 kW	12 kW
Change in V2G %	0.5%	7.63	6.10	5.09	4.36	3.81	3.39	3.05	2.77	2.54
	1.5%	2.54	2.03	1.70	1.45	1.27	1.13	1.02	0.92	0.85
	2.5%	1.53	1.22	1.02	0.87	0.76	0.68	0.61	0.55	0.51
	3.5%	1.09	0.87	0.73	0.62	0.54	0.48	0.44	0.40	0.36
	4.5%	0.85	0.68	0.57	**0.47**	0.42	0.38	0.34	0.31	0.28
	5.5%	0.69	0.55	0.46	0.40	0.35	0.31	0.28	0.25	0.23
	6.5%	0.59	0.47	0.39	0.34	0.29	0.26	0.23	0.21	0.20
	7.5%	0.51	0.41	0.34	0.29	0.25	0.23	0.20	0.18	0.17
	8.5%	0.45	0.36	0.30	0.26	0.22	0.20	0.18	0.16	0.15

Table 29 analyze the hours when energy is being discharged and the V2G availability (4.5 % is the initial parameter). If V2G penetration in the future is lower than expected (1.5%), circuit 41 will have **difficulties** in providing energy to the grid at **18h and 19h**, implying **discharge rule** values over 1; **1.4 and 1.2**. On the contrary, a rapid scale of the V2G market in the future will reduce enormously the required discharge rule in circuit 41 to provide the energy necessary to reduce circuit's peak load by 10%.

Table 29. Circuit 41 hourly sensitivity analysis of discharge rule (V2G %), equal peak load decrease scenario

		Sensitivity analysis – Discharge rule								
	Initial	**Change in V2G %**								
Hour	**4.5%**	0.5%	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%
17	**0.2**	2.2	0.7	0.4	0.3	**0.2**	0.2	0.2	0.1	0.1
18	**0.5**	4.2	1.4	0.8	0.6	**0.5**	0.4	0.3	0.3	0.2
19	**0.4**	3.6	1.2	0.7	0.5	**0.4**	0.3	0.3	0.2	0.2
20	**0.3**	2.9	1.0	0.6	0.4	**0.3**	0.3	0.2	0.2	0.2
21	**0.3**	2.3	0.8	0.5	0.3	**0.3**	0.2	0.2	0.2	0.1
22	**0.3**	2.5	0.8	0.5	0.4	**0.3**	0.2	0.2	0.2	0.1
23	**0.1**	1.2	0.4	0.2	0.2	**0.1**	0.1	0.1	0.1	0.1
24	**0.0**					**0.0**				

6.1.2. Percentage battery withdrawn analysis

The following tables analyze the influence of **V2G availability in the future and the change in load increase**. The charger's discharge power is not analyzed as it has no influence in the percentage of battery withdrawn from each BEV. Table 30 showcases that the influence of V2G availability in the future is important. If **V2G availability** in the future differs from the initial assumption, **1.5%** for example, it can be appreciated that the **percentage of battery depletion** increases steeply (47%).

Table 30. Circuit 41 sensitivity analysis of percentage of battery withdrawn (load increase and V2G %), equal peak load decrease scenario

		Sensitivity analysis - % Battery withdrawn								
	Initial	**Change in load increase**								
	16%	0%	5%	10%	15%	20%	25%	30%	35%	40%
Change in V2G %	0.5%	140%	149%	159%	170%	181%	192%	203%	214%	225%
	1.5%	47%	50%	53%	57%	60%	64%	68%	71%	75%
	2.5%	28%	30%	32%	34%	36%	38%	41%	43%	45%
	3.5%	20%	21%	23%	24%	26%	27%	29%	31%	32%
	4.5%	**16%**	17%	18%	19%	20%	21%	23%	24%	25%
	5.5%	13%	14%	14%	15%	16%	17%	18%	19%	20%
	6.5%	11%	11%	12%	13%	14%	15%	16%	16%	17%
	7.5%	9%	10%	11%	11%	12%	13%	14%	14%	15%
	8.5%	8%	9%	9%	10%	11%	11%	12%	13%	13%

Table 31 analyze the percentage of battery withdrawn when V2G availability is 4.5% and Table 32 analyze the percentage of battery withdrawn when the load increase parameter is 0% load increase. They imply that the **change in V2G % is more critical for the rate of EV battery usage**. As the penetration is higher, the level of EV battery utilization is decreased following CCE's idea of using a little discharge of BEV batteries during evenings.

Table 31. Circuit 41 sensitivity analysis of percentage of battery withdrawn (load increase), equal peak load decrease scenario

Sensitivity analysis - % Battery withdrawn (4.5% V2G)								
Change in load increase								
0%	5%	10%	15%	20%	25%	30%	35%	40%
16%	17%	18%	19%	20%	21%	23%	24%	25%

Table 32 Circuit 41 sensitivity analysis of percentage of battery withdrawn (V2G %), equal peak load decrease scenario

Sensitivity analysis - % Battery withdrawn (0% Load increase)								
Change in V2G %								
0.5%	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%
140%	47%	28%	20%	16%	13%	11%	9%	8%

6.2. Case 2. Circuit 41 analysis – peak load decrease maximized

In case 2, peak load decrease has been maximized. In circuit 41, as in section 5.6.2. is outlined, the **maximized value obtained is 15%** when the constrain of the battery percentage is achieved. This case offers similar output as case 1 but with a different threshold obtained, 0.77 instead of 0.82. In section 6.4. a comparison of all simulated circuits is elaborated. The simulation of circuit 41 is displayed in Table 33. The Models of the rest of circuits are presented in Appendix IV.

Table 33.Circuit 41 model – Case 2: Peak load decrease maximized

41	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	6241 kWh	26%	26%	7842 kWh	99%	437 BEVs		0.00	7842 kWh		
2	5692 kWh	22%	22%	6930 kWh	99%	438 BEVs		0.00	6930 kWh		
3	5388 kWh	18%	18%	6352 kWh	100%	440 BEVs		0.00	6352 kWh		
4	5180 kWh	15%	15%	5956 kWh	100%	441 BEVs		0.00	5956 kWh		
5	5106 kWh	13%	13%	5768 kWh	99%	437 BEVs		0.00	5768 kWh		
6	5089 kWh	12%	12%	5703 kWh	96%	422 BEVs		0.00	5703 kWh		
7	5319 kWh	11%	11%	5889 kWh	87%	383 BEVs		0.00	5889 kWh		
8	5432 kWh	8%	8%	5862 kWh	68%	300 BEVs		0.00	5862 kWh		
9	5758 kWh	5%	5%	6034 kWh	51%	225 BEVs		0.00	6034 kWh		
10	6402 kWh	2%	2%	6519 kWh	42%	187 BEVs		0.00	6519 kWh		
11	7151 kWh	-3%	-3%	6917 kWh	38%	166 BEVs		0.00	6917 kWh		
12	7420 kWh	-7%	-7%	6910 kWh	35%	154 BEVs		0.00	6910 kWh		
13	7694 kWh	-7%	-7%	7177 kWh	33%	144 BEVs		0.00	7177 kWh		
14	7789 kWh	-5%	-5%	7400 kWh	28%	125 BEVs		0.00	7400 kWh		
15	8027 kWh	-1%	-1%	7971 kWh	28%	122 BEVs		0.00	7971 kWh		
16	8110 kWh	3%	3%	8312 kWh	33%	144 BEVs	277 kWh	0.30	8035 kWh	3%	1.9
17	8391 kWh	5%	5%	8827 kWh	46%	203 BEVs	792 kWh	0.60	8035 kWh	9%	3.9
18	8708 kWh	8%	8%	9432 kWh	68%	302 BEVs	1396 kWh	0.71	8035 kWh	15%	4.6
19	8619 kWh	10%	10%	9456 kWh	82%	360 BEVs	1421 kWh	0.61	8035 kWh	15%	3.9
20	8477 kWh	10%	10%	9313 kWh	88%	387 BEVs	1278 kWh	0.51	8035 kWh	14%	3.3
21	8169 kWh	12%	12%	9187 kWh	91%	402 BEVs	1152 kWh	0.44	8035 kWh	13%	2.9
22	7988 kWh	16%	16%	9257 kWh	94%	412 BEVs	1222 kWh	0.46	8035 kWh	13%	3.0
23	7521 kWh	18%	18%	8867 kWh	96%	422 BEVs	832 kWh	0.30	8035 kWh	9%	2.0
24	6906 kWh	22%	22%	8420 kWh	98%	432 BEVs	385 kWh	0.14	8035 kWh	5%	0.9

6.2.1. Discharge rule analysis

The obtained results reveal a **higher prevalence of maximum discharge rule** values **exceeding 1** compared to case 1. This can be attributed to the fact that, with **peak load decrease maximized**, the simulation is approaching the limits of feasibility. (rate of EV batteries < 30% and discharge rule < 1).

Table 34. Circuit 41 sensitivity analysis of maximum discharge rule (load increase and V2G %), peak load decrease maximized scenario

		Sensitivity analysis - Max discharge rule								
	Initial	**Change in load increase**								
	0.71	0%	5%	10%	15%	20%	25%	30%	35%	40%
Change in V2G %	0.5%	6.42	6.59	6.76	6.92	7.09	7.26	7.42	7.59	7.76
	1.5%	2.14	2.20	2.25	2.31	2.36	2.42	2.47	2.53	2.59
	2.5%	1.28	1.32	1.35	1.38	1.42	1.45	1.48	1.52	1.55
	3.5%	0.92	0.94	0.97	0.99	1.01	1.04	1.06	1.08	1.11
	4.5%	0.71	0.73	0.75	0.77	0.79	0.81	0.82	0.84	0.86
	5.5%	0.58	0.60	0.61	0.63	0.64	0.66	0.67	0.69	0.71
	6.5%	0.49	0.51	0.52	0.53	0.55	0.56	0.57	0.58	0.60
	7.5%	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.51	0.52
	8.5%	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	0.46

As Table 34 displays, a V2G availability lower than the initial (4.5%) will result in a **discharge rule** value closer to the **limit** (5% load increase and 3.5% V2G penetration equals to **0.94**). The data in Table 35 highlights similar results as in case 1; lower discharge power and lower V2G availability result in impossible discharge values (5 kW and 3.5% V2G availability – (**1.85 which is a greater value than in case 1**).

Table 35. Circuit 41 sensitivity analysis of maximum discharge rule (power discharge and V2G %), peak load decrease maximized scenario

		Sensitivity analysis - Max discharge rule								
	Initial	**Change in power discharge**								
	0.71	4 kW	5 kW	6 kW	7 kW	8 kW	9 kW	10 kW	11 kW	12 kW
Change in V2G %	0.5%	11.56	9.25	7.71	6.61	5.78	5.14	4.63	4.21	3.85
	1.5%	3.85	3.08	2.57	2.20	1.93	1.71	1.54	1.40	1.28
	2.5%	2.31	1.85	1.54	1.32	1.16	1.03	0.93	0.84	0.77
	3.5%	1.65	1.32	1.10	0.94	0.83	0.73	0.66	0.60	0.55
	4.5%	1.28	1.03	0.86	0.71	0.64	0.57	0.51	0.47	0.43
	5.5%	1.05	0.84	0.70	0.60	0.53	0.47	0.42	0.38	0.35
	6.5%	0.89	0.71	0.59	0.51	0.44	0.40	0.36	0.32	0.30
	7.5%	0.77	0.62	0.51	0.44	0.39	0.34	0.31	0.28	0.26
	8.5%	0.68	0.54	0.45	0.39	0.34	0.30	0.27	0.25	0.23

The finding depicted in the Table 36 shows that if V2G penetration in the future is lower than expected (2.5% for Ex.), circuit 41 will have difficulties in providing energy to the grid at 19h (**discharge rule 1.1**).

The V2G availability for which the discharge process would not be possible is higher than in case 1, **2.5% in case 2 and 1.5% in case 1.**

Table 36. Circuit 41 hourly sensitivity analysis of discharge rule (V2G %), peak load decrease maximized scenario

		Sensitivity analysis - Discharge rule								
	Initial	**Change in V2G %**								
Hour	**4.5%**	0.5%	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%
17	**0.6**	5.4	1.8	1.1	0.8	**0.6**	0.5	0.4	0.4	0.3
18	**0.7**	6.4	2.1	1.3	0.9	**0.7**	0.6	0.5	0.4	0.4
19	**0.6**	5.5	1.8	1.1	0.8	**0.6**	0.5	0.4	0.4	0.3
20	**0.5**	4.6	1.5	0.9	0.7	**0.5**	0.4	0.4	0.3	0.3
21	**0.4**	4.0	1.3	0.8	0.6	**0.4**	0.4	0.3	0.3	0.2
22	**0.5**	4.1	1.4	0.8	0.6	**0.5**	0.4	0.3	0.3	0.2
23	**0.3**	2.7	0.9	0.5	0.4	**0.3**	0.2	0.2	0.2	0.2
24	**0.1**	1.2	0.4	0.2	0.2	**0.1**	0.1	0.1	0.1	0.1

6.2.2. Percentage battery withdrawn analysis

Identically as in section 6.1.1., the difference in the percentage of EV battery drained increases with the increase of load increase parameter and the decrease of V2G availability, see Table 37. The proportion of BEV battery withdrawn increases 10% for the following change, 0% to 5% load increase and 4.5% to 3.5% in V2G percentage, whereas for 20% to 25% load increase and 3.5% to 2.5% in V2G penetration, the increase is 21%. **In case 1, these values were 7% and 12% respectively, which implies that the disparity becomes more prominent in case 2**.

Table 37. Circuit 41 sensitivity analysis of percentage of battery withdrawn (load increase and V2G %), peak load decrease maximized scenario

		Sensitivity analysis - % Battery withdrawn								
	Initial	**Change in load increase**								
	30%	0%	5%	10%	15%	20%	25%	30%	35%	40%
Change in V2G %	0.5%	270%	282%	293%	306%	320%	333%	347%	360%	374%
	1.5%	90%	94%	98%	102%	107%	111%	116%	120%	125%
	2.5%	54%	56%	59%	61%	64%	67%	69%	72%	75%
	3.5%	39%	40%	42%	44%	46%	48%	50%	51%	53%
	4.5%	**30%**	31%	33%	34%	36%	37%	39%	40%	42%
	5.5%	25%	26%	27%	28%	29%	30%	32%	33%	34%
	6.5%	21%	22%	23%	24%	25%	26%	27%	28%	29%
	7.5%	18%	19%	20%	20%	21%	22%	23%	24%	25%
	8.5%	16%	17%	17%	18%	19%	20%	20%	21%	22%

As in case 2 the **constrain of 30% battery withdrawal** has been **reached**, the decrease in the V2G availability and the increment of load increase result in **higher values of energy percentage of BEV battery withdrawn**, see Table 38 and Table 39.

Table 38. Circuit 41 sensitivity analysis of percentage of battery withdrawn (load increase), peak load decrease maximized scenario

Sensitivity analysis - % Battery withdrawn (4.5% V2G)								
Change in load increase								
0%	5%	10%	15%	20%	25%	30%	35%	40%
30%	31%	33%	34%	36%	37%	39%	40%	42%

Table 39. Circuit 41 sensitivity analysis of percentage of battery withdrawn (V2G %), peak load decrease maximized scenario

Sensitivity analysis - % Battery withdrawn (0% load increase)								
Change in V2G %								
0.5%	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%
270%	90%	54%	39%	30%	25%	21%	18%	16%

6.3. Circuits comparison - Case 1

Differences in peak load decrease infer not very accurate conclusions on the potential asset of V2G as distributed energy resources in the future. To compare circuits with different nº of households and residential consumer distribution, **equal peak load decrease has to assume for all circuits in order to obtain conclusions** that draw tremendous benefits from V2G technology to solve duck curve and mitigate peak load.

In this section, a **comparative analysis of the simulated circuits is presented**. Since the **distribution** of **residential consumers** in each circuit differs from the others, the **number of BEVs available** to discharge energy will vary, **limiting** the capacity of energy discharge and therefore increasing the discharge rule and the portion of the battery discharged.

6.3.1. 2030 load profiles with V2G

Following, the load profile graphs of all simulated circuits are displayed. In the following figures the 2022 load, the assumed 2030 load and the 2030 load profile with V2G are included. These figures represent case 1 and have a 10% peak load decrease in all circuits.

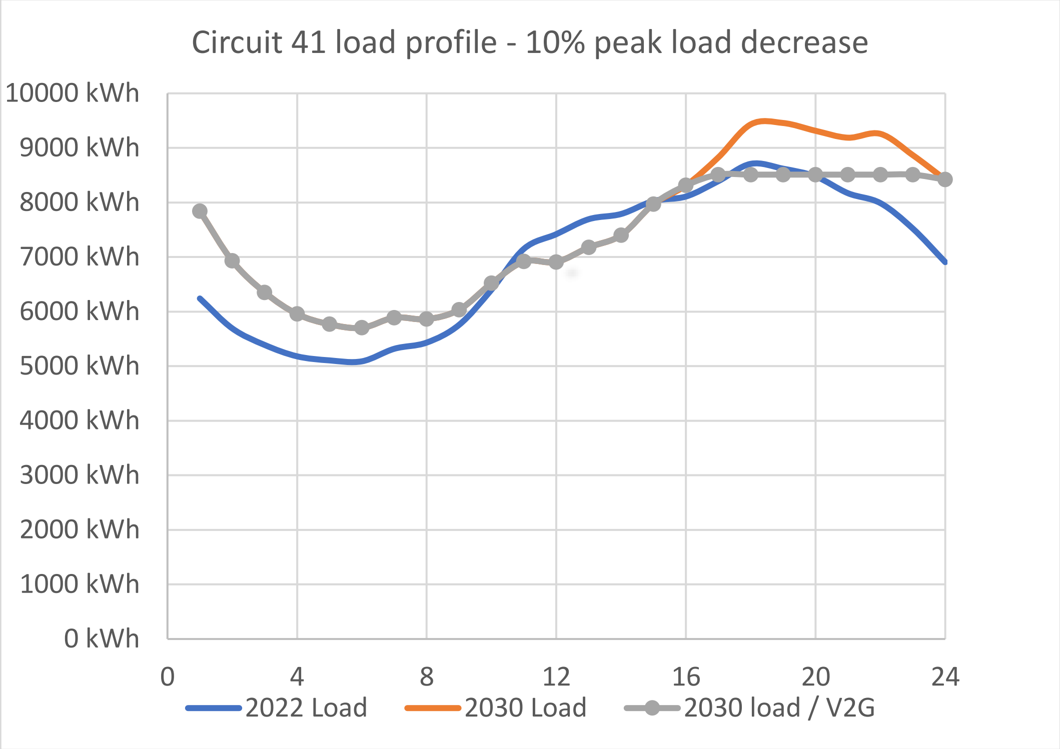


Figure 41. Circuit 41 load profile, 10 % peak load decrease scenario

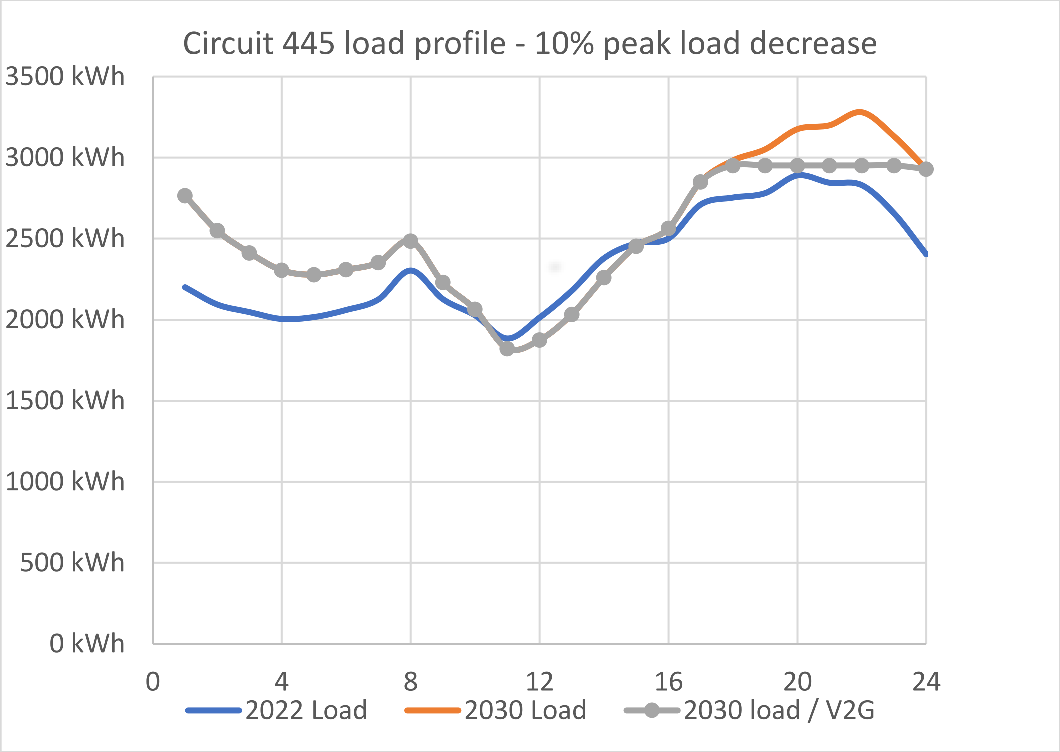


Figure 42. Circuit 445 load profile, 10 % peak load decrease scenario

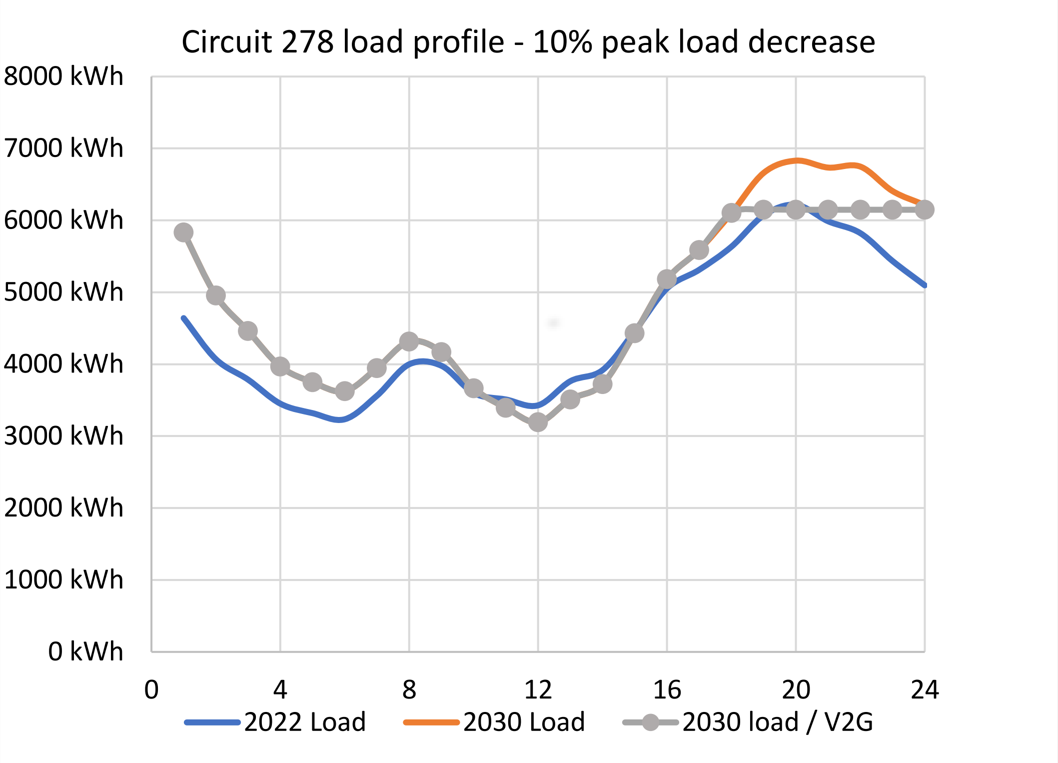


Figure 43. Circuit 278 load profile, 10 % peak load decrease scenario

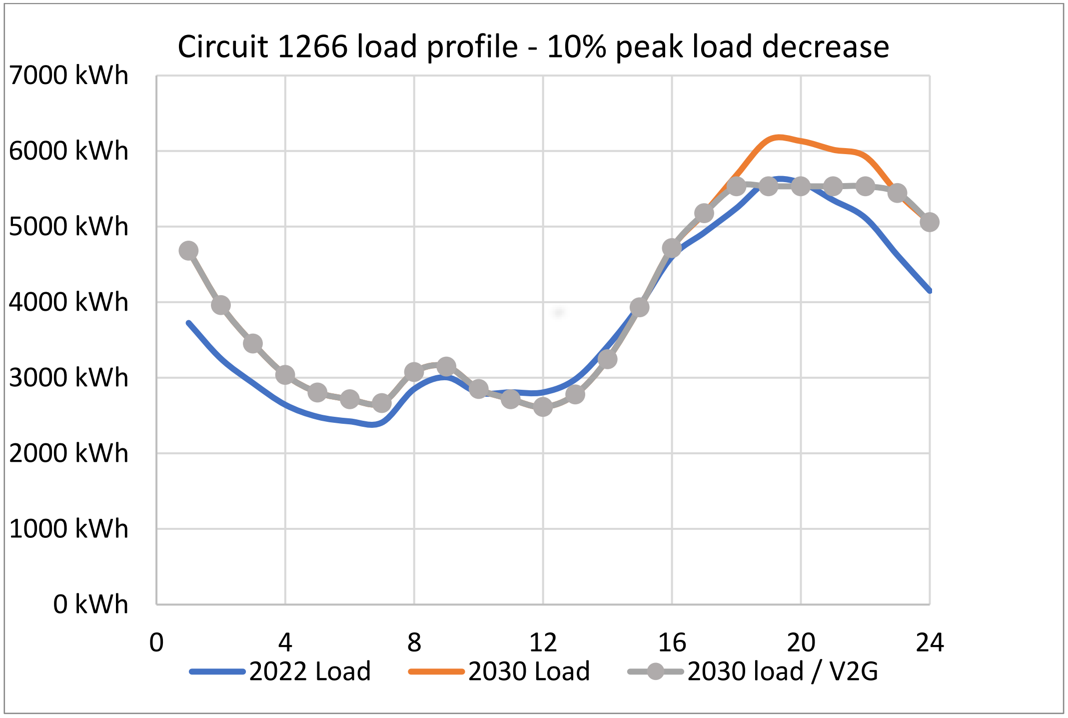


Figure 44. Circuit 1266 load profile, 10 % peak load decrease scenario

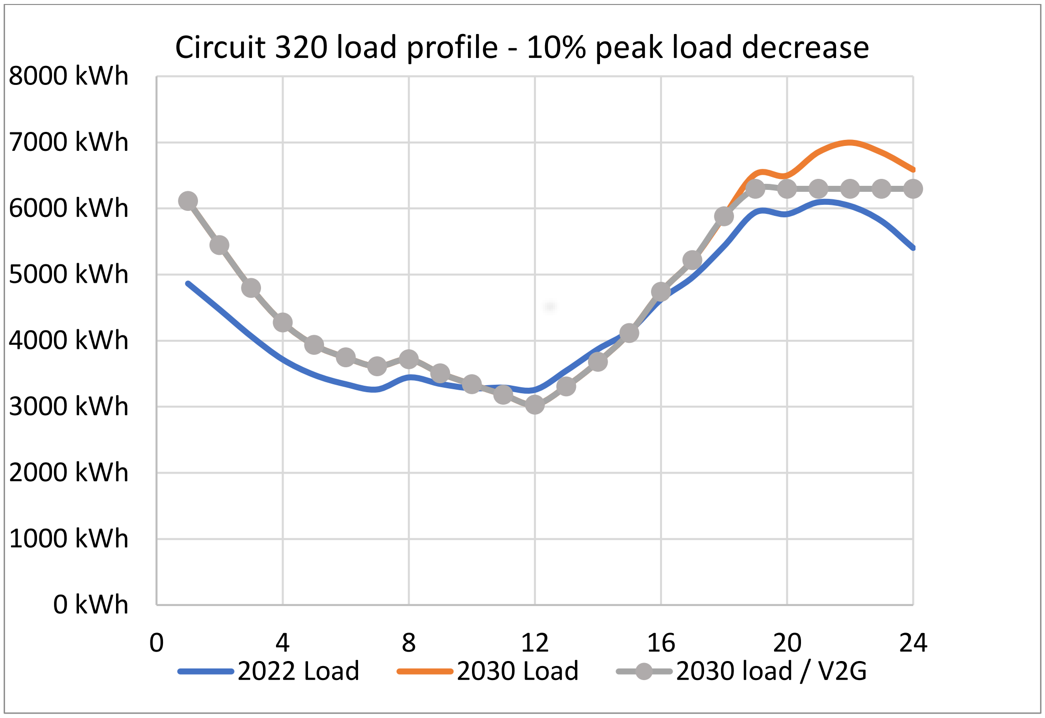


Figure 45. Circuit 320 load profile, 10 % peak load decrease scenario

All figures above display the 10% peak load decrease thanks to the discharge of energy from BEV's batteries. From the comparison between figures, it can be appreciated that depending on the profile, peak load is not always located at 19h in all circuits. Peak load is placed at 18h in circuit 41, at 22 in circuit 445, at 20h in circuit 278, at 19h in circuit 1266 and at 22h in circuit 320.

6.3.2. Summary table

Table 40 display the results of the 2030 simulation of circuits 41, 445, 278, 1266 and 320 and offers insights into the **threshold required, maximum discharge rule and the level of BEV battery utilization for each circuit**. It is presented as a summary of the output of the simulation.

Table 40. Output summary of simulated circuit, 10% peak load decrease scenario

	Circuit 41	Circuit 445	Circuit 278	Circuit 1266	Circuit 320
Residential consumers	4260	787	3772	1879	3199
Comercial consumers	624	165	80	81	67
Industrial consumers	1	1	25	5	7
% residential	87%	83%	97%	96%	98%
Facility loading	84%	25%	50%	45%	49%
Max load/consumer	2.0 kWh	3.7 kWh	1.6 kWh	3.0 kWh	1.9 kWh
Max peak load decrease	10%	10%	10%	10%	10%
Thershold required	0.82	0.27	0.49	0.44	0.51
Max discharge rule	0.47	0.66	0.31	0.60	0.35
Battery % discharged	16%	17%	9%	15%	9%

The findings depicted in the table suggest the following conclusions for a 10% peak load decrease in all circuits.

- The **higher the residential consumer distribution**, the **lower** the proportion of **BEV's battery depletion**. This assertion is logical as more BEV per distribution line will be available and less energy has to be withdrawn from their batteries. In this way, as circuit 278 and 320 have similar input parameters, the results obtained are very promising with only discharging 9% of batteries. On the other hand, when the residential consumer allocation is lower, more energy is needed to meet the 10% peak load decrease and the battery use increases. An example of it are circuits 41 and 445 with 16% and 17% of percentage of battery depletion.

- As the discharge rule is a measure of the bidirectional charger's load factor, if the $\mathbf{BEV\ availability}$ **is higher**, **less energy will be withdrawn from batteries**. Following this, circuits 278 and 320 presents similar results, 0.31 and 0.35, due to the similarity on the residential consumer distribution. On the contrary, circuits 41 and 445 show similar battery percentage depletion but different maximum discharge rule value, 0.47 and 0.66. Despite they present similar residential customers distribution, the number of residential consumers of circuit 445 is considerably lower than circuit 41. Therefore the $\mathrm{BEV\ availability}$ is lower and the $\frac{\max load}{consumers}$ in circuit 445 is greater than in circuit 41.

- **High values** of the percentage of **BEV batteries discharged** can be explained with the fact of a **wider peak load profile**, which means that more energy has to be discharged throughout the evening. Circuit 41, 445 and 1266 present similar outputs despite their differences in the residential consumer distribution. This is because the $\frac{\max load}{consumers}$ in 1266 and 445 is greater than 41 (see Table 40) and the corresponding load profiles display wider peak load with higher energy discharge rate per BEV per hour, see Table 41.

Table 41. Energy discharged per BEV per hour circuits 41, 445 and 1266. 10% peak load decrease scenario

Hour	Circuit 41	Circuit 445	Circuit 1266
17	1.6 kWh		
18	3.1 kWh	0.5 kWh	1.1 kWh
19	2.6 kWh	1.5 kWh	3.9 kWh
20	2.1 kWh	3.1 kWh	3.5 kWh
21	1.7 kWh	3.3 kWh	2.7 kWh
22	1.8 kWh	4.3 kWh	2.2 kWh
23	0.8 kWh	2.3 kWh	
24			

- Differences between 1266 and 320 are due to circuit 1266 having greater load after peak load at 19h, (see Figure 44), and higher $\frac{\max load}{consumers}$, see Table 40. Although they have similar residential consumer allocation, more energy is required to meet the threshold in circuit 1266 and therefore the level of BEV battery depletion is higher.

- As in section 5.2.4., is mentioned, it is noted that **threshold values vary across all circuits**. This difference arises from the calculation of circuit-specific thresholds to achieve a 10% reduction in peak load, facilitating comparisons between circuits. The threshold value is contingent upon the facility's loading, whereby a **higher facility loading results in a higher threshold value**.

6.4. Circuits comparison - Case 2

Case 2 has been studied to **showcase the potential of peak load decrease** in different circuits in San Diego. Table 42 presents data that indicates very interesting and promising results which show the ability that V2G can potentially reduce and shave peak load in the future.

6.4.1. 2030 load profiles with V2G

Following, the load profile graphs of all simulated circuits are displayed. In the following figures the 2022 load, the assumed 2030 load and the 2030 load profile with V2G are included. These figures represent case 2 and **peak load decrease is maximized**. Therefore, the decrement in the 2030 load profile with V2G is more pronounced than in case 1. The graphs of all simulated circuits reveal that 2030 peak load with the addition of V2G could be lower than actual values, just discharging 30% of BEV batteries in San Diego. Peak load values have decreased in a greater way than the hourly load increase factor expected.

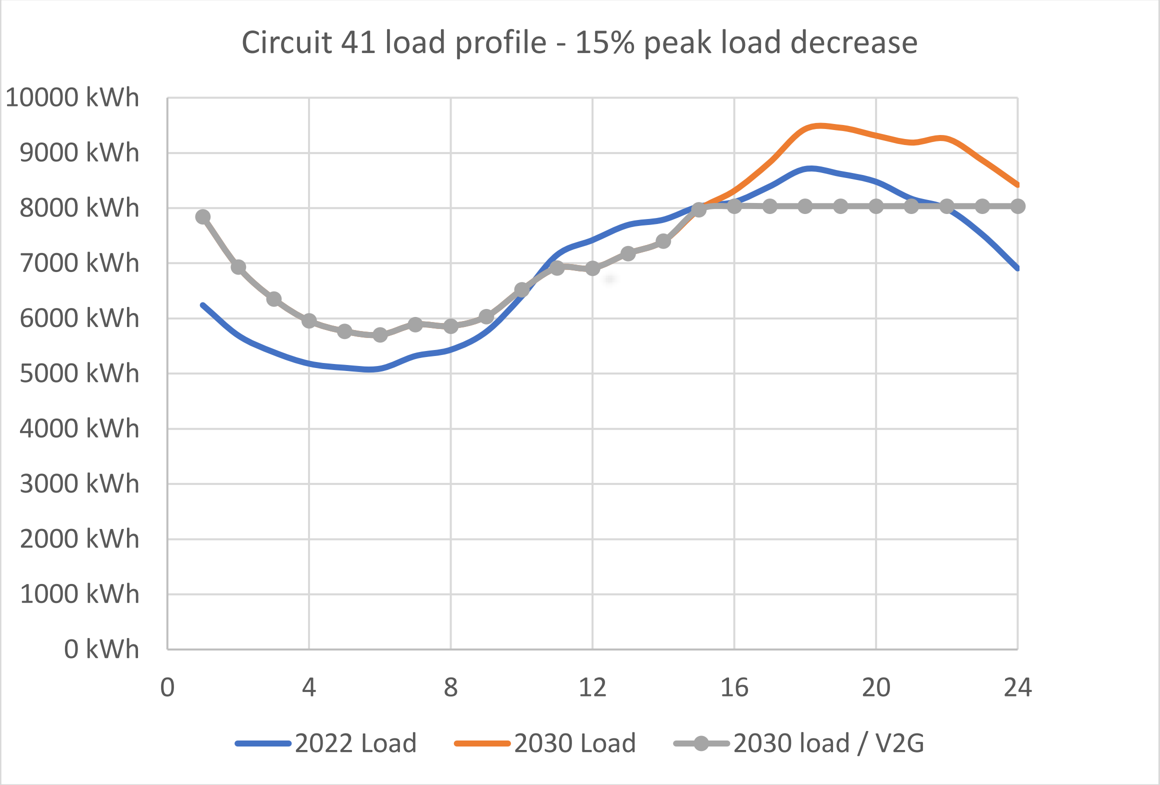


Figure 46. Circuit 41 load profile- peak load decrease maximized scenario

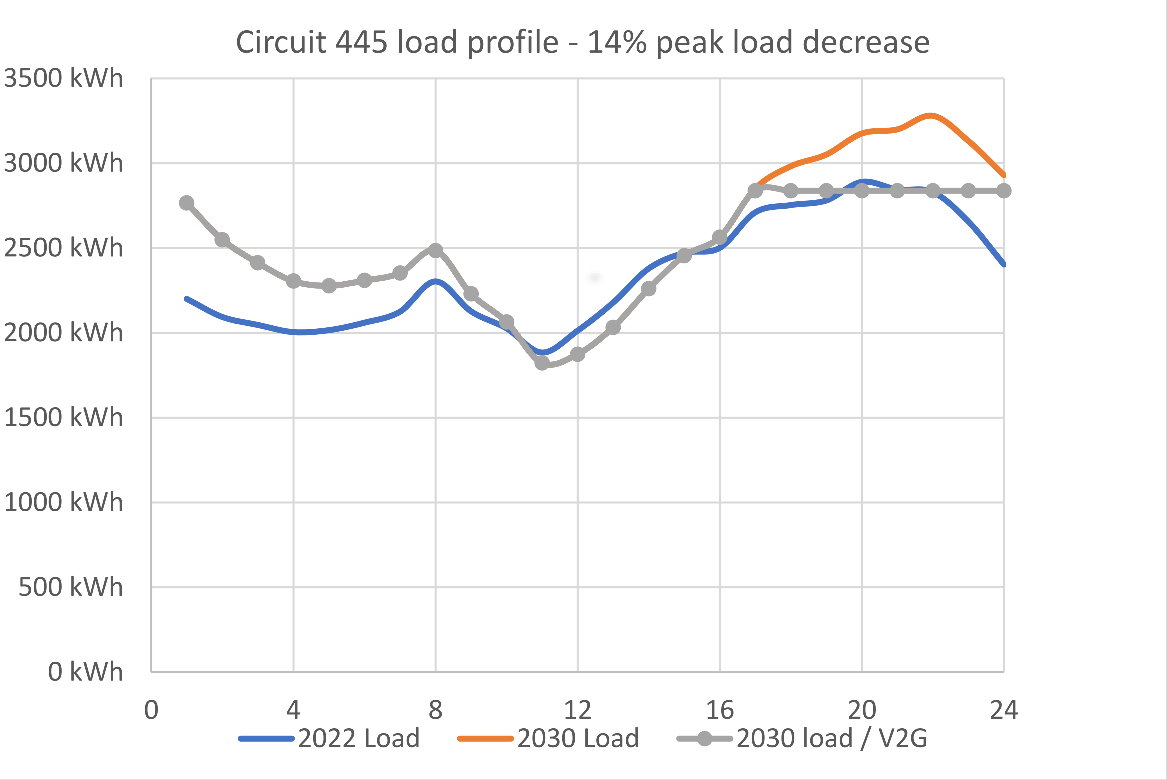


Figure 47. Circuit 445 load profile- peak load decrease maximized scenario

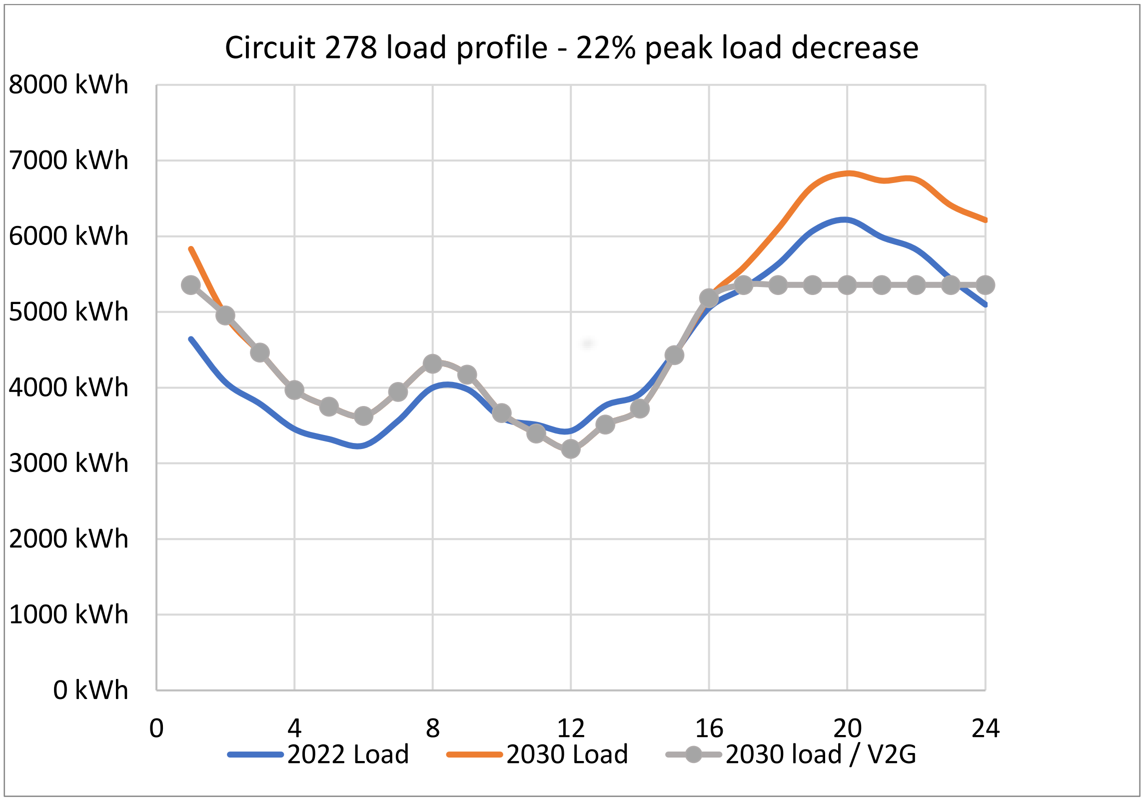


Figure 48. Circuit 278 load profile- peak load decrease maximized scenario

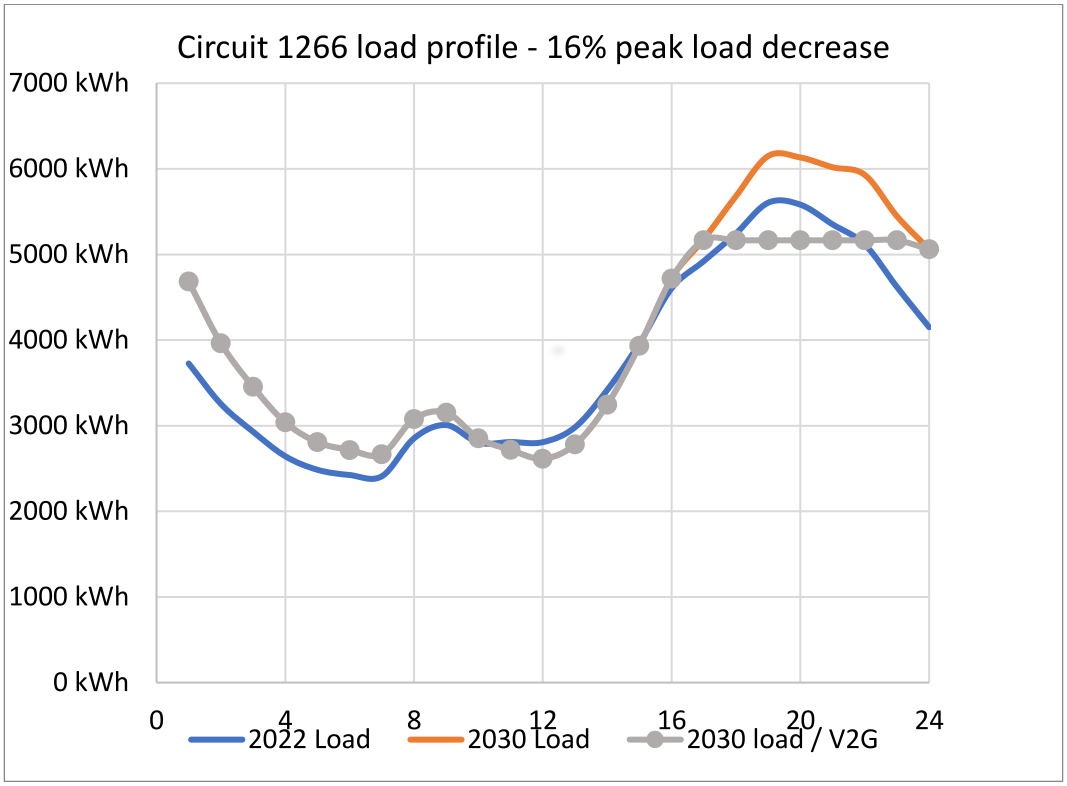


Figure 49. Circuit 1266 load profile- peak load decrease maximized scenario

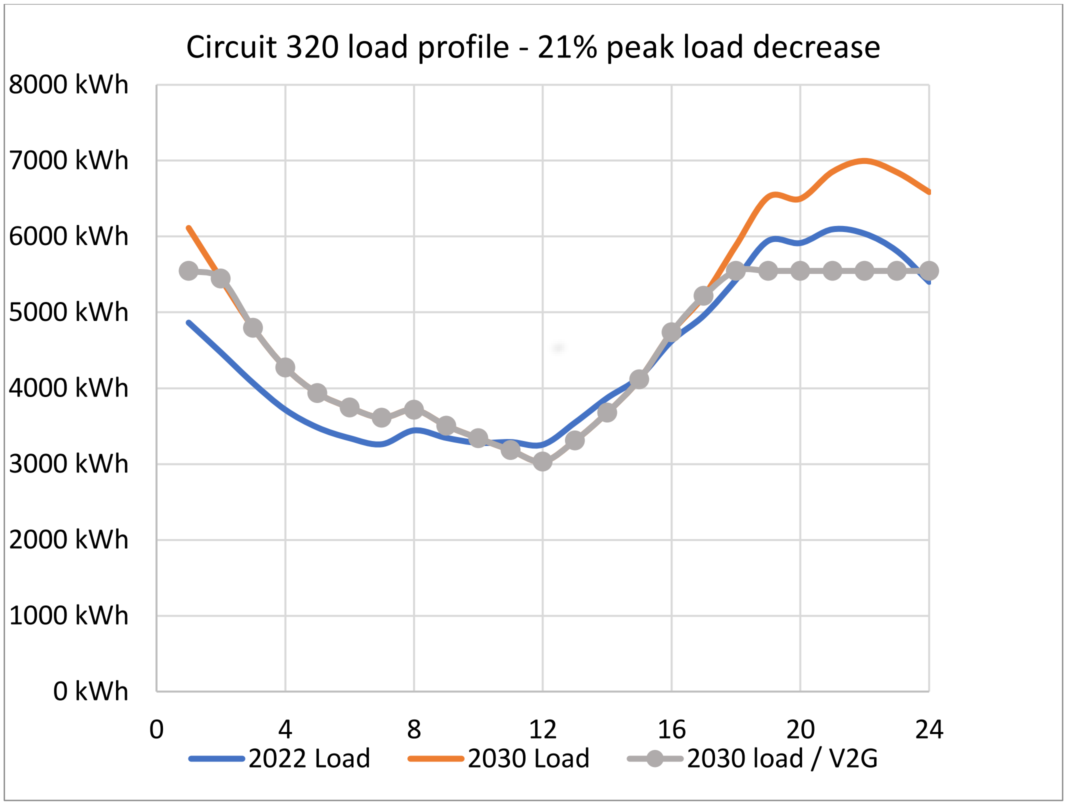


Figure 50. Circuit 320 load profile- peak load decrease maximized scenario

6.4.2. Summary table

In this case the constraints of the simulation were: discharge rule less than 1 and battery percentage discharged less than 30%. As Table 42 reflects, the **battery constrain has reached in all circuits** which gives insight into the **risk of over discharging** energy back to the grid, which would not follow CCE's proposal of discharging little energy from BEV.

Table 42. Output summary of simulated circuit, peak load decrease maximized scenario

	Circuit 41	Circuit 445	Circuit 278	Circuit 1266	Circuit 320
Residential consumers	4260	787	3772	1879	3199
Comercial consumer	624	165	80	81	67
Industrial consumer	1	1	25	5	7
% residential	87%	83%	97%	96%	98%
Facility loading 2022	84%	25%	50%	45%	49%
Max load/consumer	2.0 kWh	3.7 kWh	1.6 kWh	3.0 kWh	1.9 kWh
Power discharge	7.2 kW	7.2 kW	7.2 kW	7.2 kW	7.2 kW
Max peak load decrease	15%	14%	22%	16%	21%
Thershold required	0.77	0.26	0.43	0.41	0.45
Max discharge rule	0.71	0.89	0.66	0.96	0.72
Battery % discharged	30%	30%	30%	30%	30%

The data presented in the table implies the following:

- The **higher the residential consumer distribution,** the **higher the maximum peak load decrease** that can be achieved as a result of being more BEV available per circuit. Circuits 320 and 278 show the highest value among all circuits with 21% and 22% respectively. On the contrary, as circuit 445 residential consumer allocation is the lowest (83%) and $\frac{\max load}{cosnumer}$ is the highest (3.7 kWh, see Table 42), peak load decrease obtained is minimum, 14%. This implies that **achieving a significant reduction in peak load in circuit 445** may be more **challenging** compared to circuits with higher residential distribution.

- Interestingly, circuits 445 and 1266 are close to reach the constrain of a maximum discharge rule lower of 1 (0.89 and 0.96). Circuit 1266 shows a higher value because of a more elevated peak load decrease. The difference between circuits 41 and 445 are derived from the fact that circuit 445 has a higher $\frac{\max load}{cosnumer}$ value, 3.7 kWh respect 2 kWh. Although 320 and 41 have a similar discharge value (0.71 and 0.72), the maximized value is different (21% and 15% respectively) due to the residential allocation (98% and 87% respectively).

- Despite circuit 1266 shows a high residential consumer distribution, similar to circuits 320 and 278, the potential of reducing peak load is lower, 16% peak load decrease against 21% and

22%. This is because the $\frac{\max load}{cosnumer}$ is higher in circuit 1266 (3 kWh against 1.6 kWh and 1.9 kWh, see Table 42).

- As peak load decrease is dependent on the threshold required in each circuit (see equations in section 5.3), **threshold values haven been reduced compared to case 1** (Table 40), because peak load decrease is higher in all circuits.

7. DESCRIPTION OF THE PERFORMED TASKS. GANTT

In this section, the planning of the work carried out is detailed. The main tasks of the project are presented, and a brief description of each one is explained. Finally, the Gantt diagram of the planning is displayed.

7.1. Description of performed tasks

P.T.1 Beginning of the project

In this task, the previous research about V2G is covered. During this phase, the project was preliminary structured and the sections of the project were detailed. This covered from studying the current situation of EV in the United States, specifically in California, to investigating the innovative V2G technology.

P.T.2 Research of assumptions and input parameters for the simulation

During the second task, EV assumptions and distribution lines in the San Diego area were researched to simulate V2G in distribution lines in the San Diego area. This covered studying the specific circuits that fit CCE simulation requirements. Besides, detailed research was done to find the correct EV assumptions, the car home status distribution and the parameters to scale the actual 2022 specifications to 2030. Several meetings were held with Jose Torre-Bueno to discuss the progress of the research. Besides preliminary data was discussed with San Diego Gas & Electric.

P.T.3 Simulation of V2G in distribution lines in the San Diego area

The third task covers the creation of the model in excel, where the simulation of all circuits were performed. Once the simulation was done, different cases were studied, and sensitivity analysis were carried out.

P.T.4 Analysis and verification of the results obtained

In this task, the results obtained were discussed and errors were fixed in collaboration with Jose Torre-Bueno and San Diego Gas & Electric advisor.

P.T.5 Thesis writing

Writing of the thesis which covers the analysis and simulation of V2G in distribution lines in the San Diego area to reduce electric peak load during the evening.

P.T.6 Review

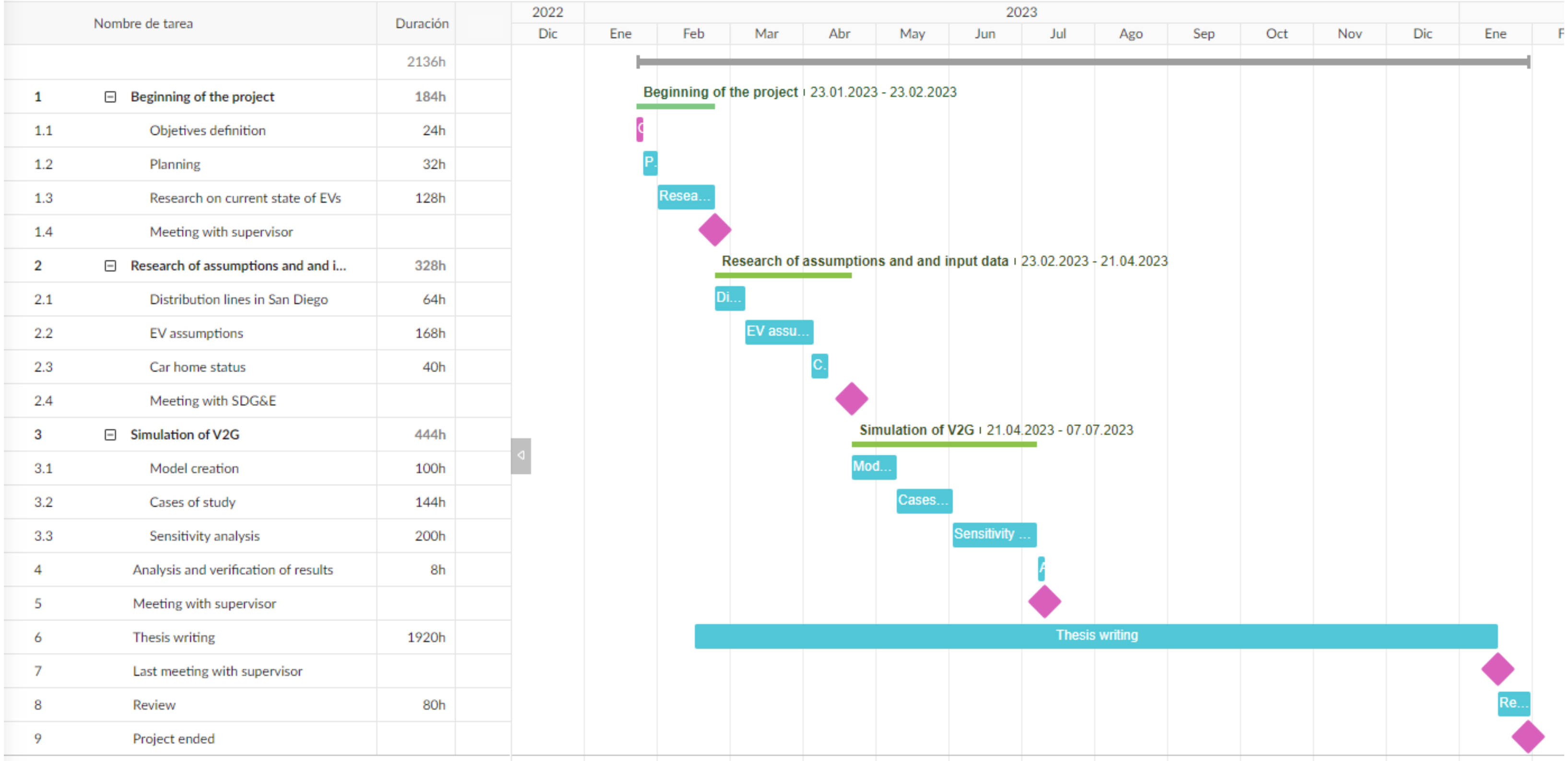
Review of the thesis by the supervisor and verification of the work carried out.

A series of milestones have been established, that have been of vital importance for the successful completion of the work:

- **M.1 Meeting with supervisor about research done on V2G and current EV situation**
- **M.2 Meeting with SDG&E regarding circuits in the San Diego area**

- **M.3 Meeting with supervisor to review the simulation**
- **M.4 Last meeting with supervisor**
- **M.5 Thesis ended**

7.2. Gantt diagram



	Nombre de tarea	Duración
		2136h
1	**Beginning of the project**	184h
1.1	Objetives definition	24h
1.2	Planning	32h
1.3	Research on current state of EVs	128h
1.4	Meeting with supervisor	
2	**Research of assumptions and and i...**	328h
2.1	Distribution lines in San Diego	64h
2.2	EV assumptions	168h
2.3	Car home status	40h
2.4	Meeting with SDG&E	
3	**Simulation of V2G**	444h
3.1	Model creation	100h
3.2	Cases of study	144h
3.3	Sensitivity analysis	200h
4	Analysis and verification of results	8h
5	Meeting with supervisor	
6	Thesis writing	1920h
7	Last meeting with supervisor	
8	Review	80h
9	Project ended	

Figure 51. Gantt Diagramm

8. COST BENEFIT ANALYSIS

8.1. Hours

- The student has completed the thesis in 600 hours.
- The thesis director has helped the project with 40.

8.2. Depreciation

For the depreciation of the PC, a useful lifetime of 5 years and a cost of 1000€ has been assumed. The computer was used approximately 580 hours.

The Microsoft Excel license has been provided by the university.

8.3. Costs

As the nature of this work involves individual research carried out in partnership with CCE, there have been no expenses incurred during the process of crafting the thesis.

8.4. Summary of cost benefit analysis

Table 43 shows the summary of the cost benefit analysis.

Table 43. Summary of cost benefit analysis

Concept	Quantity (h)	Unit price (€/h)	Total price
Hours			13,600.00 €
Director TFM	40	40	1,600.00 €
Student	600	20	12,000.00 €
Depreciation			13.42 €
PC	580	0.023	13.42 €
Microsoft Excel license	-	-	- €
TOTAL			13,613.42 €

9. Conclusion

This study aims to simulate and present a **theoretical model for the concept of charging EVs with solar energy during the daytime and discharging them in the evening when cars arrive home**. This **model** is flexible and can **analyze** the **viability of a V2G scenario** in a specific distribution line in the future. Although this specific idea has not been extensively researched, the model here presented provides an approximate understanding of how such a simulation could be potentially modeled. Although lack of real information has constrained the difficulty of this model, the results obtained are very promising. Acknowledging that CCE's proposal is currently a theoretical concept without real validation, this study offers various interesting cases of study to explore and obtain a wide variety of results. These cases enable the insight of different approaches towards the idea, allowing for a more comprehensive analysis.

To support the V2G model, the work here presented **showcases the potential of EV** to **reduce peak load in the San Diego** area during the evening in 2030. Following Center for Community idea of discharging little amount of energy from EV, peak load during the evening could easily be reduced. The highlights from the simulation made in the San Diego area for 2030 are the following:

- In **case 1**, a 10% peak load decrease is required by discharging energy from batteries. Whereas **circuits 278 and 320** present the most promising results with only discharging **10%** of BEV batteries, **circuits 41 and 445** indicate a value of **15% and 16%** respectively. The reason behind is the fact that these circuits **residential consumers distribution** is lower than circuits 278 and 445. By only discharging this little amount of energy from every BEV connected to the grid, the **hourly load increase factor from 2022-2030 in the peak load could be mitigated**, (9.72% at 19h, see section 5.2.5).
  Since the discharge rule reflects the load factor of a bidirectional charger, it implies that **when there is greater $BEV\ availability$, the amount of energy withdrawn from the batteries will be reduced**. Consequently, circuits 278 and 320 exhibit comparable outcomes due to the similarity in the distribution of residential consumers, with discharge rule values of 0.31 and 0.35 respectively. In contrast, circuits 41 and 445 demonstrate similar levels of battery percentage depletion but different maximum discharge rule values, specifically 0.47 and 0.66. This discrepancy can be attributed to the difference in the number of residential consumers and therefore the $\frac{\max load}{consumer}$. The greater the $\frac{\max load}{consumer}$, the higher the discharge rule.

- As far as **case 2** is concerned, peak load decrease has been maximized in all circuits. Circuits with a higher residential consumer allocation result in **higher peak load decrease** values, as the $BEV\ availability$ is higher. As a maximization problem, the constrain of the model of 30% of battery discharged has been achieved in all circuits. **Distribution lines 320 and 278** show the **highest decreasement** among all circuits with 21% and 22% respectively. On the contrary, as **circuit 445** residential consumer allocation is the lowest (83%), peak load decrease obtained is **minimum**, 14%.
  Interestingly, circuits 445 and 1266 are close to reach the constrain of a maximum discharge rule (0.89 and 0.96 respectively). Circuit 1266 has a higher value due to a more significant

reduction in peak load. The disparity between circuits 41 and 445 can be attributed to the fact that circuit 445 has a higher $\frac{\max load}{cosnumer}$, specifically 3.7 kWh compared to 2 kWh for circuit 41. Although circuits 320 and 41 have similar discharge values (0.71 and 0.72 respectively), the maximized values differ (21% and 15% respectively) due to the **residential allocation** (98% and 87% respectively). The **higher the residential allocation the higher the peak load decreasement.**

With this model a significant contribution to the field of sustainable energy and transportation has been made by offering a versatile model that empowers users to study and evaluate the viability of V2G in any distribution line. The research outcomes contribute to the ongoing discourse on the integration of electric vehicles into the grid.

Overall, this thesis serves as a valuable resource for anyone interested in exploring the potential of V2G scenarios, emphasizing a user-friendly approach to model V2G during the evening and contributing to the advancement of knowledge in the field. Gratitude is extended to Jose and the CCE team for their contributions, as their collaboration has led to the successful completion of this work, delivering highly promising results that affirm the technical feasibility of CCE's business concept.

10. APPENDIX

10.1. Appendix I: Comparison of percentage increase light EV load for scenarios DRAFT, LOW and HIGH from 2022-2030

This table has been used to calculate the Load increase factor parameter. Light EV load is shown in MW and represents the variation of load in 2030 compared to 2022.

Table 44. Light EV load and the variation of load in 2030 compared to 2022.

Hour	DRAFT	LOW	HIGH	DRAFT	LOW	HIGH
1	85	66	94	440%	282%	569%
2	66	51	74	440%	282%	568%
3	44	34	54	442%	285%	574%
4	28	22	35	448%	282%	580%
5	18	14	22	455%	279%	591%
6	10	8	13	475%	450%	769%
7	13	18	26	618%	433%	831%
8	25	28	41	647%	457%	861%
9	36	32	48	666%	459%	856%
10	40	31	48	673%	461%	856%
11	38	31	48	672%	455%	854%
12	34	28	43	674%	454%	867%
13	33	27	41	663%	441%	841%
14	30	25	38	666%	444%	853%
15	29	23	35	656%	448%	829%
16	26	22	32	636%	427%	819%
17	26	22	32	609%	395%	756%
18	28	27	38	569%	356%	700%
19	33	28	41	529%	339%	676%
20	35	29	43	502%	324%	640%
21	37	36	47	473%	300%	606%
22	44	39	56	460%	290%	598%
23	48	60	77	440%	268%	561%
24	74	76	107	416%	293%	567%

10.2. Appendix II: Comparison of percentage increase Behind-The-Meter PV load for scenarios DRAFT, LOW and HIGH from 2022-2030

BTM-PV consumption is shown in MW in 3 columns in the left and represent the variation of load in 2030 compared to 2022. Negative values in the table represent generation, therefore helping the grid not consuming energy from fossil fuel energy plants.

Table 45. BTM-PV consumption and the variation of load in 2030 compared to 2022

Hour	DRAFT	LOW	HIGH	DRAFT	LOW	HIGH
1	0	0	0	0%	0%	0%
2	0	0	0	0%	0%	0%
3	0	0	0	0%	0%	0%
4	0	0	0	0%	0%	0%
5	0	0	0	0%	0%	0%
6	0	0	0	0%	0%	0%
7	0	0	0	0%	0%	0%
8	-89	-92	-87	68%	88%	31%
9	-378	-390	-367	66%	86%	29%
10	-627	-651	-604	60%	78%	25%
11	-723	-750	-697	60%	78%	25%
12	-778	-807	-750	60%	78%	25%
13	-779	-808	-750	60%	78%	25%
14	-695	-721	-670	60%	78%	25%
15	-513	-532	-494	60%	78%	25%
16	-265	-275	-255	60%	77%	25%
17	-13	-13	-12	60%	85%	25%
18	0	0	0	0%	0%	0%
19	0	0	0	0%	0%	0%
20	0	0	0	0%	0%	0%
21	0	0	0	0%	0%	0%
22	0	0	0	0%	0%	0%
23	0	0	0	0%	0%	0%
24	0	0	0	0%	0%	0%

10.3. Appendix III: Model for Case 1: 10% peak load decrease

Table 46. Model for circuit 445, case 1

Circuit 445	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	2200 kWh	26%	26%	2765 kWh	99%	81 BEVs		0.00	2765 kWh		
2	2094 kWh	22%	22%	2549 kWh	99%	81 BEVs		0.00	2549 kWh		
3	2047 kWh	18%	18%	2413 kWh	100%	81 BEVs		0.00	2413 kWh		
4	2004 kWh	15%	15%	2305 kWh	100%	81 BEVs		0.00	2305 kWh		
5	2016 kWh	13%	13%	2277 kWh	99%	81 BEVs		0.00	2277 kWh		
6	2060 kWh	12%	12%	2308 kWh	96%	78 BEVs		0.00	2308 kWh		
7	2125 kWh	11%	11%	2352 kWh	87%	71 BEVs		0.00	2352 kWh		
8	2303 kWh	8%	8%	2485 kWh	68%	55 BEVs		0.00	2485 kWh		
9	2127 kWh	5%	5%	2229 kWh	51%	42 BEVs		0.00	2229 kWh		
10	2027 kWh	2%	2%	2064 kWh	42%	35 BEVs		0.00	2064 kWh		
11	1884 kWh	-3%	-3%	1822 kWh	38%	31 BEVs		0.00	1822 kWh		
12	2013 kWh	-7%	-7%	1874 kWh	35%	28 BEVs		0.00	1874 kWh		
13	2178 kWh	-7%	-7%	2032 kWh	33%	27 BEVs		0.00	2032 kWh		
14	2379 kWh	-5%	-5%	2260 kWh	28%	23 BEVs		0.00	2260 kWh		
15	2471 kWh	-1%	-1%	2454 kWh	28%	23 BEVs		0.00	2454 kWh		
16	2501 kWh	3%	3%	2563 kWh	33%	27 BEVs		0.00	2563 kWh		
17	2710 kWh	5%	5%	2851 kWh	46%	37 BEVs		0.00	2851 kWh		
18	2753 kWh	8%	8%	2982 kWh	68%	56 BEVs	30 kWh	0.08	2952 kWh	1%	0.5 kWh
19	2781 kWh	10%	10%	3051 kWh	82%	67 BEVs	99 kWh	0.23	2952 kWh	3%	1.5 kWh
20	2890 kWh	10%	10%	3175 kWh	88%	72 BEVs	224 kWh	0.48	2952 kWh	7%	3.1 kWh
21	2845 kWh	12%	12%	3199 kWh	91%	74 BEVs	248 kWh	0.51	2952 kWh	8%	3.3 kWh
22	2830 kWh	16%	16%	3280 kWh	94%	76 BEVs	328 kWh	0.66	2952 kWh	10%	4.3 kWh
23	2656 kWh	18%	18%	3131 kWh	96%	78 BEVs	180 kWh	0.36	2952 kWh	6%	2.3 kWh
24	2403 kWh	22%	22%	2930 kWh	98%	80 BEVs		0.00	2930 kWh		

Table 47. Model for circuit 278, case 1

Circuit 278	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	4641 kWh	26%	26%	5832 kWh	99%	387 BEVs		0.00	5832 kWh		
2	4070 kWh	22%	22%	4956 kWh	99%	388 BEVs		0.00	4956 kWh		
3	3785 kWh	18%	18%	4462 kWh	100%	389 BEVs		0.00	4462 kWh		
4	3451 kWh	15%	15%	3968 kWh	100%	390 BEVs		0.00	3968 kWh		
5	3320 kWh	13%	13%	3750 kWh	99%	387 BEVs		0.00	3750 kWh		
6	3235 kWh	12%	12%	3625 kWh	96%	374 BEVs		0.00	3625 kWh		
7	3563 kWh	11%	11%	3945 kWh	87%	339 BEVs		0.00	3945 kWh		
8	3999 kWh	8%	8%	4315 kWh	68%	266 BEVs		0.00	4315 kWh		
9	3978 kWh	5%	5%	4170 kWh	51%	199 BEVs		0.00	4170 kWh		
10	3599 kWh	2%	2%	3665 kWh	42%	165 BEVs		0.00	3665 kWh		
11	3510 kWh	-3%	-3%	3395 kWh	38%	147 BEVs		0.00	3395 kWh		
12	3429 kWh	-7%	-7%	3193 kWh	35%	136 BEVs		0.00	3193 kWh		
13	3764 kWh	-7%	-7%	3511 kWh	33%	127 BEVs		0.00	3511 kWh		
14	3918 kWh	-5%	-5%	3722 kWh	28%	111 BEVs		0.00	3722 kWh		
15	4460 kWh	-1%	-1%	4429 kWh	28%	108 BEVs		0.00	4429 kWh		
16	5054 kWh	3%	3%	5181 kWh	33%	127 BEVs		0.00	5181 kWh		
17	5313 kWh	5%	5%	5589 kWh	46%	179 BEVs		0.00	5589 kWh		
18	5634 kWh	8%	8%	6102 kWh	68%	267 BEVs		0.00	6102 kWh		
19	6070 kWh	10%	10%	6660 kWh	82%	319 BEVs	512 kWh	0.25	6147 kWh	8%	1.6 kWh
20	6217 kWh	10%	10%	6831 kWh	88%	343 BEVs	683 kWh	0.31	6147 kWh	10%	2.0 kWh
21	5988 kWh	12%	12%	6734 kWh	91%	356 BEVs	587 kWh	0.25	6147 kWh	9%	1.6 kWh
22	5822 kWh	16%	16%	6748 kWh	94%	365 BEVs	600 kWh	0.25	6147 kWh	9%	1.6 kWh
23	5435 kWh	18%	18%	6407 kWh	96%	374 BEVs	260 kWh	0.11	6147 kWh	4%	0.7 kWh
24	5096 kWh	22%	22%	6213 kWh	98%	382 BEVs	66 kWh	0.03	6147 kWh	1%	0.2 kWh

Table 48. Model for circuit 1266, case 1

Circuit 1266	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	3727 kWh	26%	26%	4683 kWh	99%	193 BEVs		0.00	4683 kWh		
2	3254 kWh	22%	22%	3962 kWh	99%	193 BEVs		0.00	3962 kWh		
3	2930 kWh	18%	18%	3453 kWh	100%	194 BEVs		0.00	3453 kWh		
4	2643 kWh	15%	15%	3039 kWh	100%	194 BEVs		0.00	3039 kWh		
5	2485 kWh	13%	13%	2807 kWh	99%	193 BEVs		0.00	2807 kWh		
6	2424 kWh	12%	12%	2716 kWh	96%	186 BEVs		0.00	2716 kWh		
7	2410 kWh	11%	11%	2668 kWh	87%	169 BEVs		0.00	2668 kWh		
8	2853 kWh	8%	8%	3079 kWh	68%	132 BEVs		0.00	3079 kWh		
9	3007 kWh	5%	5%	3152 kWh	51%	99 BEVs		0.00	3152 kWh		
10	2802 kWh	2%	2%	2853 kWh	42%	82 BEVs		0.00	2853 kWh		
11	2809 kWh	-3%	-3%	2717 kWh	38%	73 BEVs		0.00	2717 kWh		
12	2808 kWh	-7%	-7%	2615 kWh	35%	68 BEVs		0.00	2615 kWh		
13	2981 kWh	-7%	-7%	2781 kWh	33%	63 BEVs		0.00	2781 kWh		
14	3417 kWh	-5%	-5%	3246 kWh	28%	55 BEVs		0.00	3246 kWh		
15	3960 kWh	-1%	-1%	3933 kWh	28%	54 BEVs		0.00	3933 kWh		
16	4605 kWh	3%	3%	4720 kWh	33%	63 BEVs		0.00	4720 kWh		
17	4923 kWh	5%	5%	5178 kWh	46%	89 BEVs		0.00	5178 kWh		
18	5245 kWh	8%	8%	5681 kWh	68%	133 BEVs	147 kWh	0.17	5534 kWh	3%	1.1 kWh
19	5604 kWh	10%	10%	6149 kWh	82%	159 BEVs	615 kWh	0.60	5534 kWh	10%	3.9 kWh
20	5582 kWh	10%	10%	6132 kWh	88%	171 BEVs	598 kWh	0.54	5534 kWh	10%	3.5 kWh
21	5352 kWh	12%	12%	6019 kWh	91%	177 BEVs	484 kWh	0.42	5534 kWh	8%	2.7 kWh
22	5116 kWh	16%	16%	5929 kWh	94%	182 BEVs	395 kWh	0.34	5534 kWh	7%	2.2 kWh
23	4620 kWh	18%	18%	5447 kWh	96%	186 BEVs		0.00	5447 kWh		
24	4151 kWh	22%	22%	5060 kWh	98%	190 BEVs		0.00	5060 kWh		

Table 49. Model for circuit 320, case 1

Circuit 320	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	4864 kWh	26%	26%	6112 kWh	99%	328 BEVs		0.00	6112 kWh		
2	4471 kWh	22%	22%	5444 kWh	99%	329 BEVs		0.00	5444 kWh		
3	4068 kWh	18%	18%	4795 kWh	100%	330 BEVs		0.00	4795 kWh		
4	3716 kWh	15%	15%	4273 kWh	100%	331 BEVs		0.00	4273 kWh		
5	3482 kWh	13%	13%	3934 kWh	99%	328 BEVs		0.00	3934 kWh		
6	3341 kWh	12%	12%	3744 kWh	96%	317 BEVs		0.00	3744 kWh		
7	3261 kWh	11%	11%	3611 kWh	87%	287 BEVs		0.00	3611 kWh		
8	3444 kWh	8%	8%	3716 kWh	68%	225 BEVs		0.00	3716 kWh		
9	3345 kWh	5%	5%	3506 kWh	51%	169 BEVs		0.00	3506 kWh		
10	3279 kWh	2%	2%	3339 kWh	42%	140 BEVs		0.00	3339 kWh		
11	3290 kWh	-3%	-3%	3182 kWh	38%	124 BEVs		0.00	3182 kWh		
12	3256 kWh	-7%	-7%	3032 kWh	35%	116 BEVs		0.00	3032 kWh		
13	3546 kWh	-7%	-7%	3308 kWh	33%	108 BEVs		0.00	3308 kWh		
14	3871 kWh	-5%	-5%	3677 kWh	28%	94 BEVs		0.00	3677 kWh		
15	4145 kWh	-1%	-1%	4116 kWh	28%	92 BEVs		0.00	4116 kWh		
16	4623 kWh	3%	3%	4738 kWh	33%	108 BEVs		0.00	4738 kWh		
17	4958 kWh	5%	5%	5215 kWh	46%	152 BEVs		0.00	5215 kWh		
18	5430 kWh	8%	8%	5881 kWh	68%	227 BEVs		0.00	5881 kWh		
19	5943 kWh	10%	10%	6520 kWh	82%	270 BEVs	223 kWh	0.13	6297 kWh	3%	0.8 kWh
20	5914 kWh	10%	10%	6498 kWh	88%	291 BEVs	201 kWh	0.11	6297 kWh	3%	0.7 kWh
21	6095 kWh	12%	12%	6854 kWh	91%	302 BEVs	558 kWh	0.28	6297 kWh	8%	1.8 kWh
22	6037 kWh	16%	16%	6997 kWh	94%	310 BEVs	700 kWh	0.35	6297 kWh	10%	2.3 kWh
23	5808 kWh	18%	18%	6847 kWh	96%	317 BEVs	550 kWh	0.27	6297 kWh	8%	1.7 kWh
24	5402 kWh	22%	22%	6587 kWh	98%	324 BEVs	290 kWh	0.14	6297 kWh	4%	0.9 kWh

10.4. Appendix IV: Model for Case 2: peak load decrease maximized

Table 50. Model for circuit 445, case 2

Circuit 445	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	2200 kWh	26%	26%	2765 kWh	99%	81 BEVs		0.00	2765 kWh		
2	2094 kWh	22%	22%	2549 kWh	99%	81 BEVs		0.00	2549 kWh		
3	2047 kWh	18%	18%	2413 kWh	100%	81 BEVs		0.00	2413 kWh		
4	2004 kWh	15%	15%	2305 kWh	100%	81 BEVs		0.00	2305 kWh		
5	2016 kWh	13%	13%	2277 kWh	99%	81 BEVs		0.00	2277 kWh		
6	2060 kWh	12%	12%	2308 kWh	96%	78 BEVs		0.00	2308 kWh		
7	2125 kWh	11%	11%	2352 kWh	87%	71 BEVs		0.00	2352 kWh		
8	2303 kWh	8%	8%	2485 kWh	68%	55 BEVs		0.00	2485 kWh		
9	2127 kWh	5%	5%	2229 kWh	51%	42 BEVs		0.00	2229 kWh		
10	2027 kWh	2%	2%	2064 kWh	42%	35 BEVs		0.00	2064 kWh		
11	1884 kWh	-3%	-3%	1822 kWh	38%	31 BEVs		0.00	1822 kWh		
12	2013 kWh	-7%	-7%	1874 kWh	35%	28 BEVs		0.00	1874 kWh		
13	2178 kWh	-7%	-7%	2032 kWh	33%	27 BEVs		0.00	2032 kWh		
14	2379 kWh	-5%	-5%	2260 kWh	28%	23 BEVs		0.00	2260 kWh		
15	2471 kWh	-1%	-1%	2454 kWh	28%	23 BEVs		0.00	2454 kWh		
16	2501 kWh	3%	3%	2563 kWh	33%	27 BEVs		0.00	2563 kWh		
17	2710 kWh	5%	5%	2851 kWh	46%	37 BEVs	13 kWh	0.05	2838 kWh	0%	0.3 kWh
18	2753 kWh	8%	8%	2982 kWh	68%	56 BEVs	144 kWh	0.40	2838 kWh	5%	2.6 kWh
19	2781 kWh	10%	10%	3051 kWh	82%	67 BEVs	213 kWh	0.49	2838 kWh	7%	3.2 kWh
20	2890 kWh	10%	10%	3175 kWh	88%	72 BEVs	337 kWh	0.73	2838 kWh	11%	4.7 kWh
21	2845 kWh	12%	12%	3199 kWh	91%	74 BEVs	361 kWh	0.75	2838 kWh	11%	4.9 kWh
22	2830 kWh	16%	16%	3280 kWh	94%	76 BEVs	442 kWh	0.89	2838 kWh	13%	5.8 kWh
23	2656 kWh	18%	18%	3131 kWh	96%	78 BEVs	293 kWh	0.58	2838 kWh	9%	3.8 kWh
24	2403 kWh	22%	22%	2930 kWh	98%	80 BEVs	92 kWh	0.18	2838 kWh	3%	1.2 kWh

Table 51. Model for circuit 278, case 2

Circuit 278	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	4641 kWh	26%	26%	5832 kWh	99%	387 BEVs	475 kWh	0.19	5358 kWh	8%	1.2
2	4070 kWh	22%	22%	4956 kWh	99%	388 BEVs		0.00	4956 kWh		
3	3785 kWh	18%	18%	4462 kWh	100%	389 BEVs		0.00	4462 kWh		
4	3451 kWh	15%	15%	3968 kWh	100%	390 BEVs		0.00	3968 kWh		
5	3320 kWh	13%	13%	3750 kWh	99%	387 BEVs		0.00	3750 kWh		
6	3235 kWh	12%	12%	3625 kWh	96%	374 BEVs		0.00	3625 kWh		
7	3563 kWh	11%	11%	3945 kWh	87%	339 BEVs		0.00	3945 kWh		
8	3999 kWh	8%	8%	4315 kWh	68%	266 BEVs		0.00	4315 kWh		
9	3978 kWh	5%	5%	4170 kWh	51%	199 BEVs		0.00	4170 kWh		
10	3599 kWh	2%	2%	3665 kWh	42%	165 BEVs		0.00	3665 kWh		
11	3510 kWh	-3%	-3%	3395 kWh	38%	147 BEVs		0.00	3395 kWh		
12	3429 kWh	-7%	-7%	3193 kWh	35%	136 BEVs		0.00	3193 kWh		
13	3764 kWh	-7%	-7%	3511 kWh	33%	127 BEVs		0.00	3511 kWh		
14	3918 kWh	-5%	-5%	3722 kWh	28%	111 BEVs		0.00	3722 kWh		
15	4460 kWh	-1%	-1%	4429 kWh	28%	108 BEVs		0.00	4429 kWh		
16	5054 kWh	3%	3%	5181 kWh	33%	127 BEVs		0.00	5181 kWh		
17	5313 kWh	5%	5%	5589 kWh	46%	179 BEVs	231 kWh	0.20	5358 kWh	4%	1.3 kWh
18	5634 kWh	8%	8%	6102 kWh	68%	267 BEVs	745 kWh	0.43	5358 kWh	12%	2.8 kWh
19	6070 kWh	10%	10%	6660 kWh	82%	319 BEVs	1302 kWh	0.63	5358 kWh	20%	4.1 kWh
20	6217 kWh	10%	10%	6831 kWh	88%	343 BEVs	1473 kWh	0.66	5358 kWh	22%	4.3 kWh
21	5988 kWh	12%	12%	6734 kWh	91%	356 BEVs	1376 kWh	0.60	5358 kWh	20%	3.9 kWh
22	5822 kWh	16%	16%	6748 kWh	94%	365 BEVs	1390 kWh	0.59	5358 kWh	21%	3.8 kWh
23	5435 kWh	18%	18%	6407 kWh	96%	374 BEVs	1050 kWh	0.43	5358 kWh	16%	2.8 kWh
24	5096 kWh	22%	22%	6213 kWh	98%	382 BEVs	856 kWh	0.35	5358 kWh	14%	2.2 kWh

Table 52. Model for circuit 1266, case 2

Circuit 1266	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	3727 kWh	26%	26%	4683 kWh	99%	193 BEVs		0.00	4683 kWh		
2	3254 kWh	22%	22%	3962 kWh	99%	193 BEVs		0.00	3962 kWh		
3	2930 kWh	18%	18%	3453 kWh	100%	194 BEVs		0.00	3453 kWh		
4	2643 kWh	15%	15%	3039 kWh	100%	194 BEVs		0.00	3039 kWh		
5	2485 kWh	13%	13%	2807 kWh	99%	193 BEVs		0.00	2807 kWh		
6	2424 kWh	12%	12%	2716 kWh	96%	186 BEVs		0.00	2716 kWh		
7	2410 kWh	11%	11%	2668 kWh	87%	169 BEVs		0.00	2668 kWh		
8	2853 kWh	8%	8%	3079 kWh	68%	132 BEVs		0.00	3079 kWh		
9	3007 kWh	5%	5%	3152 kWh	51%	99 BEVs		0.00	3152 kWh		
10	2802 kWh	2%	2%	2853 kWh	42%	82 BEVs		0.00	2853 kWh		
11	2809 kWh	-3%	-3%	2717 kWh	38%	73 BEVs		0.00	2717 kWh		
12	2808 kWh	-7%	-7%	2615 kWh	35%	68 BEVs		0.00	2615 kWh		
13	2981 kWh	-7%	-7%	2781 kWh	33%	63 BEVs		0.00	2781 kWh		
14	3417 kWh	-5%	-5%	3246 kWh	28%	55 BEVs		0.00	3246 kWh		
15	3960 kWh	-1%	-1%	3933 kWh	28%	54 BEVs		0.00	3933 kWh		
16	4605 kWh	3%	3%	4720 kWh	33%	63 BEVs		0.00	4720 kWh		
17	4923 kWh	5%	5%	5178 kWh	46%	89 BEVs	13 kWh	0.02	5165 kWh	0%	0.1 kWh
18	5245 kWh	8%	8%	5681 kWh	68%	133 BEVs	516 kWh	0.60	5165 kWh	9%	3.9 kWh
19	5604 kWh	10%	10%	6149 kWh	82%	159 BEVs	984 kWh	0.96	5165 kWh	16%	6.2 kWh
20	5582 kWh	10%	10%	6132 kWh	88%	171 BEVs	967 kWh	0.87	5165 kWh	16%	5.7 kWh
21	5352 kWh	12%	12%	6019 kWh	91%	177 BEVs	853 kWh	0.74	5165 kWh	14%	4.8 kWh
22	5116 kWh	16%	16%	5929 kWh	94%	182 BEVs	764 kWh	0.65	5165 kWh	13%	4.2 kWh
23	4620 kWh	18%	18%	5447 kWh	96%	186 BEVs	281 kWh	0.23	5165 kWh	5%	1.5 kWh
24	4151 kWh	22%	22%	5060 kWh	98%	190 BEVs		0.00	5060 kWh		

Table 53. Model for circuit 320, case 2

Circuit 320	2022 Load	Assumed icrease	Fixed increase	2030 Load	% cars home	BEV availables	Energy discharged	Discharge rule	2030 load / V2G	Peak Load decrease	Energy discharged per BEV per hour
1	4864 kWh	26%	26%	6112 kWh	99%	328 BEVs	566 kWh	0.27	5546 kWh	9%	1.7
2	4471 kWh	22%	22%	5444 kWh	99%	329 BEVs		0.00	5444 kWh		
3	4068 kWh	18%	18%	4795 kWh	100%	330 BEVs		0.00	4795 kWh		
4	3716 kWh	15%	15%	4273 kWh	100%	331 BEVs		0.00	4273 kWh		
5	3482 kWh	13%	13%	3934 kWh	99%	328 BEVs		0.00	3934 kWh		
6	3341 kWh	12%	12%	3744 kWh	96%	317 BEVs		0.00	3744 kWh		
7	3261 kWh	11%	11%	3611 kWh	87%	287 BEVs		0.00	3611 kWh		
8	3444 kWh	8%	8%	3716 kWh	68%	225 BEVs		0.00	3716 kWh		
9	3345 kWh	5%	5%	3506 kWh	51%	169 BEVs		0.00	3506 kWh		
10	3279 kWh	2%	2%	3339 kWh	42%	140 BEVs		0.00	3339 kWh		
11	3290 kWh	-3%	-3%	3182 kWh	38%	124 BEVs		0.00	3182 kWh		
12	3256 kWh	-7%	-7%	3032 kWh	35%	116 BEVs		0.00	3032 kWh		
13	3546 kWh	-7%	-7%	3308 kWh	33%	108 BEVs		0.00	3308 kWh		
14	3871 kWh	-5%	-5%	3677 kWh	28%	94 BEVs		0.00	3677 kWh		
15	4145 kWh	-1%	-1%	4116 kWh	28%	92 BEVs		0.00	4116 kWh		
16	4623 kWh	3%	3%	4738 kWh	33%	108 BEVs		0.00	4738 kWh		
17	4958 kWh	5%	5%	5215 kWh	46%	152 BEVs		0.00	5215 kWh		
18	5430 kWh	8%	8%	5881 kWh	68%	227 BEVs	335 kWh	0.23	5546 kWh	6%	1.5 kWh
19	5943 kWh	10%	10%	6520 kWh	82%	270 BEVs	974 kWh	0.56	5546 kWh	15%	3.6 kWh
20	5914 kWh	10%	10%	6498 kWh	88%	291 BEVs	951 kWh	0.50	5546 kWh	15%	3.3 kWh
21	6095 kWh	12%	12%	6854 kWh	91%	302 BEVs	1308 kWh	0.67	5546 kWh	19%	4.3 kWh
22	6037 kWh	16%	16%	6997 kWh	94%	310 BEVs	1450 kWh	0.72	5546 kWh	21%	4.7 kWh
23	5808 kWh	18%	18%	6847 kWh	96%	317 BEVs	1301 kWh	0.63	5546 kWh	19%	4.1 kWh
24	5402 kWh	22%	22%	6587 kWh	98%	324 BEVs	1040 kWh	0.50	5546 kWh	16%	3.2 kWh

10.5. Appendix V: Home status

Following, the Excel tables downloaded from the National Highway Travel Survey are displayed. Both tables have been used to complete the home status assumption.

Trip purpose: WORK

Table 54. Car home status calculation, Trip Home-work

Trip End Time	Sample Size	Share of sampled vehicles	Work home status
0	52	0%	99.9%
1	24	0%	99.9%
2	30	0%	99.9%
3	36	0%	99.8%
4	864	1%	98.9%
5	3,338	4%	95.3%
6	8,866	10%	85.7%
7	18,239	20%	66.0%
8	16,512	18%	48.1%
9	8,635	9%	38.7%
10	5,067	5%	33.3%
11	4,172	5%	28.7%
12	5,752	6%	22.5%
13	6,276	7%	15.7%
14	4,200	5%	11.2%
15	3,215	3%	7.7%
16	2,456	3%	5.0%
17	1,771	2%	3.1%
18	1,203	1%	1.8%
19	548	1%	1.2%
20	324	0%	0.9%
21	331	0%	0.5%
22	318	0%	0.2%
23	163	0%	0.0%
All	92,392	100%	

Trip purpose: HOME

Table 55. Car home status calculation, Trip Home-work

Trip End Time	Sample Size	Share of sampled vehicles	Home work status
0	523	1%	1%
1	203	0%	2%
2	153	0%	2%
3	124	0%	2%
4	42	0%	2%
5	91	0%	3%
6	264	1%	3%
7	470	1%	4%
8	374	1%	5%
9	301	1%	6%
10	297	1%	6%
11	833	2%	8%
12	1,730	4%	12%
13	1,144	3%	15%
14	1,720	4%	19%
15	3,684	8%	27%
16	7,100	16%	43%
17	10,817	24%	67%
18	6,421	15%	82%
19	3,008	7%	89%
20	1,623	4%	92%
21	1,204	3%	95%
22	1,161	3%	98%
23	995	2%	100%
All	44,282	100%	

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