Blueprint to California Energy Commission Clean Transportation Program: Blueprints for Medium- and Heavy-Duty Zero-Emission Vehicle Infrastructure

Grossmont Union High School District (GUHSD) School Bus Fleet Electrification Blueprint

Task 3: Advanced Electrification of School Bus Service

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SECTION 1. PROJECT CONTEXT

PROJECT SUMMARY

The goal of this project is to develop a blueprint for the full transition of the Grossmont Union High School District (GUHSD) fleet of school buses to a clean, affordable, and resilient electric fleet over the next 20 years. This shift to zero-emission vehicles (ZEVs) will reduce greenhouse gas (GHG) emissions in the communities GUHSD serves, improving overall air quality and reducing students' exposure to harmful pollutants. This blueprint will also inform GUHSD's efforts to expand bus service in underserved areas, to endorse and support innovation that helps future-proof their electric fleet, to secure financial resources for deployment, and to facilitate meaningful community-learning and workforce-development opportunities.

Notably, the process, findings, and insights from this project can be leveraged and replicated to guide school bus fleet electrification efforts by school districts across California and across the US, thereby supporting a steady and significant adoption of electric school buses over the next few years.

TASK GOALS

This report covers the activities outlined in Task 3 in the original application's Scope of Work.

Task 3. Advanced Electrification of School Bus Service: The goal of this task is to further advance innovation for school bus electrification by accounting for bi-directional charging capabilities, leveraging the buses as an energy and grid asset while still fulfilling their mobility service. Building on the previous work in "Task 2- Essential Electrification of Existing School Bus Service" (hereby known as Task 2), this task quantifies how bi-directional charging changes the optimal fleet configuration and operation for specific vehicle-to-building (V2B) and/or vehicle-to-grid (V2G) use-cases.

SECTION 2. THE TWO V2G USE-CASES

This report analyzes two overarching use-cases that look at two ways for V2G-enabled buses and charging stations to add value for GUHSD. Each use-case entails several scenario analyses and sensitivity analyses.

- Use-case 1 examines the optimal technical configuration and economics of a fully functional V2G fleet, to minimize GHG emissions and total cost of ownership.
- Use-case 2 examines how GUHSD can utilize V2G capabilities to optimize revenue from participating in SDG&E's Emergency Load Reduction Program (ELRP).
- The subsections below outline how each use-case is defined, and the steps taken to validate these use-cases through stakeholder engagement.

DEFINING THE USE-CASES

The use-cases analyzed in this report are determined through a 2-step process:

- Step 1: We mapped out the range of possible vehicle-grid-integration use-cases. The California Joint Agencies Vehicle-grid Integration Group provides a framework to define a variety of use-cases, based on multiple dimensions (see Figure 1).[1] From these dimensions, we evaluated which range of V2G applications are potentially relevant for GUHSD.
- Step 2: The use-cases in this report are determined based on two key objectives:
    - Deliver economic value to GUHSD: Use-cases must clearly provide economic value, in the form of additional revenue or cost savings.
    - Leverage commercial or nearly commercial technologies and business models: Use-cases must not be overly complex. A use-case must be simple enough to be:
        - Accurately modeled to determine the reasonable range of expected revenue
        - Implementable by GUHSD staff and contractors, with the ability to realize tangible economic value, starting in 2025

Based on the above steps, for the two chosen use-cases, we describe (i) *what* the use-case examines, (ii) *why* the use-case is relevant, and (iii) *how* the analysis is designed.

- Use-case 1: Optimal technical configuration and economics of a fully functional V2G fleet
    - What: This use-case analyzes the minimum TCO that a fully functional V2G fleet can achieve through daily operations. This use-case examines three V2G scenarios, looking at different configurations of V2G buses and charging stations, combined with distributed energy resources (DERs) (these scenarios are detailed in the next section).
    - Why: V2G enables more efficient use of energy, which could result in energy cost savings. Use-case 1 highlights the changes in technical specifications and economics of GUHSD's fleet upon adding V2G capabilities.
    - How: Use-case 1 is analyzed based on the same optimization tool used in Task 2, Prosumer. Modeling assumes the same baseline conditions as Task 2, but models only V2G-capable buses and charging. The analysis covers Phases 3, 4a, and 4b, since those are the phases that will be developed far enough in the future (beyond 2025) to

[1] https://gridworks.org/wp-content/uploads/2020/09/GW_VehicleGrid-Integration-Working-Group.pdf

plan for V2G infrastructure.

- Use-case 2: Use V2G capabilities to optimize GUHSD fleet's participation in the ELRP
  - What: This use-case examines how GUHSD can utilize V2G to generate revenue during events called under SDG&E's ELRP. ELRP events occur in May through October. Each event lasts up to 5 hours and can occur up to 12 total days each year.
  - Why: The ELRP is meant to offer incentives for end-customers to support grid resiliency, especially in the face of emerging climate-change challenges like wildfires. During an ELRP event, the utility offers $1 per kWh of energy that is discharged back to the grid. The revenue is in addition to any cost savings provided through V2G applications in Use-case 1. Relative to other vehicles, school buses are particularly well positioned to discharge during ELRP events because of their large batteries and low operational demands when the events take place (between 4:00pm and 9:00pm).
  - How: We develop a customized techno-economic simulation model to evaluate the ability of school buses to discharge during an ELRP event. As with Use-case 1, the analysis covers Phases 3, 4a, and 4b, since those are the phases that will be developed far enough in the future (beyond 2025) to plan for V2G infrastructure.

VALIDATING USE-CASES THROUGH STAKEHOLDER ENGAGEMENT

Communication with stakeholders is a priority during every project task. During Task 3, stakeholder communication allowed the two abovementioned use-cases to be properly created, vetted, and populated with appropriate assumptions. Stakeholders that were engaged as part of Task 3 fall under three categories:

- Decision-making stakeholders
  - Katy Wright: Executive Director of Facilities at GUHSD
  - Clarence "CJ" Rasure: Director of Transportation Solutions at GUHSD
  - Lindsey Danner: Aquatics and Energy Manager at GUHSD
  - Dialogue with the decision-making stakeholders occurs weekly through virtual meetings as well as email and phone call correspondence as needed. They remain actively involved with ENGIE Impact to ensure coordination in all planning efforts and to provide all relevant data and assumptions about the GUHSD fleet.
- Advisory stakeholders
  - Staff, teachers, and students from GUHSD
    - Scott Patterson: Deputy Superintendent
    - John Stevenson: Fleet Maintenance Supervisor
    - Esteban Monge: Teacher
    - Madison Chesebro: Student
    - Austin Mitchell: Student
    - Sophie Morton: Student
    - Lina Shammas: Student
    - Nadeen Youhanan: Student

    - Local city-level government officials:
        - Hilary Ego: Environmental Program Manager, City of La Mesa
        - Chris Jacobs: Principal Planner, City of Santee
    - Utility representatives from SDG&E:
        - Michelle White: Senior Account Executive
        - Dinah Willier: Account Manager, Power Your Drive program
    - Local non-profits and non-governmental organizations:
        - Ian Baird: Associate Energy Specialist, California Energy Commission (CEC)
        - Sarah Burns: Director of Research Applications, San Diego Workforce Partnership (SDWP)
    - Dialogue with the advisory stakeholders occurred in virtual, hour-long Town Hall sessions. One session was held at the end of Task 2 / beginning of Task 3, and a second was held roughly six weeks later, at the end of Task 3. The objective of these sessions was to share progress on all aspects of the GUHSD fleet electrification Blueprint and to receive feedback on critical decisions made by the planning team.
- Other stakeholders:
    - EV Bus manufacturers: including Blue Bird, Green Power Motor Company, IC Bus, Lion Electric Company, Motiv Power Systems, Phoenix Motorcars, and Proterra.
    - EV Charging Station manufacturers: including ABB, Blink Charging, BTC Power, ChargePoint, EVBox, Rhombus Energy, Nuvve, and Proterra.
    - Engineering Procurement and Construction (EPC) firms: including ENGIE North America, Aetna Corp, and Bureau Veritas.
    - Utility representatives (in addition to the advisory stakeholders): including additional staff from SDG&E and from Dominion Energy.
    - Dialogue with these stakeholders occurred via emails and phone calls as needed, during Task 2 and/or Task 3. The objective of these discussions was to gather market information, update internal databases on products' technical and pricing specifications, and validate modeling assumptions.

With such a diverse group of stakeholders, it is important to regularly communicate with all relevant parties to ensure that questions and concerns were handled efficiently and effectively. Communication is bi-directional, allowing the GUHSD and ENGIE Impact team to validate operational and technology assumptions required for modeling and enabling stakeholders to ask probing questions regarding the project. In doing so, the stakeholders play a vital role in identifying any potential blind spots or risks coming out of the modeling exercise and recommendations to ensure the successful completion of the analysis. With the buy-in and engagement of this diverse group of stakeholders, GUHSD remains confident in the successful completion of this project.

Figure 1: Dimensions of a use-case assessment framework and use-case definition options (source: California Joint Agencies Vehicle-Grid Integration Working Group)

SECTOR	APPLICATION	TYPE	APPROACH	RESOURCE ALIGNMENT
Residential-Single-Family Home	Customer-Bill Management	V1G	Indirect (passive)	Unified and Aligned
Residential-Single-Family Home, Rideshare	Customer-Upgrade Deferral	V2G	Direct (active)	Fragmented and Aligned
Residential-Multi-Unit Dwelling	Customer-Backup, Resiliency			Fragmented and Misaligned
Residential-Multi-Unit Dwelling Rideshare	Customer-Renewable Self-Consumption			
Commercial-Workplace	System-Grid Upgrade Deferral			
Commercial-Public, Destination	System-Backup, Resiliency			
Commercial-Public, Destination Rideshare	System-Voltage Support			
Commercial-Public, Commute	System-Day-Ahead Energy			
Commercial-Public, Commute Rideshare	System-Real-Time Energy			
Commercial-Fleet, Transit Bus	System-Renewable Integration			
Commercial-Fleet, School Bus	System-GHG Reduction			
Commercial-Fleet, Small Truck (class 3-5)	System-RA, System Capacity			
Commercial-Fleet, Large Truck (class 6-8)	System-RA, Flex Capacity			
	System-RA, Local Capacity			
	System-Frequency Regulation Up/Down			
	System-Spinning Reserve			
	System-Non-Spinning Reserve			

SECTION 3. USE-CASE 1: OPTIMAL TECHNICAL CONFIGURATION AND ECONOMICS OF A FULLY FUNCTIONAL V2G FLEET

METHODOLOGY

Digital Tools & Modeling Approach: Prosumer

The analysis was conducted using a digital tool developed in-house by ENGIE Impact, called Prosumer. Prosumer is a multi-objective optimization tool which comes with a library of reference data. Through a robust platform, Prosumer considers the existing energy and mobility infrastructure, the new energy and mobility demand profiles that need to be satisfied, and the list of energy and mobility hardware technologies to consider. From that, Prosumer calculates the optimal investment strategy in mobility and energy assets for a predetermined project lifetime. The analyses by ENGIE Impact leverage extensive up-to-date databases to select the optimal electric buses, charging stations, and DERs from a variety of existing and competitive technology options, tailored and customized to GUHSD's geographical setting in San Diego, California, and within the SDG&E service area.

The analyses seek to minimize the total cost of ownership and CO2 emissions for a V2G-enabled fleet over a total project lifetime of 20 years. In particular, the model optimizes the bus charging/discharging profiles and the integration of charging with energy supply from both the grid and/or distributed energy resources (DERs), given different scenarios and constraints. In this task, we do not optimize explicitly for electric bus model, charging infrastructure size and type, or battery assets. Rather, we use the optimal selection of these variables from Task 2.

Modeling Scenarios

GUHSD's fleet electrification is divided into 4 Phases, with routes in each phase corresponding to the order in which their service buses will be transitioned to electric vehicles in the future.

As explained in Task 2, Phase 1 fleet electrification is deemed out of scope for this report, since the planning analysis and modeling for Phase 1 has already been completed and procurement processes are active. Here we also exclude Phase 2, which we assume will be implemented before V2G options reach large-scale commercial and regulatory maturity.

This analysis focuses on modeling V2G-enabled electric buses within Phase 3 and 4, for a total of 40 routes. The vehicle breakdown is as follows:

- Phase 3: 11 buses
- Phase 4: 29 buses
    - Phase 4a: 14 buses
    - Phase 4b: 15 buses

Within each Phase, we model three distinct V2G Scenarios. These scenarios highlight the interactions between system variables like the size of the solar PV, bus battery capacity, and charger maximum nameplate capacity, as well as the sensitivity of the overall economics to these variables.

- Scenario 1 [V2G Only]:
  - No DERs (i.e. solar PV) are allowed.
  - Buses and chargers are selected based on Task 2 (essential electrification without V2G). If a bus or charger selected in Task 2 is not bi-directionally capable, we exchange it with a bi-directional technology and match specifications as closely as possible.
  - Buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.

  Scenario Rationale: This scenario is designed to show the fundamentals of V2G behavior within the Tiered NEM system.

- Scenario 2 [V2G; DERs]:
  - Solar is optimally selected
  - Buses and chargers are selected based on Task 2 (essential electrification without V2G). If a bus or charger selected in Task 2 is not bi-directionally capable, we exchange it with a bi-directional technology and match specifications as closely as possible.
  - Buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.

  Scenario Rationale: This scenario is designed as the "baseline" V2G case, and the most realistic choice for GUHSD.

- Scenario 3 [V2G; DERs; Upgraded Buses + Chargers]:
  - Solar is optimally selected
  - Buses are upgraded uniformly to 226 kWh Thomas C2 Jouley2 buses and chargers are upgraded uniformly to 60 kW Proterra bi-directional chargers.
  - The buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.

  Scenario Rationale: This scenario is designed to explore the economic and operational sensitivity of the V2G fleet to larger batteries and faster charge rates.

Other key modeling constraints:

- The project lifetime for each phase of fleet electrification, used to estimate total cost of ownership, is 20 years. The phases of fleet electrification are staggered, one coming subsequently after the other.
- While rooted in and based on real technological options for buses, charging stations, and distributed energy resources, this analysis emphasizes conceptual technological and economic specifications, e.g., bus battery range, bus seating capacity, and EVSE charging power; the specific product brand or vendor identity is deprioritized. The vendor selection is less relevant to this planning and blueprinting effort, and becomes more relevant during the procurement process, as we explain later.
- Inflation and WACC are assumed to both be 0%. This assumption can be adjusted in the final dashboard output available to GUHSD, to get an updated Total Cost of Ownership calculation.

Inputs & Assumptions

Many inputs and assumptions in this model are identical to those for a non-V2G fleet; more detailed descriptions of these assumptions can be found in the Task 2 report. Other assumptions specific to V2G are updated.

Inputs and assumptions carried over from Task 2:

- Bus routes and schedules: based on GUHSD-provided data.
- Bus technology: ENGIE leverages its extensive internal database of technical specifications, cost, lifetime, and performance metrics for all buses.
    - As a reminder, OPEX is not included due to lack of sufficient data.
- Solar profile: A solar irradiance profile[2,3] from 2019 is used, specific for the geographic location of GUHSD in San Diego, California. The 2019 solar radiance profile is assumed to be repeated year after year, over the project's total 20-year lifetime.
- Solar technology: Cost estimates related to onsite solar PV systems are based on ENGIE's market estimates and informed by actual project experience. These estimates include full installation costs, which is important to compare the fully loaded cost of energy from DER vs. utility rates from the grid.
- Utility Time-of-Use (TOU) pricing: Electricity cost for EV charging is calculated based on SDG&E EV-HP billing rate. EV-HP is a time-of-use (TOU) rate, with three pricing tiers: Super-off-peak (least expensive), Off-peak (moderately expensive), and On-peak (most expensive). For modeling purposes, the electricity billing rate is assumed to be fixed for the whole 20-year duration of project and is the average price between Rate 1 (year 1 through 3), and Rate 2 (beyond year 11) (See Task 2, Table 6).

Inputs and assumptions updated in Task 3:

- EVSE technology: ENGIE leverages its extensive internal database of electric vehicle charging infrastructure, technical specifications, cost (both CAPEX and OPEX), and lifetime for all charging stations. This database was updated to incorporate bi-directional charger specifications and costs as part of this scope of work.
    - As a reminder, engineering, procurement, and construction (EPC) costs for charging stations are not included in this analysis. Also, we assume that modular 30 kW bi-directional Proterra chargers might become available in the future, by the time Grossmont is ready to initiate the implementation of V2G capabilities in its fleet.
- Tiered Net Energy Metering (NEM):
    - Net-energy-metering (NEM) is a utility-billing accounting mechanism that allows utility customers to send their excess energy from behind-the-meter onsite solar systems back to the grid in order to offset the electricity they draw from the grid. GUHSD pays for the

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[2] Solar irradiance is the output of light energy from the Sun, as received and measured here on Earth. In more technical terms, it's the power per unit area received in the form of electromagnetic radiation. Solar panels collect light from the sun to turn it into electricity. The efficiency of solar panels depends on the amount of light the panels receive at their location - or solar irradiance - [What is Global Horizontal Irradiance (GHI) and Why Does It Matter? (globalweathercorp.com)]

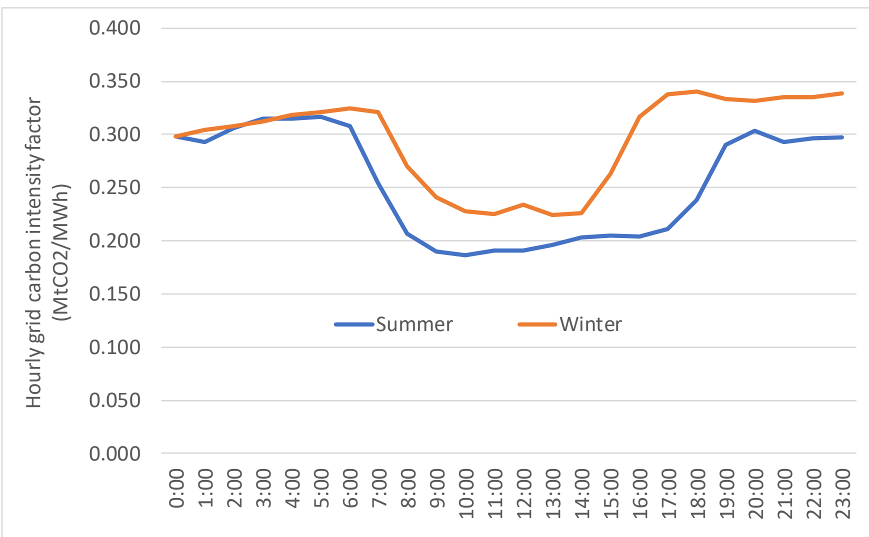
[3] PVWatts Calculator by NREL: https://pvwatts.nrel.gov/pvwatts.php

net energy consumed from the utility grid. This accounting mechanism is explained thoroughly in Task 2.

- Here, we assume that energy discharged by the V2G-capable buses generate NEM credits in the same way as solar; the compensation rate is identical and follows the TOU billing rate structure. At the end of the monthly billing cycle, solar and V2G credits are combined and netted against total energy imports in each of the three distinct tiers.
    - While there is no existing regulatory mechanism in SDG&E territory for V2G credit accounting using Tiered NEM, we assume here that a kWh exported to the grid is equal in value regardless of origin (solar or V2G).

- Grid emissions:
    - The total reduction in GHG emissions is analyzed over the 20-year lifetime period for each fleet electrification phase, by comparing the carbon intensity of the original diesel buses to those of the new electric buses powered by the grid and onsite solar PV.
    - To ensure accurate and realistic accounting, the modeling only accounts for the GHG emissions associated with energy used for bus mobility needs. GHG emissions associated with the energy stored and then discharged from the buses are not accounted for.

Figure 2: Average Daily Grid Carbon Intensity



RESULTS

The analysis builds on the results of Task 2 to quantify how the addition of vehicle-to-grid (V2G) capabilities, as well as the integration of V2G with onsite solar and NEM mechanisms, changes the optimal configuration and operation for the GUHSD fleet. Each Phase (Phase 3, 4a, and 4b) of bus replacement follows three possible V2G Scenarios, as described above.

- One key result is that integrating V2G with optimally selected solar PV can *more successfully balance NEM credits for an electric fleet*, therefore decreasing grid energy costs – and overall energy supply costs, compared to either solar PV or V2G alone. This is a direct result of several important observations:
    - Solar energy is generated primarily during off-peak hours, with little generation during on-peak and super-off-peak hours. While Tiered NEM allows using the grid as a virtual storage system, enabling the balancing of some grid-energy expense with solar-energy credits, NEM is limited by the rigidity of the solar generation profile; without additional physical storage, there is no physical way to shift the energy credits among the various tiers to minimize total energy cost.
    - The levelized cost of deployed rooftop solar is cheaper than even the super-off-peak pricing once the demand charge subscription fee is accounted for. This means that there is an economic benefit from storing solar energy and using it to recover NEM credits across all tiers: super-off-peak, off-peak, and on-peak.
    - Buses that are V2G-capable act as flexible, albeit constrained, batteries. The vehicles store solar energy, primarily on Friday afternoon and over the weekends when there is no mobility demand to complete trips, and can discharge this energy as needed to optimally balance NEM expenses with credits within each and all three NEM tiers.
    - Without solar energy, buses can still perform energy arbitrage from the super-off-peak period to the on-peak and off-peak periods, but there are no opportunities to offset costs during super-off-peak hours. Thus, V2G provides more value in the presence of solar PV.
- A second key result is that combining V2G and solar leads to a complex relationship between bus charging/discharging profiles, NEM credit balance, and grid peak load. When solar capacity and/or bus battery capacity is increased, there is more flexibility and more options to minimize energy costs.
    - If the size of the deployed solar system increases: more NEM credits are generated and can be reallocated to balance NEM accounting, particularly the deficit in the super-off-peak tier. To achieve this balance, buses may shift some super-off-peak charging after midnight to other tiers, and thus need to charge at a higher rate for fewer hours to meet mobility demands. This in turn may increase the grid peak load.
    - If buses are upgraded to incorporate larger batteries than needed (optimally selected) for their mobility needs: Buses may either overcharge directly from solar in the middle of the day on weekdays, or they may overcharge directly from solar throughout the day on weekends. Each overcharging option will have its own unique implication on the redistribution of charging and discharging profiles, peak grid load, and the balancing of NEM credits and expenses across the various tiers. However, all options result in overall lower energy supply from the grid, and therefore less NEM energy expenses.
    - Despite minimizing energy costs, increasing the capacity of solar PV systems and/or bus batteries also results in a nontrivial increase in CAPEX. The trade-off between reducing total energy cost and increasing capital costs for assets is important, and upsizing solar and/or buses may not always be beneficial for minimizing the overall total cost of ownership.

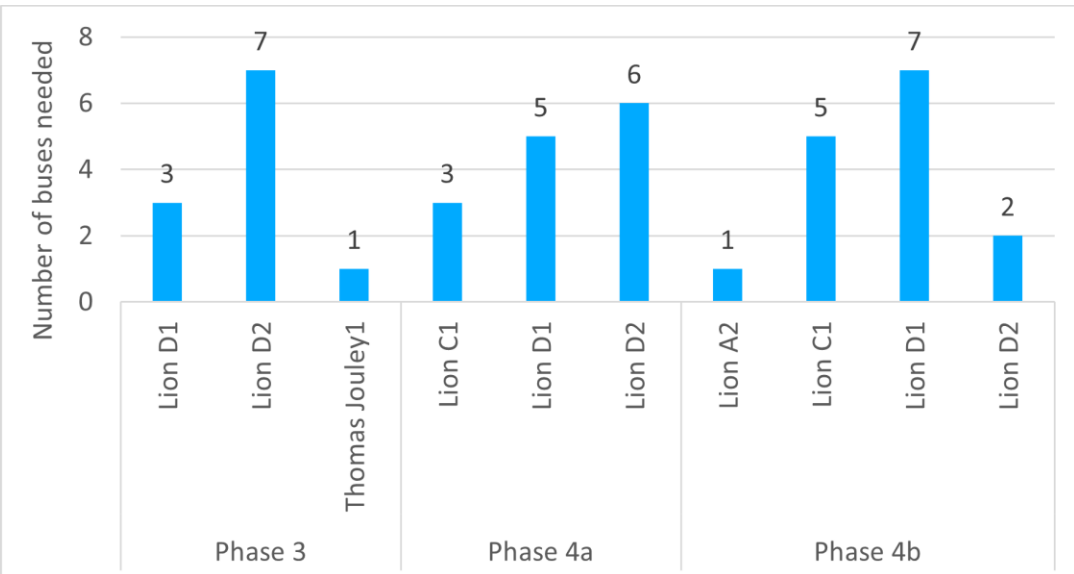
While Scenario 1 (V2G only) and Scenario 3 (V2G; DERs; Upgraded Buses + Chargers) provide additional insights to the V2G model behavior (described in detail in the following sections), we focus here on the baseline Scenario 2 (V2G; DERs). As a reminder, buses and chargers are selected based on Task 2, and onsite PV is optimally selected to minimize the total cost of ownership.

<u>Buses and Chargers:</u>

Bus selection closely follows the results of Task 2; in fact, only one bus is substituted:

- 1 Lion A2 bus (54 seats, 168 kWh battery, 150 mile range)
    - substituted for non-V2G-capable Motiv & Collins bus
- 8 Lion C1 buses (77 seats, 126 kWh battery, 100 mile range)
- 15 Lion D1 buses (61 seats, 132 kWh battery, 100 mile range)
- 15 Lion D2 buses buses (83 seats, 168 kWh battery, 125 mile range)
- 1 Thomas Jouley1 bus (54 seats, 226 kWh battery, 138 mile range)

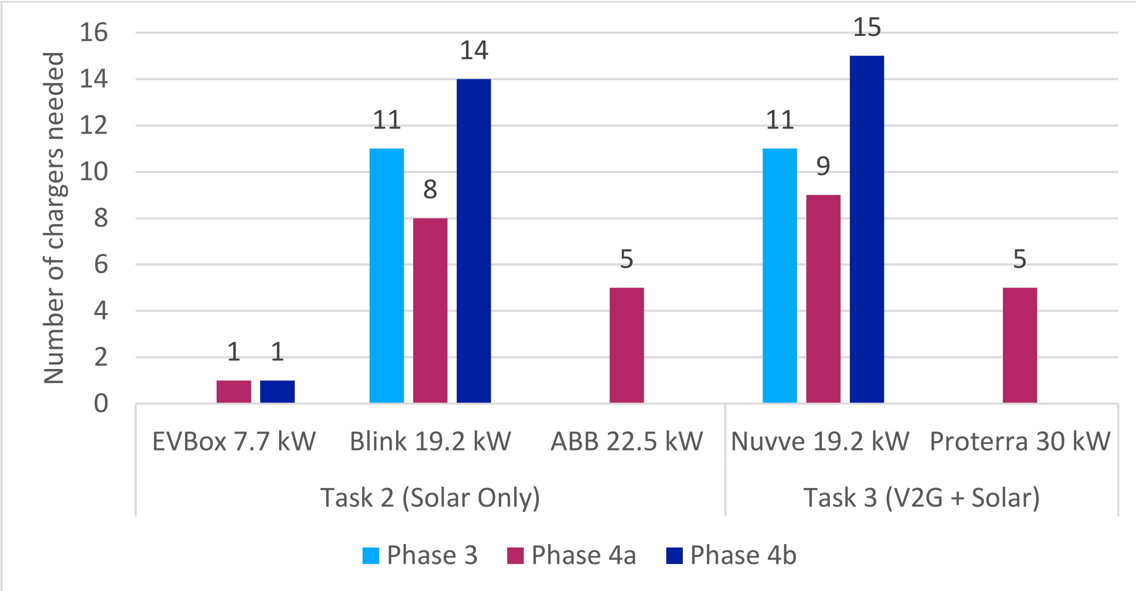
Figure 3. Number of buses for V2G-enabled fleet



To power the buses and discharge energy back to the grid, we select two types of bi-directional chargers with charge rates designed to match Task 2 results as closely as possible, given market availability; however, some chargers are necessarily upgraded (Figure 4). Specifically, the recommended chargers for a V2G-enabled fleet are:

- 35 Nuvve 19.2 kW AC Powerport Chargers
- 5 Proterra 30 kW DCFC Chargers (modeled as a dual-port 60 kW system)

Figure 4. Number of EVSEs for V2G-enabled fleet, compared to solar only (Task 2)



<u>Grid infrastructure:</u>

Adding the nameplate capacity of the charging stations shows that the theoretical grid capacity to charge the buses is 822 kW. However, the peak grid load does not exceed 375 kW. This is because the Prosumer model optimizes the charging behavior of the fleet to minimize TCO, including demand charges, so not all buses will charge at the maximum rate at the same time. Equally important, the maximum "V2G Peak", or maximum discharge rate, does reach the nameplate capacity of 822 kW.

<u>Onsite DERs:</u>

The optimization yields investment in a 827 kW rooftop PV system for Phase 3, 4a, and 4b. The solar system produces about 1.12 GWh every year. About 33% of solar energy generated is directly used for bus charging, while the remaining 67% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

<u>Economics:</u>

Assuming current market prices and incentives, adding V2G capabilities to GUHSD fleet results in higher TCO. Scenario 2 that integrates V2G with solar and NEM results in the most favorable total cost of ownership for a V2G-capable fleet, but still at a premium. V2G results in meaningful decrease in total energy costs of the fleet by about roughly 8%, but that is not sufficient to offset the incremental capital costs of V2G hardware.

Table 1. Total cost of ownership for V2G electric fleet, compared to original electric fleet

Cost	V2G-capable electric fleet (Task 3 – Scenario 2, Phase 3, 4a, 4b)	Basic electric fleet (Task 2, Phase 3, 4a, 4b)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$2,700,407**	**$2,924,689**
Total costs	**$28,580,104**	**$27,657,692**

* *Information redacted for confidentiality*

The total cost of ownership for the fleet transition is about $28.6 million, which consists of $27.5 million for CAPEX and $1.1 million for OPEX. The CAPEX expenses consist of about 87% electric buses, 7% charging stations, and 7% onsite solar PV. The OPEX expenses consist of 57% energy supply from the grid, 21% maintenance and networking fees for the charging stations, and 22% maintenance for solar PV. As a reminder, the OPEX for buses is not accounted for due to lack of sufficient data. In general, we see a decrease in total cost associated with energy (solar costs + grid energy supply), and an increase in EVSE and bus costs, leading to an overall higher TCO than Task 2. This is a major finding from this analysis: **unless bi-directional hardware costs decline, it is not economically attractive for GUHSD to invest in V2G for grid energy arbitrage.** This finding is expanded upon in the Procurement Guidelines and Recommendations Section.

<u>Emissions:</u>

Notably, transitioning Phase 3, 4a, and 4b of the GUHSD fleet to electric buses with V2G reduces its total GHG emissions by 87%, from 38,250 metric tons of CO2-equivalent (MtCO2-e) to 4,972 MtCO2-e. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 4,972 MtCO2 factors in only 33% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

<u>Energy flow and Charging Profiles:</u>

- During weekdays, bus charging occurs using a mix of solar and grid energy in the middle of the day and using grid energy in the evenings and overnight.
- On weekends, bus charging occurs during the day using abundant solar energy, supplemented by grid energy in the evenings.
- During weekdays, the majority of solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. In the middle of the day, solar is used to charge the buses directly, when the buses are in the depot between their morning and afternoon trips.
- On weekends, the majority of solar is used to charge the buses, which then store this solar energy and discharge it back to the grid, mostly during on-peak (summer months) and occasionally during super-off-peak (winter months). These distinct optimal behaviors help balance overall expenses with NEM credits in each tier.
- In all cases, the discharge rate seems to be concentrated in a narrow time window within a specific tier. It is very likely that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak of 822 kW, which would minimize any grid infrastructure upgrades (e.g., cables, service panels).
- As discussed, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of solar credits and minimum total cost of ownership. While partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited to minimize total cost of ownership.

In the following sections, we provide a more granular description of the results for each Phase of the V2G fleet electrification, with snapshots of the optimal charging behavior of the system on weekly basis.

- Energy Flows: the flow of energy across the entire system for a given week
- Charging Profiles: times and sources of energy for bus charging
- Net-Energy-Metering (NEM) Credit Balance: the yearly balance of charges for energy intake from the grid and credits for solar energy surplus fed into the grid

The graphics for Energy Flows and Charging Profiles are based on data from the 28th week of the year, during the summer season. Data corresponding to 4th week of the year from the winter season is available in the Appendix.

Phase 3

To show how the optimal operations and economics of the fleet change with the introduction of V2G capabilities, we analyze Phase 3 using three different scenarios. These scenarios highlight the interactions between system variables like the size of the solar PV, bus battery capacity, and charger maximum nameplate capacity, as well as the sensitivity of the overall economics to these variables.

The Scenarios for Phase 3 are constructed as follows:

- Scenario 1: No DERs are allowed; buses and chargers are selected based on Task 2 (essential electrification without V2G); the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.
- Scenario 2: Solar is optimally selected; buses and chargers are selected based on Task 2 (essential electrification without V2G); the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.
- Scenario 3: Solar is optimally selected; buses and chargers are upgraded in battery size and charging rates, respectively, to increase V2G potential; the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.

Table 2. Bus and charger selection for Phase 3

<table>
<tr><th></th><th>Scenario 1: V2G; no DERs</th><th>Scenario 2: V2G; DERs</th><th>Scenario 3: V2G; DERs; Upgraded Buses + Chargers</th></tr>
<tr><td rowspan="3">Buses</td><td>3 Lion D1 buses
(132 kWh battery)</td><td>3 Lion D1 buses
(132 kWh battery)</td><td rowspan="3">11 Thomas C2 Jouley2
(226 kWh battery)</td></tr>
<tr><td>7 Lion D2 buses
(168 kWh battery)</td><td>7 Lion D2 buses
(168 kWh battery)</td></tr>
<tr><td>1 Thomas Jouley 1 bus
(226 kWh battery)</td><td>1 Thomas Jouley 1 bus
(226 kWh battery)</td></tr>
<tr><td>Chargers</td><td>Nuvve 19.2 kW
bi-directional chargers</td><td>Nuvve 19.2 kW
bi-directional chargers</td><td>Proterra 60 kW
bi-directional chargers</td></tr>
</table>

In the following subsections, we provide a more granular description of the results for each Scenario, including comparisons between charging and energy flow behavior for each run. We also compare the fleet performance with and without V2G.

Scenario 1: V2G; no DERs

Buses and Chargers:

- 3 Lion D1 buses, 7 Lion D2 buses, and 1 Thomas Jouley 1 bus
- 11 Nuvve 19.2 kW L2 bi-directional chargers

Grid infrastructure: Adding the nameplate capacity of all required charging stations shows that the theoretical grid capacity needed to charge the buses is about 211 kW. However, the maximum grid peak load does not exceed 106 kW at any point in time. This is because the optimal charging behavior spreads out charging over a longer period, primarily during super-off-peak periods, to minimize demand charges. While the capacity demand is mitigated, the lack of solar energy increases the total energy pulled from the grid compared to other scenarios. Equally important, the “V2G peak”, defined as the maximum discharge rate from the buses to the grid, is 211 kW at any point in time.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier. It is very likely that the discharge to the grid can occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak hours.

Economics: The total cost of ownership for the electric fleet in Scenario 1 over 20 years is detailed in Table 3 below.

Table 3: Total cost of ownership for Scenario 1

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	82.5%
Charging Stations – CAPEX	*	5.0%
Charging Stations – OPEX	*	0.7%
Solar PV – CAPEX	*	0%
Solar PV – OPEX	*	0%
Grid energy supply – OPEX	*	11.9%

* *Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 3 from diesel to electric with V2G capabilities reduces the GHG emissions from the buses by about 81%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 2,049 MtCO2, compared to an estimate of 10,702 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions can be lower, primarily for two reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Second, the ability for buses to discharge energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits.

Energy flows: Figure 5 shows all energy flows in and out of the system, on a daily basis over the 28th week of the summer season. The results show that the buses are charging from the grid primarily during super-off-peak hours, either overnight on weekdays or overnight and during the day on weekends. At the same time, the vehicles discharge during off-peak periods and on-peak on Friday, as well as during on-peak periods on weekends, when no further trips are scheduled.

Charging profiles: Figure 6 and Figure 7 focus on the bus charging and discharging profiles. Figure 6 shows the stack of charging/discharging profiles for every bus in Phase 3, and Figure 7 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- Because there is no solar energy, the buses must charge solely from the grid.
- During weekdays, bus charging occurs after 6:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 106 kW, and the maximum discharge rate reaches 211 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a rate of 106 kW. The buses benefit from cheap super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak charging between 6:00pm and midnight. In other words, while this on-peak charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct. By charging from 6:00pm to 5:00am, the buses can charge at a slower rate and thus minimize demand charges overall.
    - In the middle of the day, between 10:00am and 12:00pm, some off-peak charging occurs. This is because some buses need a charging boost after their morning routes in

order to complete their afternoon routes.

- On weekends (Saturday and Sunday), the buses charge at 106 kW during super-off-peak periods, from after midnight through the morning hours.
- In terms of discharge, the buses mostly discharge to the grid during on-peak periods on Friday, Saturday, and Sunday. The buses discharge less energy on Sunday than Saturday to maintain a state-of-charge needed for the routes on Monday.
    - As seen in Figure 7, there is some "bus-to-bus" charging, on Friday for example. In reality, this means that one bus is discharging to the grid while another is simultaneously pulling energy from the grid, resulting in a net zero expense. Since each bus has its unique trip schedule and therefore optimal charging schedule, such behavior is reasonable.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 72 MWh of electricity are discharged from the buses back to the grid to generate NEM credits.
- As shown in Figure 8, those credits fall under three tiers: 66 MWh on-peak, 6 MWh off-peak, and 0 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible to secure lowest energy cost and therefore lowest total cost of ownership.
- For Scenario 1, the vehicles exhibit optimal operations by maximizing discharge during on-peak hours, followed by off-peak hours. On-peak credits are exactly matched to expenses, and off-peak credits are partially matched. The ability to match credits with expenses depends on bus size, route and charging demands, and charger size.

Scenario 2: V2G; DERs

In Scenario 2, the same bus and charging infrastructure is used as Scenario 1, but with the ability to optimally select and size a solar PV system. First, we present some insights from Scenario 2. Then, we compare to the results from Scenario 1 (V2G only) and Task 2 (essential electrification with no V2G). ***As a reminder, in this scenario any and all electricity discharge back to the grid is accounted for as NEM credit, regardless of whether it's produced by solar or by the V2G-enabled bus.***

<u>Buses & Chargers:</u>

- 3 Lion D1 buses, 7 Lion D2 buses, and 1 Thomas Jouley 1 bus
- 11 Nuvve 19.2 kW L2 bi-directional chargers

<u>Onsite DERs:</u> In Scenario 2, the optimization yields investment in a 225-kW rooftop PV system. The solar system produces about 305 MWh every year. About 31% of the solar energy is directly used for bus charging, while the remaining 69% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

<u>Grid infrastructure:</u> Adding the nameplate capacity of all required charging stations show that the theoretical grid capacity needed to charge the buses is about 211 kW. However, the maximum grid peak load does not exceed 105 kW at any point in time. In fact, in the summer, grid peak load does not exceed 100 kW; this is because there is more charging from solar PV in the middle of the day. Equally important, the "V2G peak", defined as the maximum discharge rate from the buses to the grid, is 211 kW at any point in time.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, most of the discharge occurs during the later hours of the on-peak tier. It is conceivable that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak hours.

GHG Emissions: Under this Scenario, GUHSD would reduce the GHG emissions from the buses by about 85%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,586 MtCO2, compared to an estimate of 10,702 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Second, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 1,586 MtCO2 factors in only 31% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

Energy flows: Figure 9 shows all energy flows in and out of the system, on a daily basis over the 28th week of the summer season. The results show how solar and grid energy is balanced throughout the week.

- During weekdays, the majority of solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. In the middle of the day, solar is used to charge the buses directly, when the buses are in the depot between their morning and afternoon trips.
- On weekends, the majority of solar is used to charge the buses, which then store this solar energy and discharge it back to the grid, mostly during on-peak and occasionally during super-off-peak.
- Both on weekdays and on weekends, grid energy is used to supplement bus charging, mostly after midnight and sometimes in the evenings when needed.

Charging profiles: Figure 10 and Figure 11 focus on the bus charging and discharging profiles. Figure 10 shows the stack of charging/discharging profiles for every bus in Phase 3, and Figure 11 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- During weekdays, bus charging occurs after 6:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 105 kW, and maximum discharge rate reaches 211 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a rate of 105 kW. The buses benefit from super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 6:00pm and 12:00am. In other words, while this charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct.
    - In the middle of the day, between 10:00am and 12:00pm, significant off-peak charging occurs for the buses to recharge between their morning and afternoon trips. The majority of energy is supplied directly from solar PV.
- On weekends (Saturday and Sunday), the buses charge during the day, anytime from 6:00am to 4:00pm. The majority of charging is attributed to direct feed from solar PV and is supplemented with grid electricity in the afternoon. The buses charge again in the evening, between 9:00pm and midnight.
- In terms of discharge, the buses display distinct optimal behaviors between the summer and winter months.
    - During summer months, the buses discharge during the peak period on Friday, Saturday, and Sunday. The discharging on Saturday is maximized, since the buses are

least constrained with trip schedules. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during on-peak hours, benefiting from the price differential and accumulating valuable on-peak credits.

   - During winter months, the buses' discharge is more limited, mostly occurring on Sunday for a few hours during the super-off-peak period. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during super-off-peak hours, to balance NEM credits (which we explain more in the next section). Because the effective cost of solar is even cheaper than super-off-peak grid electricity, this behavior makes sense; the economic benefit associated with it is small but positive, therefore still contributing to reducing costs.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 54 MWh of electricity are fed into the grid to generate NEM credits using vehicle to grid capabilities, and 210 MWh of electricity are fed into the grid to generate NEM credits using solar.
- As shown in Figure 12, those credits fall under the three tiers: 60 MWh on-peak, 151 MWh off-peak, and 53 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership. The results show that credits and expenses are completely and perfectly balanced for on-peak and off-peak tiers; no net energy expense occurs under these two tiers. The super-off-peak tier is partially balanced, with a credit deficit of about 47 MWh.
- Figure 13 provides a more granular view of where the NEM credits originate: from solar PV or from V2G-enabled buses. First, it's apparent that solar PV contributes NEM credits in all 3 tiers: on-peak, off-peak, and super-off-peak. In contrast, V2G contributes NEM credits in only two tiers: on-peak and super-off-peak. While the solar PV NEM credits are rigid (dependent on solar generation profile), the V2G NEM credits are more flexible; while partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.

Comparing Scenario 2 (V2G; DERs) to Scenario 1 (V2G; no DERs):

<u>Technology and Emissions:</u>

Table 4: Technology and emissions comparison

Output	Scenario 2 Value (V2G; DERs)	Scenario 1 Value (V2G, no DERs)
Solar PV Size	225 kW	0 kW
Grid peak load	105 kW	106 kW
GHG emission reduction	85% reduction	81% reduction

- Adding onsite solar PV improves GHG emission reductions by about 4%. This is primarily due to the 95 MWh of solar energy used to directly charge the buses every year.
- Adding onsite solar PV does not lead to significant changes in grid peak load, though the peak load in with solar shrinks to 100 kW in summer months.

Economics:

Table 5: Total Cost of Ownership Comparison

Cost	Scenario 2 Value (V2G; DERs)	Scenario 1 Value (V2G, no DERs)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$798,992**	**$991,079**
Total costs	**$8,169,792**	**$8,361,879**

** Information redacted for confidentiality*

- The addition of solar results in an overall decrease in total energy costs by about $192,000.

Energy flows: Grid energy is used much in the same way with and without solar, to provide steady charging to buses overnight from 6:00pm to 5:00am. However, upon adding solar, the majority of midday charging is provided by solar PV, and the grid energy needed between the morning and after trips is relatively limited.

Charging profiles:

- During weekdays, Scenario 1 and 2 follow overall very similar charging profiles in the evenings and overnight, charging from the grid from 6:00pm to 5:00am. However, during the day from 10:00am to 12:00pm, there are a few key differences. Upon adding solar PV (scenario 2):
    - The majority of daytime charging can be fulfilled with solar energy.
    - The grid peak load is lower in the summer months, when solar is abundant. Buses charge more during off-peak hours between 10:00 am and 12:00 pm, then can charge more slowly overnight.
    - On Friday, the buses do not exhibit the “bus-to-bus” behavior explained in Scenario 1 (without solar), likely because solar energy is available to avoid charging from the grid.
- On weekends, midday charging without solar is more uniform than with solar; upon charging from solar, the buses follow the solar generation profile. However, without solar, the buses can charge at uniform rate from the grid.
- Both with and without solar, the buses discharge on Friday, Saturday, and Sunday, when less constrained by trip schedules and the need to charge. For Scenario 1 (no solar), buses optimally discharge almost exclusively during the most expensive on-peak hours to maximize benefits. However, for Scenario 2 (with solar), buses optimally store then discharge the cheap solar energy during on-peak and super-off-peak hours; as a reminder, the levelized cost of solar energy is cheaper than the levelized cost of super-off-peak grid energy.

NEM Credit Balance:

- Both Scenarios 1 and 2 prioritize balancing the credits and the expenses in the more expensive billing tiers first. However, adding solar capacity allows for a much more balanced accounting of credits, leading to a reduction in energy expense and TCO for Scenario 2. Overall, 85% of energy drawn from the grid is offset by NEM credits in Scenario 2 (with solar), while 23% of energy drawn from the grid is offset by NEM credits in Scenario 1 (without solar).

Comparing Scenario 2 (V2G; DERs) to Task 2 (no V2G; DERs):

The comparison of the fleet operations with V2G (Scenario 2) and without V2G (earlier Task 2) entails using the same buses. Although the chargers have equivalent power rating (19.2 kW) in both cases, the chargers in Scenario 2 are bi-directional whereas the ones in Task 2 are not.

Table 6: Infrastructure and emissions comparison

Output	Scenario 2 Value (V2G, DERs)	Task 2 Value (no V2G, DERs)
Solar PV size	225 kW	223 kW
Grid peak load	105 kW	128 kW
GHG emissions reduction	85% reduction	84% reduction

- Adding V2G capability to the fleet transition in Phase 3 does not result in major changes to GHG emissions reductions; the 1% improvement in emissions reductions with V2G is likely due to the chosen optimal solar system, which is slightly bigger.
- Grid peak load with V2G is lower than that without V2G. This can be attributed to the fundamental principle that adding V2G capabilities provides the fleet with additional flexibility to fulfill the bus energy needs, all while reducing energy costs; such flexibility can manifest in installing larger solar PV or reshuffling (stretching over longer periods) the charging schedules to reduce demand charges.

Table 7: Total cost of ownership comparison

Cost	Scenario 2 Value (V2G, DERs)	Task 2 Value (no V2G, DERs)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$798,992**	**$868,377**
Total costs	**$8,169,792**	**$8,018,209**

* *Information redacted for confidentiality*

- Bus and solar costs are roughly the same with and without V2G.
- Although 19.2 kW chargers are used in both cases, V2G-capable bi-directional chargers are almost double as expensive as one-directional conventional chargers.
- V2G reduces the total energy costs (from grid + solar) by almost 8%. While the cost of the optimal solar PV system is slightly higher, the cost of grid energy supply is significantly lower, due to two reasons, both related to better balance: (i) reduced demand charges, and (ii) cheaper energy charges due to better balancing of NEM credits.
- Unless the incremental cost of V2G hardware decreases significantly, the reduction in energy cost is unlikely to be sufficient to offset the increase in hardware cost, rendering the option of adding V2G capabilities to the GUHSD fleet in Phase 3 economically unattractive.

Energy flows & charging profiles:

- During weekdays, the charging profiles for the V2G and non-V2G fleet are essentially identical.

- On weekends, the two cases charge differently due to technological differences, but with the same purpose - balancing NEM credits optimally.
  - In both cases, the buses charge from the grid during off-peak periods in the evening
  - Without V2G, solar energy feeds primarily back to the grid directly, resulting in off-peak NEM credits. In contrast, with V2G, solar energy feeds primarily to buses, which then discharge whenever needed – mostly on-peak period and occasionally super-off-peak – to optimize NEM credit balancing.

NEM Credit Balance:

- As explained before, V2G enables shifting some of discharge, reshuffling the supply of solar energy from solar-to-grid to solar-to-bus-to-grid, to result in more valuable NEM credits.
- With and without V2G, the fleet is capable of offsetting all on-peak and off-peak energy expenses through solar. However, V2G improves the balancing of NEM credits in two ways:
  - V2G allows on-peak and off-peak credits to perfectly match, with no overgeneration and therefore no wasted credits. In contrast, without V2G, about 8% of the solar credits are wasted.
  - V2G narrows down the deficit in super-off-peak credits. In one year, GUHSD would pay for 47 MWh of super-off-peak energy with V2G, compared to 65 MWh of super-off-peak energy without V2G.

Scenario 3: V2G; DERs; Upgraded Buses + Chargers

In Scenario 3, we upgrade to higher capacity buses and higher-powered chargers in order to test the sensitivity of V2G benefits to these variables. As in Scenario 2, solar PV is optimally selected. First, we present some insights from Scenario 3. Then, we compare the results of this Scenario 3 with upgraded buses and chargers to those of Scenario 2 with originally sized buses and chargers. ***As a reminder, in this scenario all bus routes remain constant, and therefore demand the same total energy consumption.***

Buses and Chargers:

- All buses are upgraded to 11 Thomas Jouley2 buses (226 kWh)
  - It is important to note that while we use the Thomas Jouley2, the bus efficiencies (kWh/mi) are the same as in Scenario 1 and 2. The model is sensitive to bus efficiency, so we hold it constant to better understand the impact of battery size.
- All chargers are upgraded to Proterra 60 kW DCFC chargers. These chargers are modeled based on the Proterra 120 kW dual-port charger. We assume that each bus has a dedicated 60 kW port, and we assume simultaneous charging is allowed.

Onsite DERs: The optimization yields investment in a 259-kW rooftop PV system, which produces about 351 MWh every year. About 32% of the solar energy is directly used for bus charging, while the remaining 68% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

Grid infrastructure: Adding the nameplate capacity of all required charging stations shows that the theoretical grid capacity needed to charge the buses is about 660 kW. However, the maximum grid peak load does not exceed 150 kW at any point in time. Equally important, the "V2G peak", defined as the maximum discharge rate from the buses to the grid, does reach the maximum rate of 660 kW.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier (in summer) and super-off-peak (in winter) tier. It is very likely that the discharge to the grid can occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak (summer) and super-off-peak (winter) hours.

GHG Emissions: Under this Scenario, GUHSD would reduce the GHG emissions from the buses by about 86%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,463 MtCO2, compared to an estimate of 10,702 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 1,463 MtCO2 factors in only 32% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

Energy flows: Figure 14 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how solar and grid energy is balanced throughout the week. During weekdays, the majority of daytime solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. In the middle of the day, solar is used to charge the buses directly, when the buses are in the depot between their morning and afternoon trips. On weekends, the majority of solar is used for daytime charging of the buses, which then discharge back to the grid during on-peak or super-off-peak hours. Both on weekdays and on weekends, grid energy is used to supplement bus charging, mostly after midnight and sometimes in the evenings when needed.

Charging profiles: Figure 15 and Figure 16 focus on the bus charging and discharging profiles. Figure 15 shows the stack of charging/discharging profiles for every bus in Phase 3, and Figure 16 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- During weekdays, bus charging occurs after 6:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 150 kW, and maximum discharge rate reaches 660 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a maximum peak rate of 150 kW. The buses benefit from super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 6:00pm and 12:00am. In other words, while this charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct.
    - In the middle of the day, between 10:00am and 12:00pm, significant off-peak charging occurs, for the buses to recharge between their morning and afternoon trips. The majority of energy is supplied directly from solar PV.
- On weekends (Saturday and Sunday), the buses charge during the day, anytime from 6:00am and 4:00pm. The majority of charging is attributed to direct feed from solar PV and is supplemented with grid electricity in the afternoon. The buses charge again the evening, between 9:00pm and midnight.
- In terms of discharge, the buses display distinct optimal behaviors between the summer and winter months.
    - During summer months, the buses discharge during the peak period on Friday, Saturday, and Sunday. The discharging on Friday and Saturday is maximized, since the buses are least constrained with trip schedules. In general, the buses use the abundant solar energy to charge, and then discharge during on-peak hours, benefiting from the price differential and accumulating valuable on-peak credits.
    - During winter months, the buses discharge during the limited hours of the super-off-peak period, mostly on Sunday and occasionally on Saturday. In general, the buses use the

abundant and cheap solar energy to charge, and then discharge during super-off-peak hours, to balance NEM credits (which we explain more in next section). Because the effective cost of solar is even cheaper than super-off-peak grid electricity, this behavior makes sense; the economic benefit associated with it is small but positive, therefore still contributing to reducing costs. In this particular case, the upgraded assets allow buses to generate enough super-off-peak NEM credits to completely offset super-off-peak energy expenses incurred during the week.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 54 MWh of electricity are fed into the grid to generate NEM credits using vehicle to grid capabilities, and 239 MWh of electricity are fed into the grid to generate NEM credits using solar.
- As shown in Figure 17, those credits fall under the three tiers: 59 MWh on-peak, 160 MWh off-peak, and 74 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership. The results show that credits and expenses are completely and perfectly balanced across all tiers; no net energy expense occurs under any tier. Also, there are no credit deficits and no overgeneration of credits in any tier.
- Figure 18 provides a more granular view of where the NEM credits originate: from solar PV or from V2G-enabled buses. First, it's apparent that solar PV contributes NEM credits in all 3 tiers: on-peak, off-peak, and super-off-peak. In contrast, V2G contributes NEM credits in only two tiers: on-peak and super-off-peak. While the solar PV NEM credits are rigid (dependent on solar generation profile), the V2G NEM credits are more flexible. While partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers
    - Upgrading the buses and chargers enhances this ability further, resulting in perfect netting of energy expenses and credits. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.

Comparing Scenario 3 (V2G; DERs; Upgraded Buses+Chargers) to Scenario 2 (V2G; DERs; Original Buses+Chargers):

<u>Technology and Emissions:</u>

Table 8: Infrastructure and emissions comparison

Output	Scenario 3 Value (V2G; DERs; Upgraded Buses + Chargers)	Scenario 2 Value (V2G; DERs; Original Buses + Chargers)
Solar PV Size	259 kW	225 kW
Grid peak load	150 kW	105 kW
GHG emissions reduction	86%	85%

- Upgrading the buses+chargers in Phase 3 does not result in major changes to GHG emissions reductions; the 1% improvement in emissions reduction is likely due to the chosen optimal solar system, which is bigger.
- Upgrading the buses+chargers results in higher grid peak load as well as V2G peak. This has economic implications of increasing grid-capacity cost (demand charges), but it also creates more flexibility to reduce the energy costs by optimizing NEM accounting. This trade-off is evident in the economic results below.

Table 9: Total cost of ownership comparison

Cost	Scenario 3 Value (V2G; DERs; Upgraded Buses + Chargers)	Scenario 2 Value (V2G; DERs; Original Buses + Chargers)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$803,890**	**$798,992**
Total costs	**$10,689,172**	**$8,169,792**

** Information redacted for confidentiality*

- The total energy costs (from grid + solar) are roughly the same in Scenario 2 and 3 (within the optimization algorithm margin of error).
    - The cost of solar PV with upgraded buses+chargers is higher because the size of the solar system selected is larger. Buses with larger batteries can store more cheap solar energy, and the high-powered chargers can discharge that energy at optimal times to avoid or offset more expensive grid electricity; effectively, upgrading the buses and chargers allow using more solar energy to arbitrage for NEM credits.
    - That increased ability to arbitrage and optimize NEM credits also impacts the grid energy OPEX. Compared to Scenario 2 with smaller buses and chargers, Scenario 3 with upgraded buses and chargers results in significantly lower grid energy OPEX. In fact, all the cost of grid energy is formed of demand chargers (kW); there is no cost associated with the energy itself (kWh) because the NEM credits perfectly offsets all grid energy.
- Upgrading the buses and chargers doesn't significantly impact the total energy costs (combination of grid and solar), but it does result in significant increase in CAPEX. Overall, the TCO for Scenario 3 (upgraded buses and chargers) is about 31% higher than that of Scenario 2 (original buses and chargers).

<u>Energy flows & charging profiles:</u>

- Throughout the week (both weekdays and weekends), the charging profiles for the original and the upgraded V2G fleets follow the same overall structure, patterns, and timing. The main difference is in the magnitude of charge (grid peak load) and discharge (V2G peak); the magnitude of charge and discharge is higher for upgraded buses+chargers.
- Buses demand the same amount of total energy needed to complete daily trips and fulfill mobility needs. However, upgraded assets allow for more flexibility and energy-arbitrage opportunities.
    - A larger solar system generates overall more energy, some of which is sent back to the grid to generate credits and some of which directly charges the buses. Compared to the original fleet, the upgraded fleet generates more energy from solar PV in all three tiers, and there is overall less energy pulled from the grid to charge buses.
    - The upgraded buses and chargers can store and discharge more solar energy than the original ones, providing more flexibility in how to reshuffle solar generation in a way that results in lowest possible total energy costs.

NEM Credit Balance:

- With originally sized buses+chargers (Scenario 2), the fleet is capable of offsetting all on-peak and off-peak energy expenses, but a deficit still exists in the super-off-peak tier where grid electricity is needed. However, upgrading the buses+chargers enables shifting additional solar energy supply into the super-off-peak tier, resulting in completely balanced credits in all three tiers and no energy expense for kWh purchased throughout the year.

Figure 5: Energy Flows for Phase 3 Scenario 1 – Summer

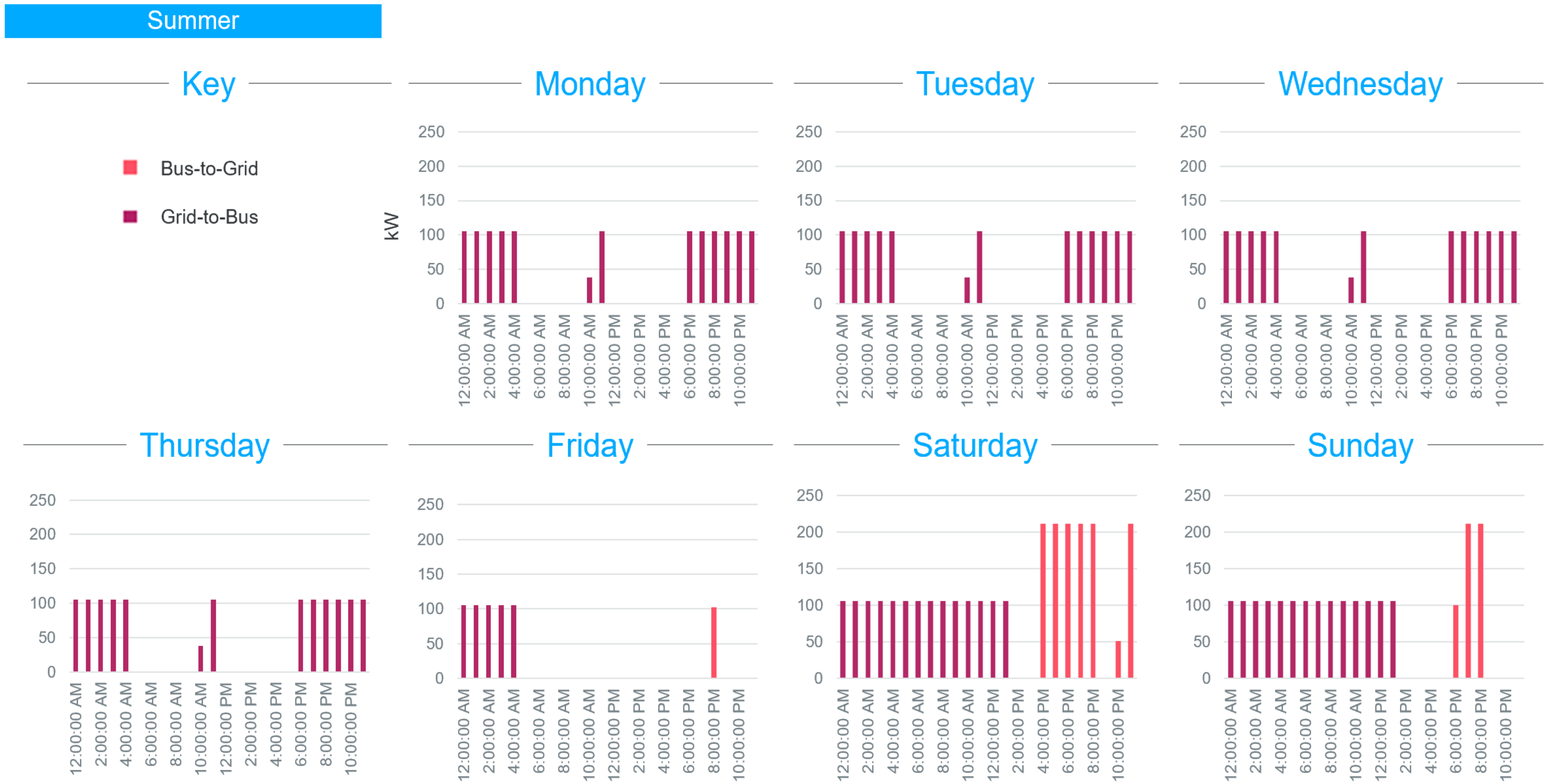


Figure 6: Charging Profiles for Phase 3 Scenario 1 – Summer

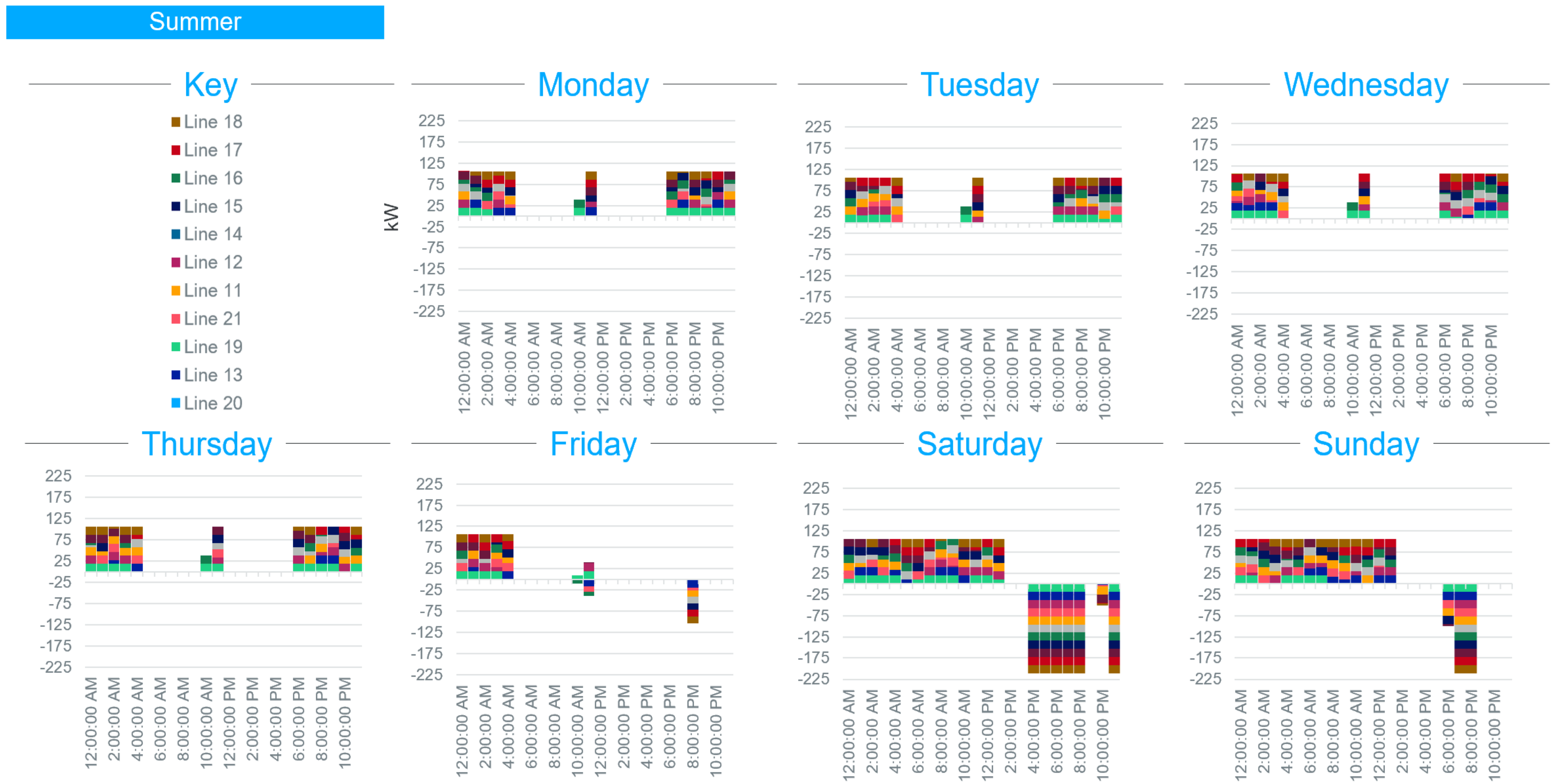


Figure 7: Sources of Energy for Bus Charging in Phase 3 Scenario 1 – Summer

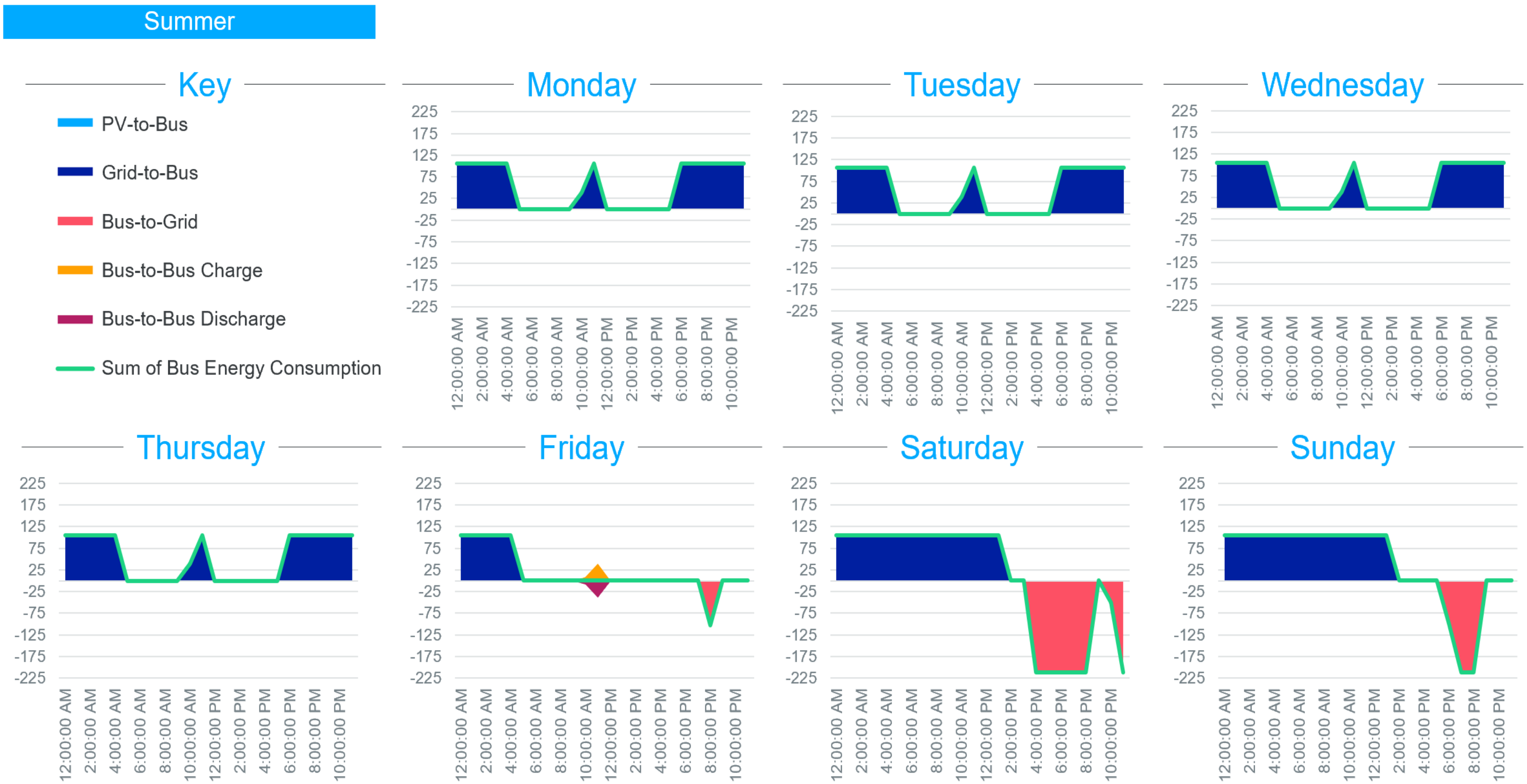


Figure 8: Tiered NEM Credit Balance for Phase 3 Scenario 1

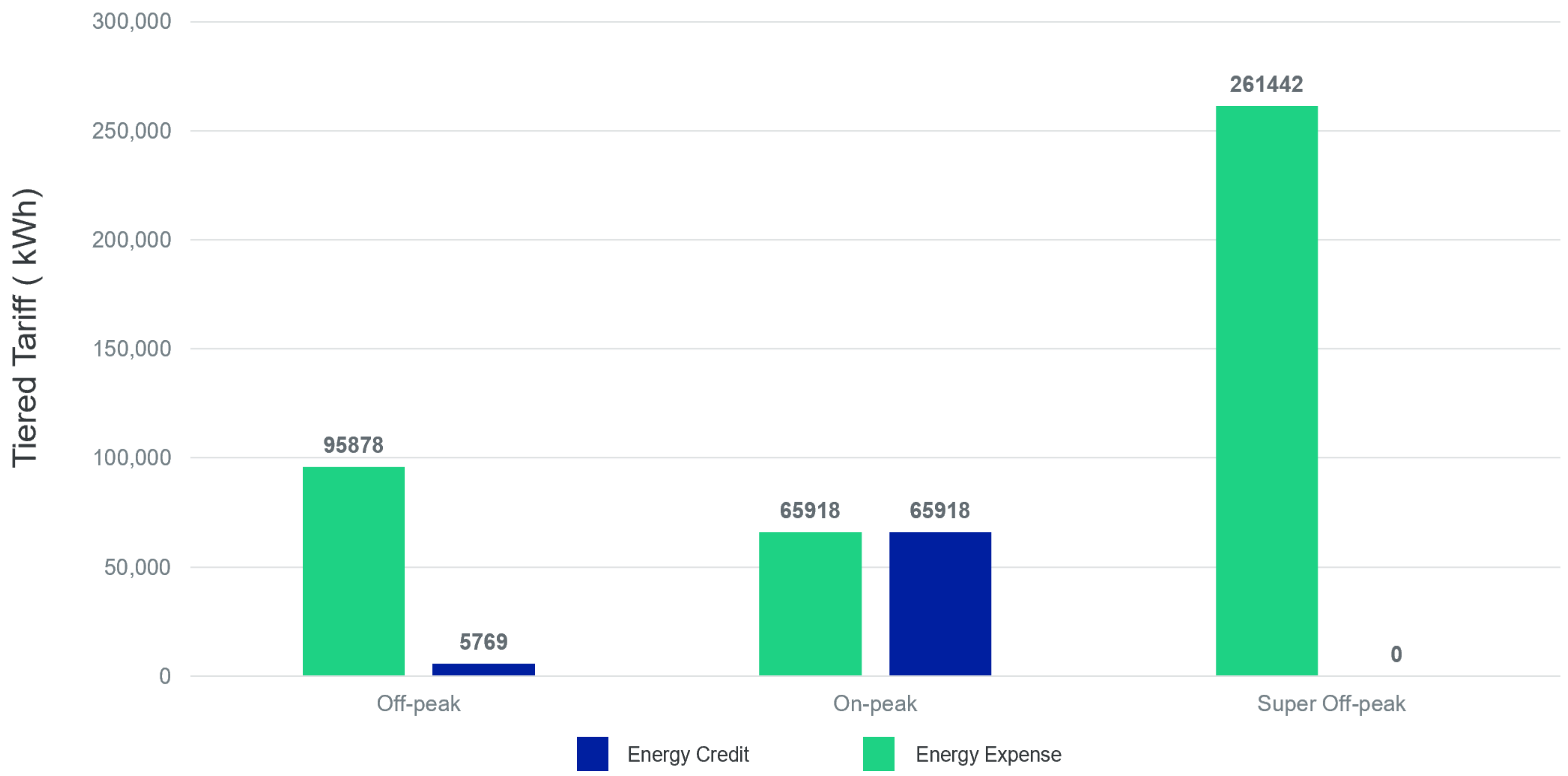


Figure 9: Energy Flows for Phase 3 Scenario 2 – Summer

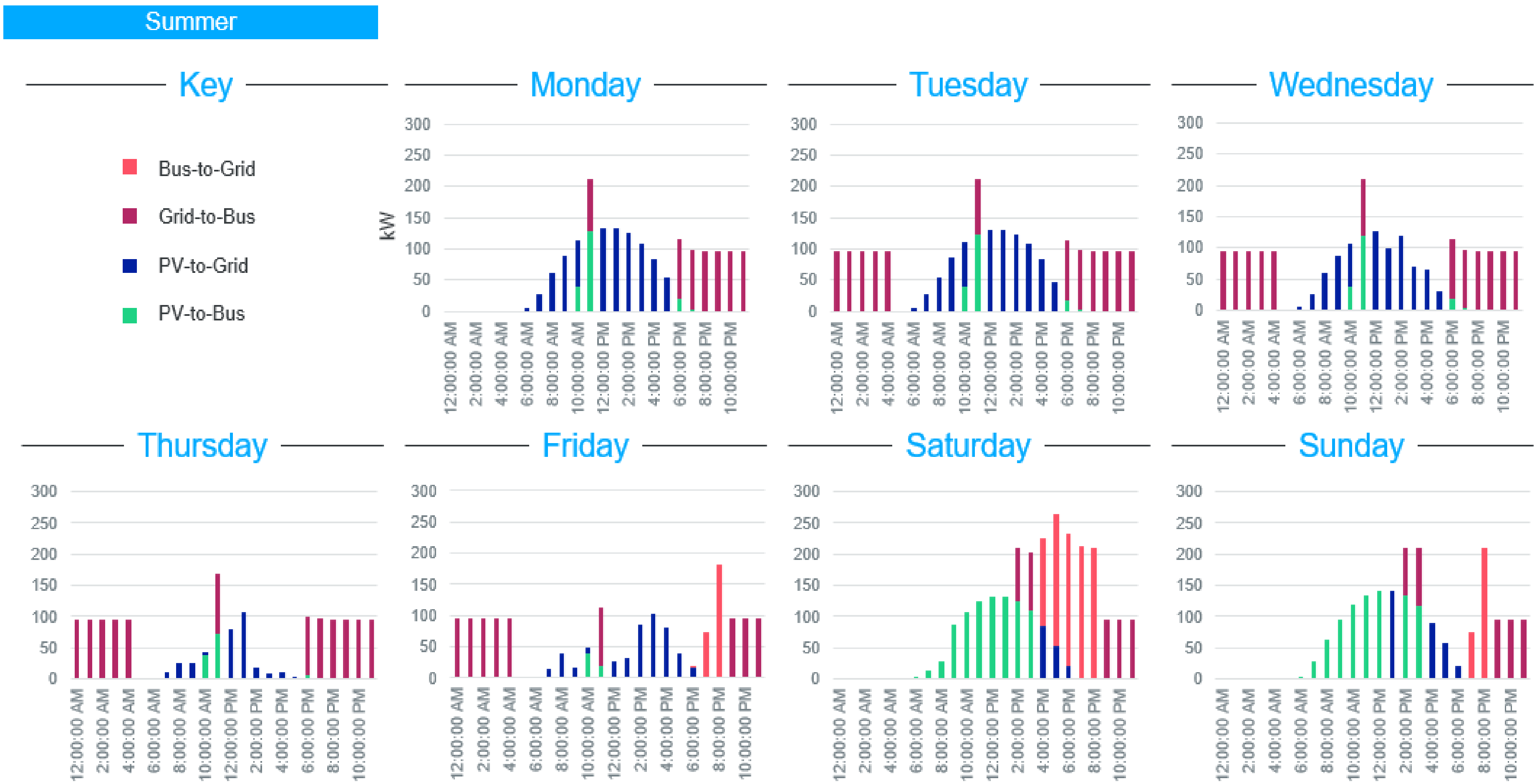


Figure 10: Charging Profiles for Phase 3 Scenario 2 – Summer

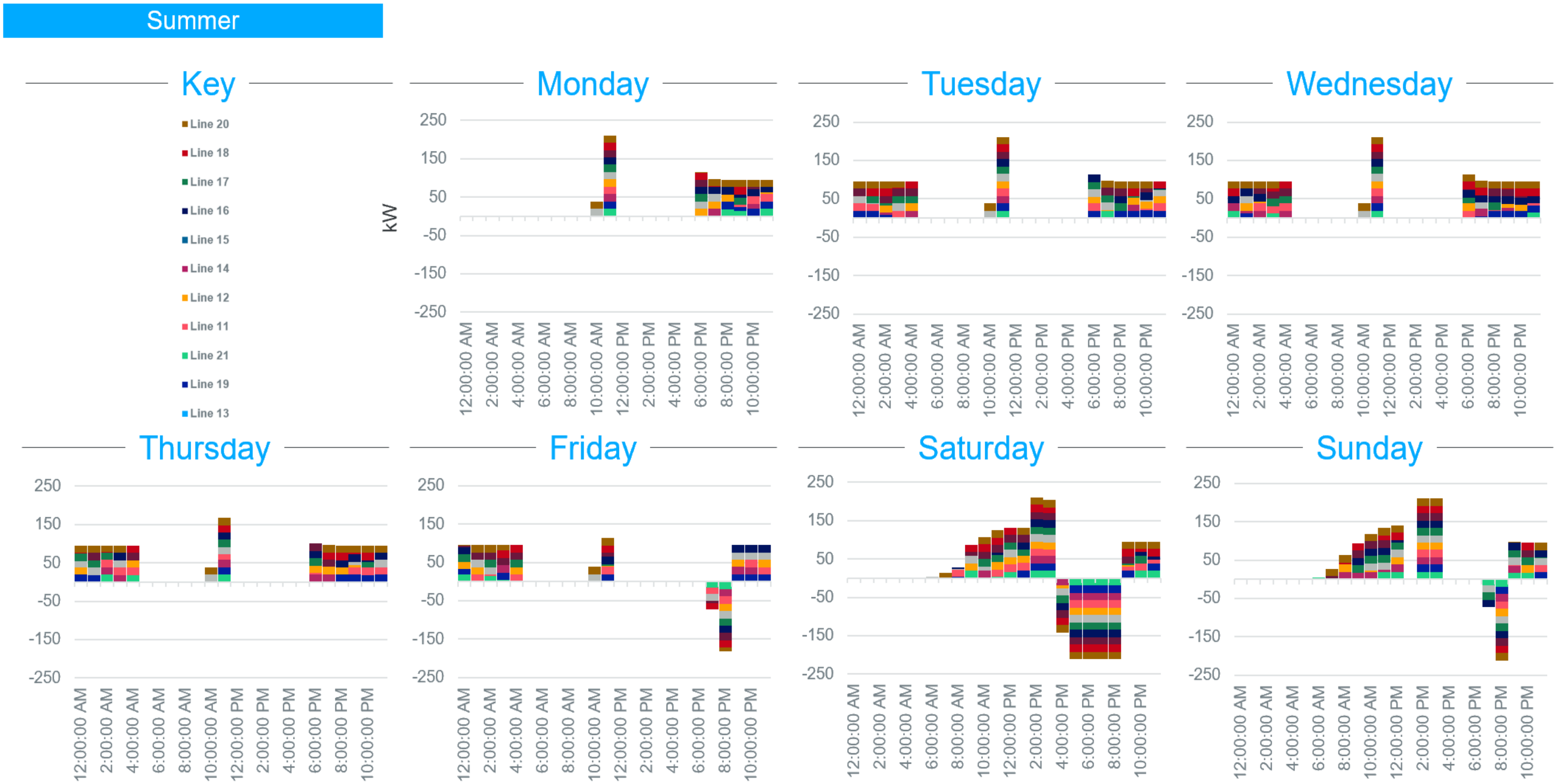


Figure 11: Sources of Energy for Bus Charging in Phase 3 Scenario 2 - Summer

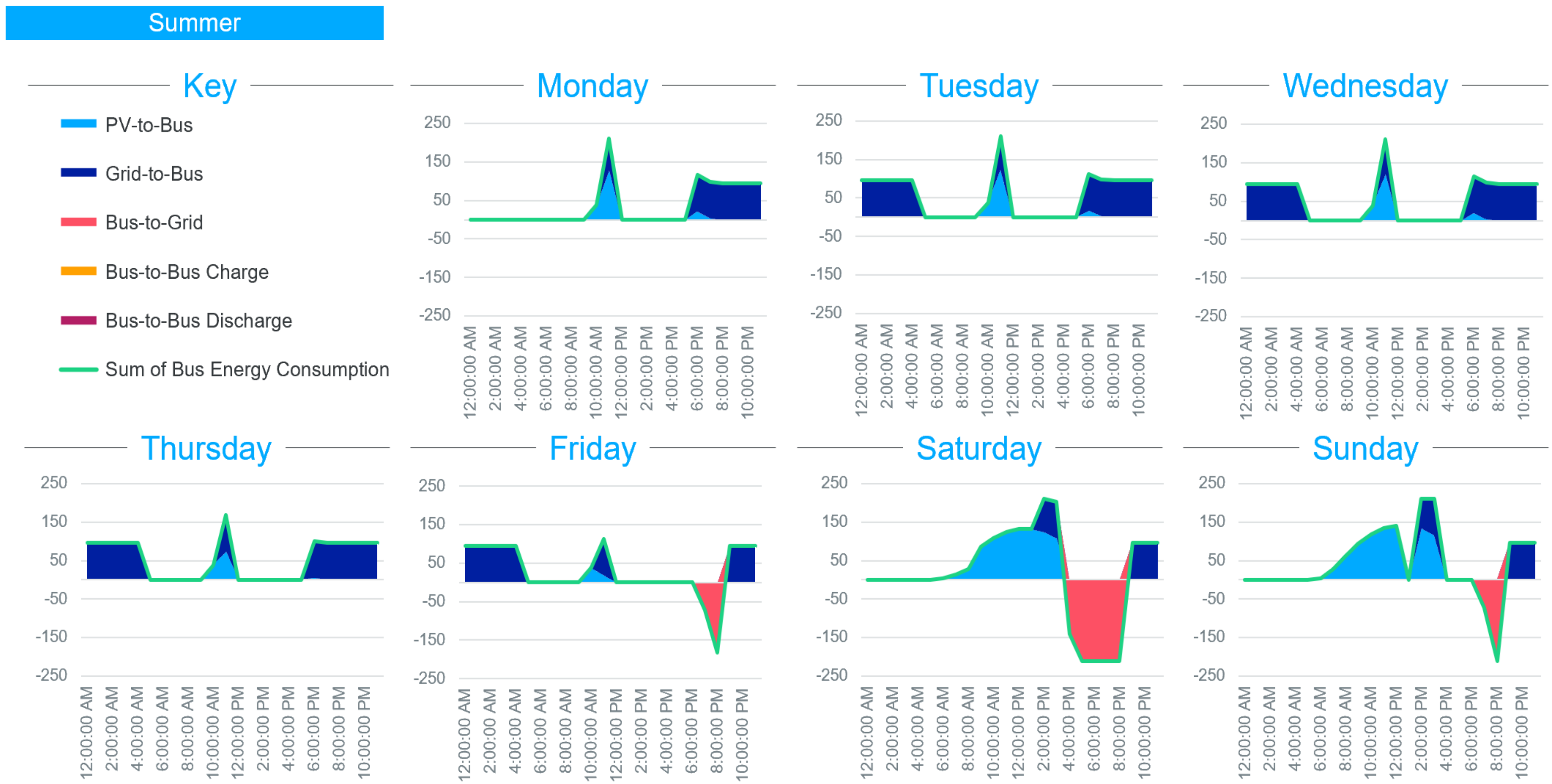


Figure 12: Tiered NEM Credit Balance for Phase 3 Scenario 2

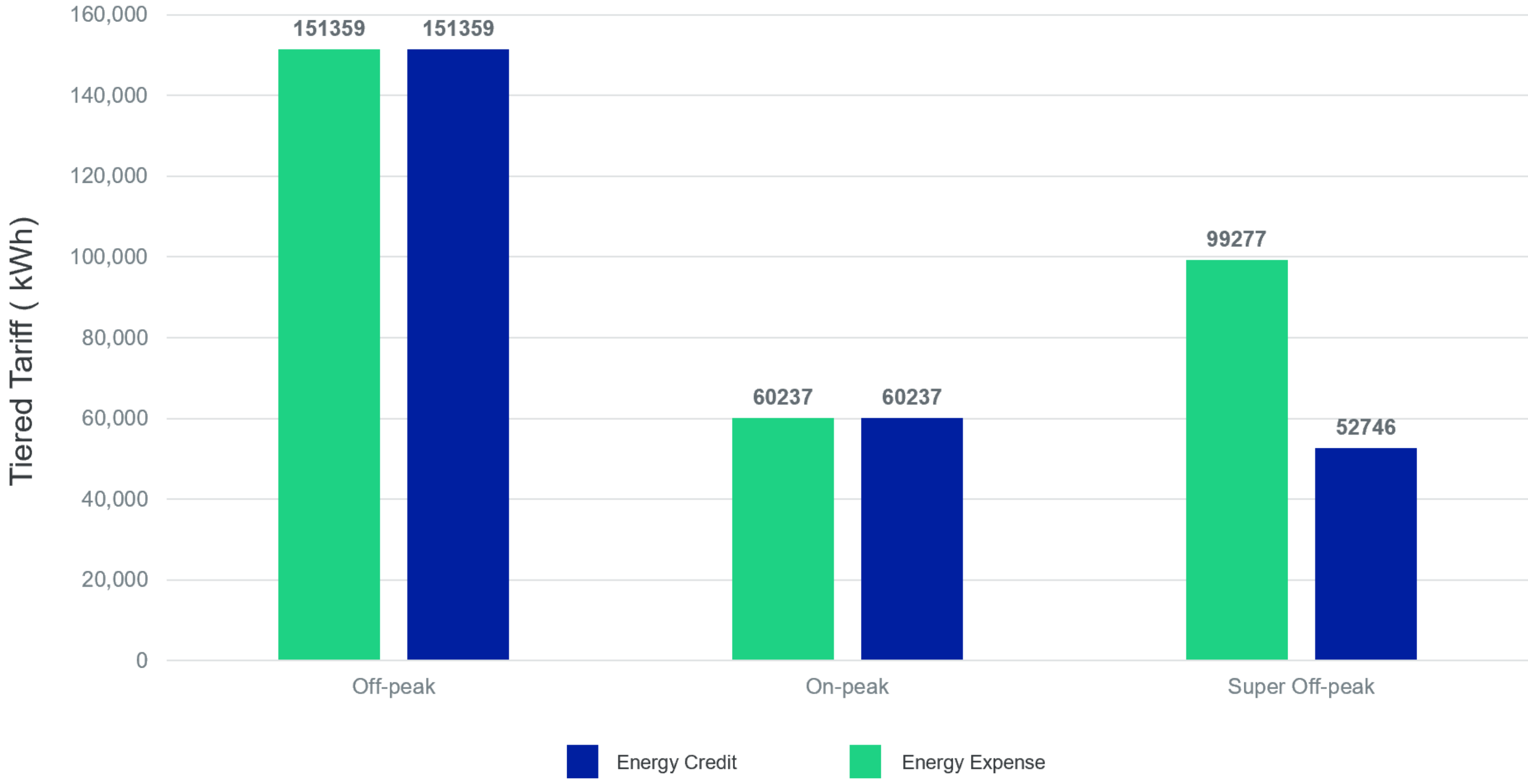


Figure 13: Solar Energy Generation and Consumption for Phase 3 Scenario 2

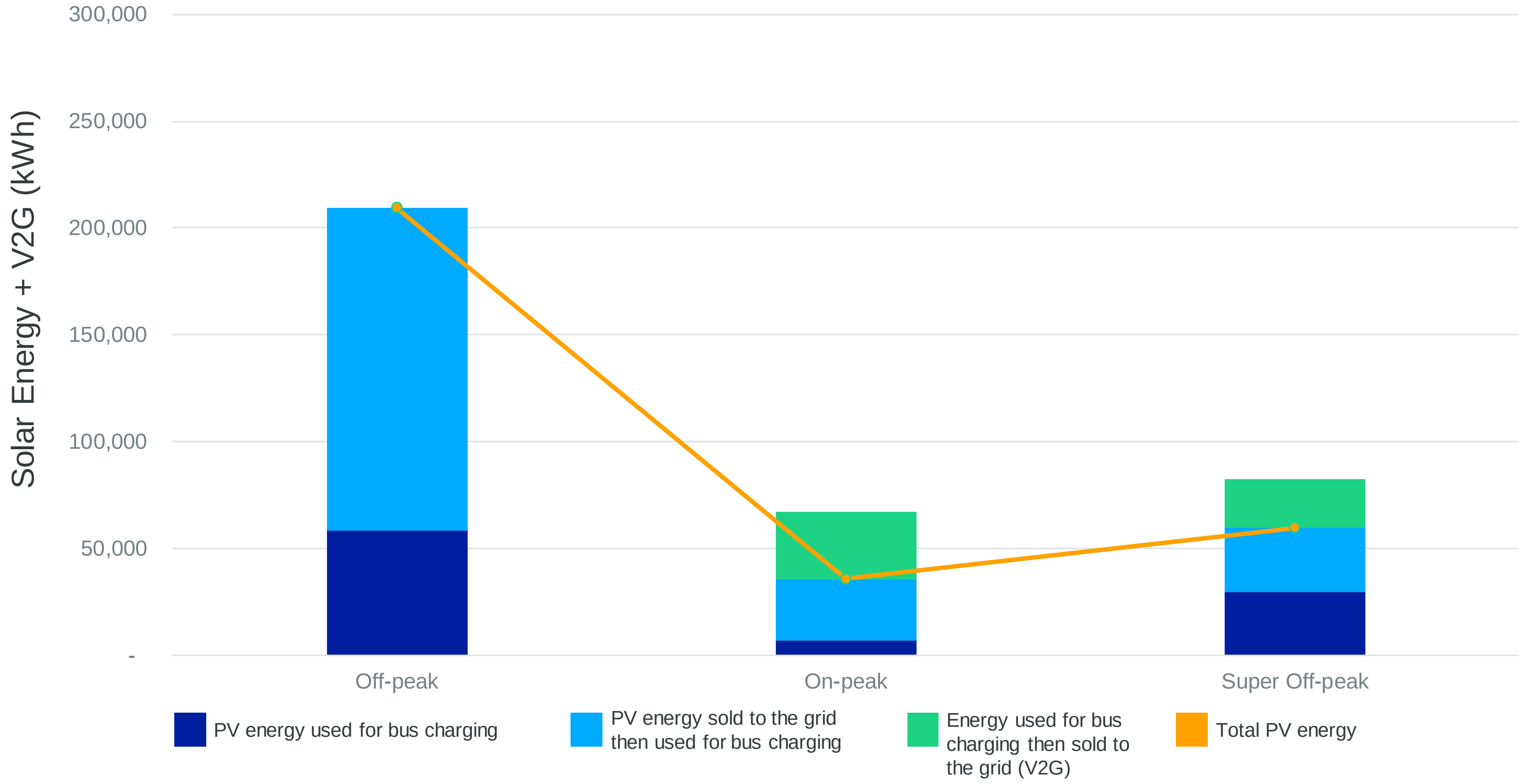


Figure 14: Energy Flows for Phase 3 Scenario 3 – Summer

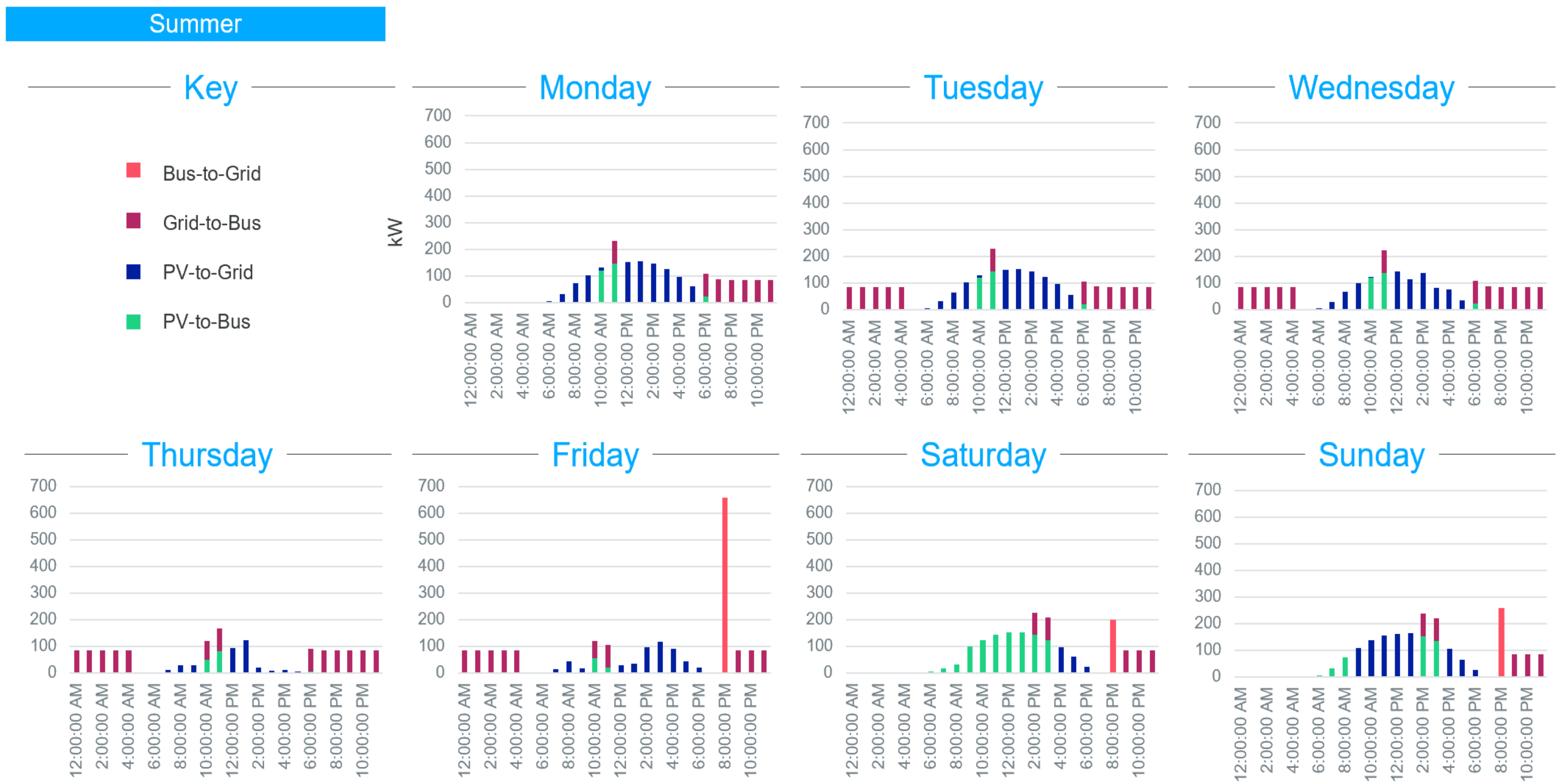


Figure 15: Charging Profiles for Phase 3 Scenario 3 – Summer

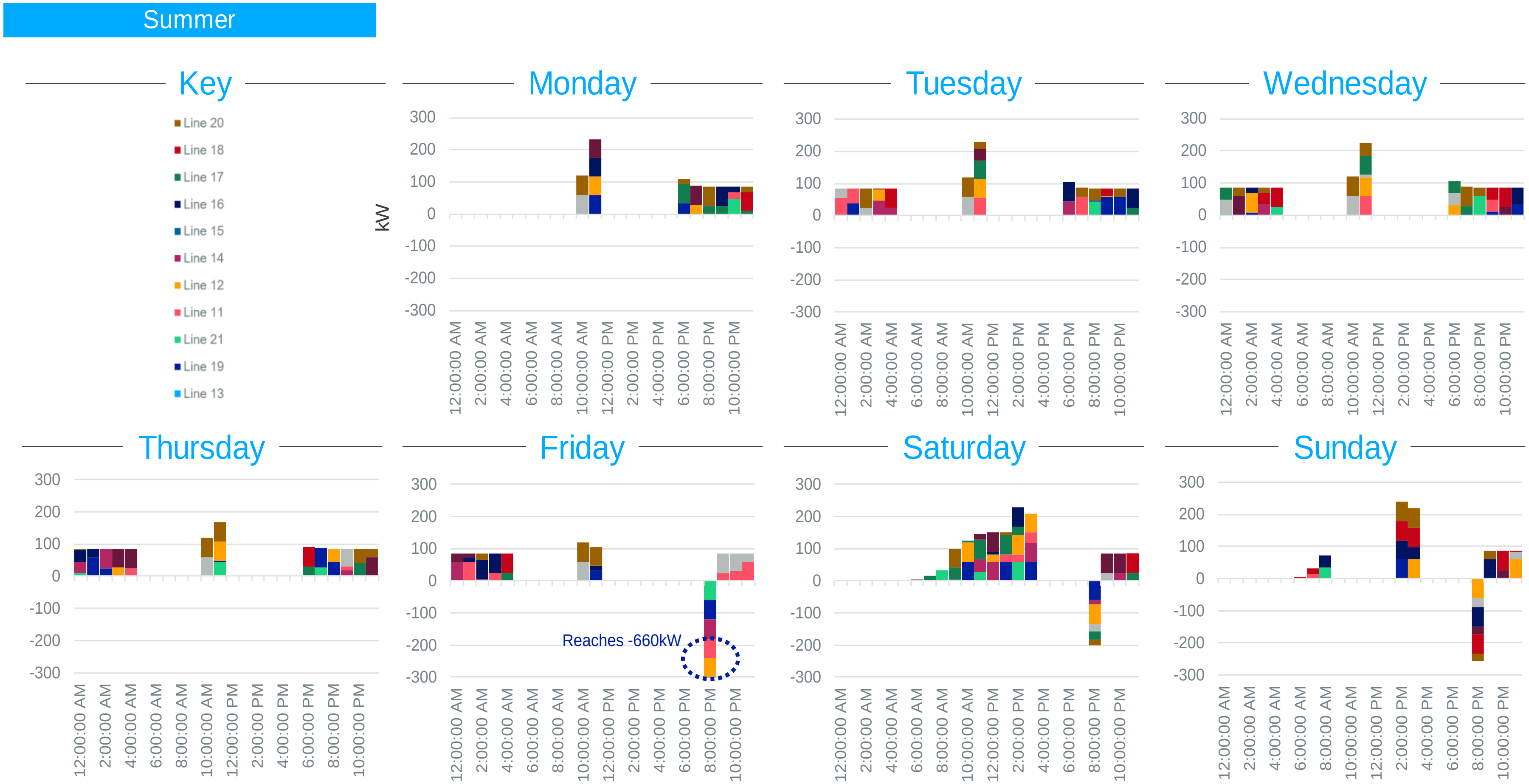


Figure 16: Sources of Energy for Bus Charging in Phase 3 Scenario 3 – Summer

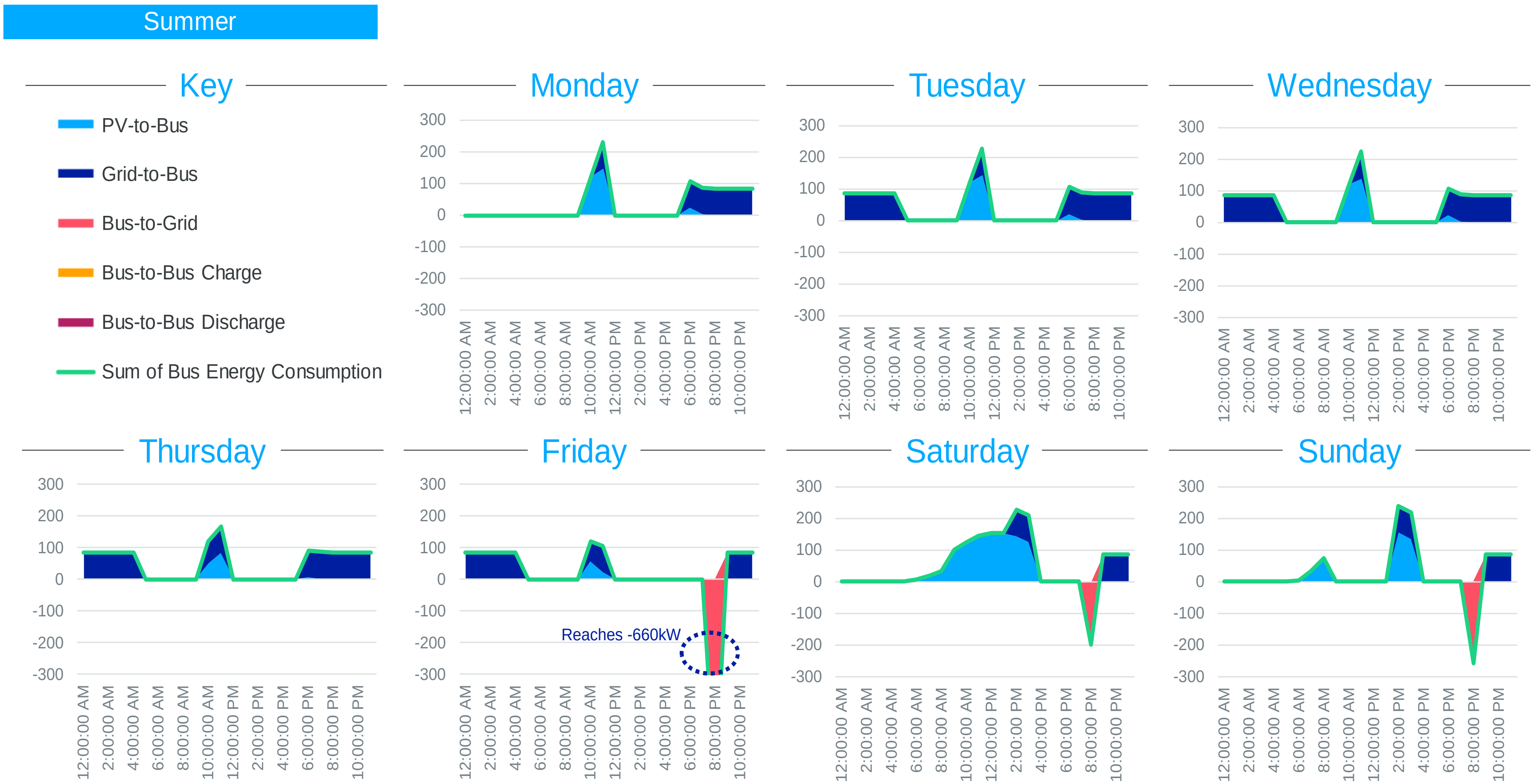


Figure 17: Tiered NEM Credit Balance for Phase 3 Scenario 3

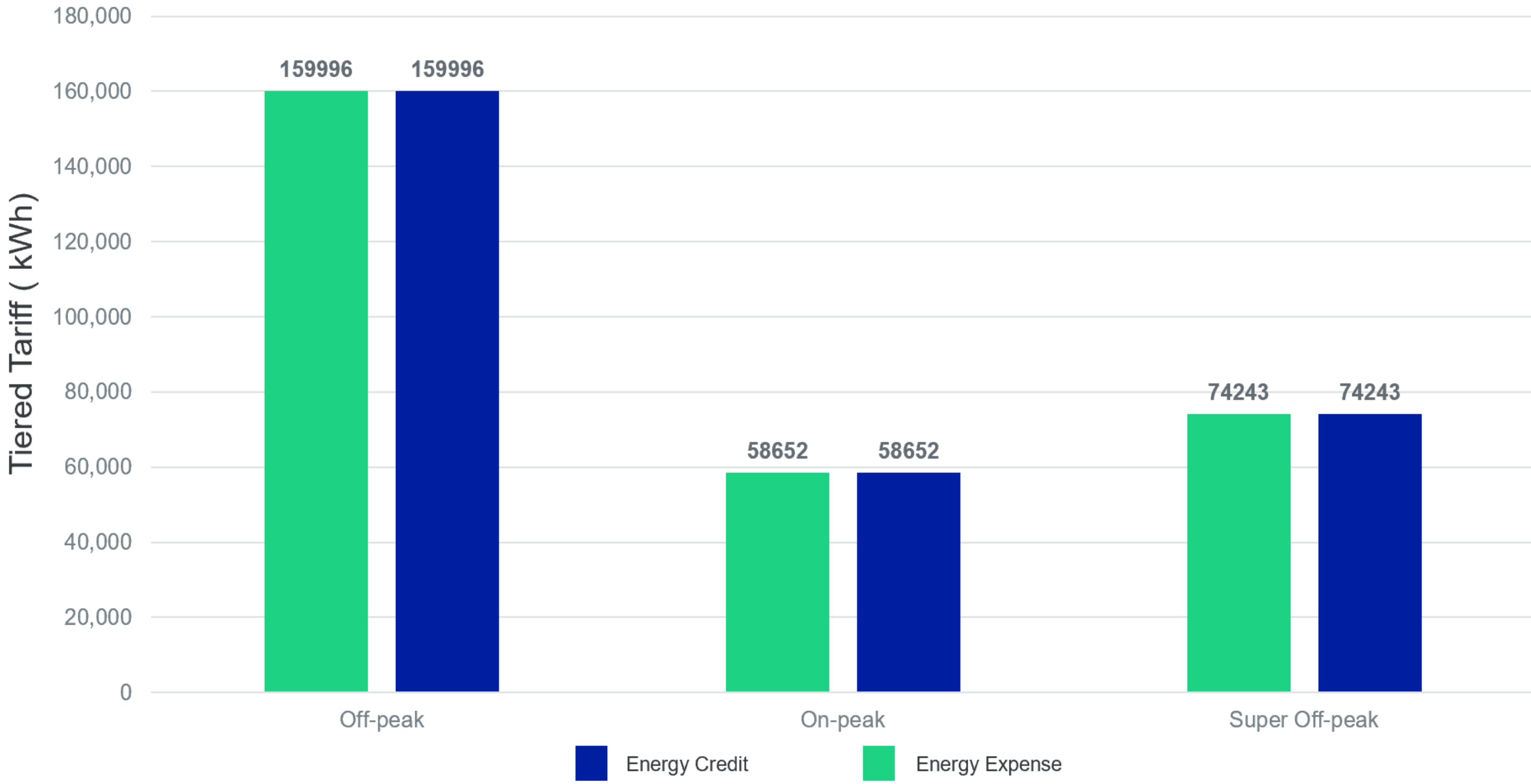
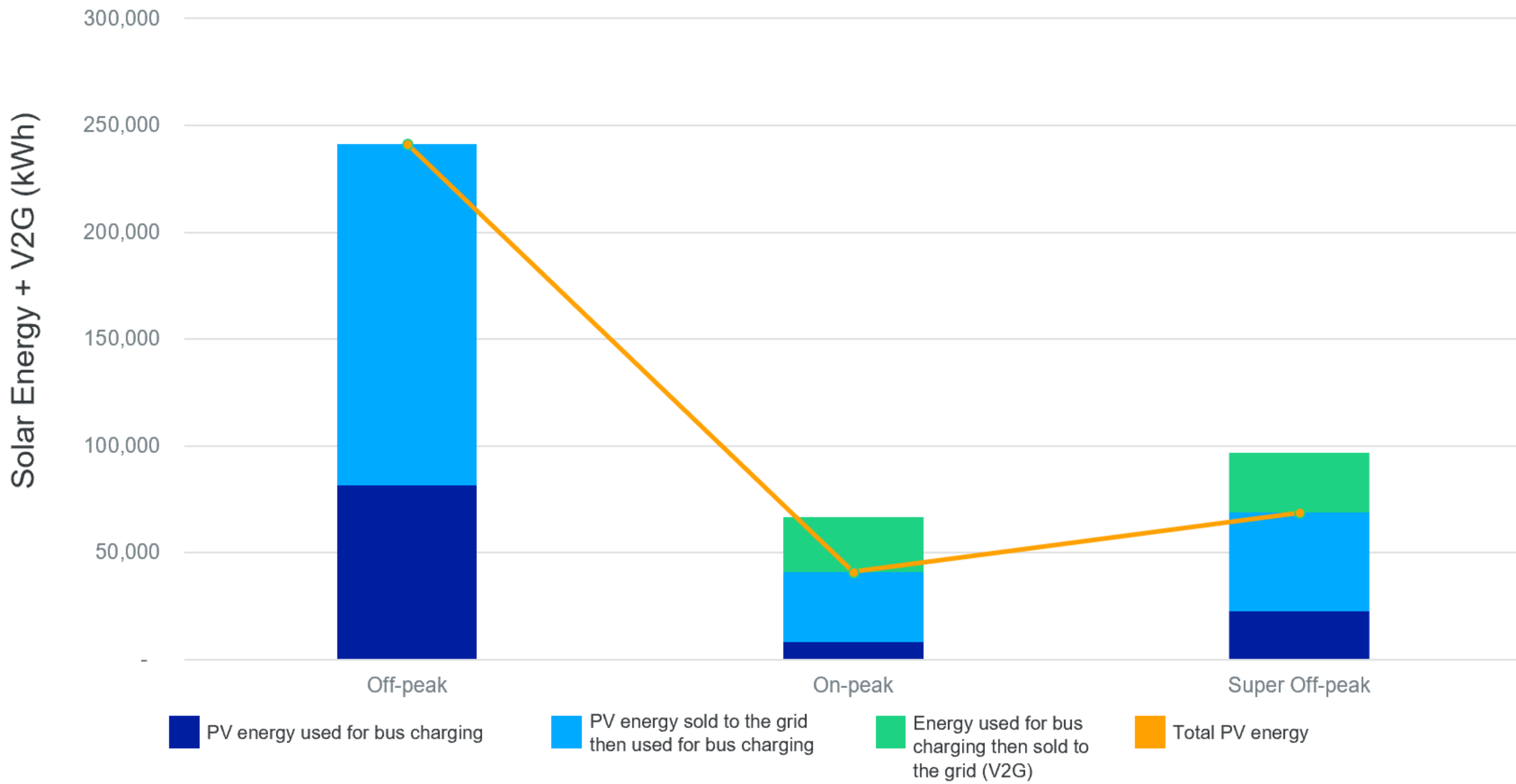


Figure 18: Solar Energy Generation and Consumption for Phase 3 Scenario 3



Phase 4a

To show how the optimal operations and economics of the fleet change with the introduction of V2G capabilities, we analyze Phase 4a using three different scenarios. These scenarios highlight the interaction between system variables like the size of the solar PV, bus battery capacity, and charger maximum nameplate capacity, as well as the sensitivity of the overall economics to these variables.

The Scenarios for Phase 4a are constructed as follows:

- Scenario 1: No DERs are allowed; buses and chargers are selected based on Task 2 (essential electrification without V2G); the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.
- Scenario 2: Solar is optimally selected; buses and chargers are selected based on Task 2 (essential electrification without V2G); the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.
- Scenario 3: Solar is optimally selected; buses and chargers are upgraded in battery size and charging rates, respectively, to increase V2G potential; the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.

Table 10. Bus and charger selection for Phase 4a

	Scenario 1: V2G; no DERs	Scenario 2: V2G; DERs	Scenario 3: V2G; DERs; Upgraded Buses + Chargers
Buses	3 Lion C1 buses (126 kWh battery)	3 Lion C1 buses (126 kWh battery)	14 Thomas C2 Jouley2 (226 kWh battery)
	5 Lion D1 buses (132 kWh battery)	5 Lion D1 buses (132 kWh battery)	
	6 Lion D2 buses (168 kWh battery)	6 Lion D2 buses (168 kWh battery)	
Chargers	9 Nuvve 19.2 kW bi-directional chargers	9 Nuvve 19.2 kW bi-directional chargers 5 Proterra 30 kW bi-directional chargers	Proterra 60 kW bi-directional chargers
	5 Proterra 30 kW bi-directional chargers	5 Proterra 30 kW bi-directional chargers	

In the following subsections, we provide a more granular description of the results for each Scenario, including comparison between charging and energy flow behavior for each run. We also compare the fleet performance with and without V2G.

Scenario 1: V2G; no DERs

Buses and Chargers:

- 3 Lion C1 buses, 5 Lion D1 buses, 6 Lion D2 buses
- 9 Nuvve 19.2 kW L2 bi-directional chargers, 5 Proterra 30 kW bi-directional chargers

Grid infrastructure: Adding the nameplate capacity of all required charging stations show that the theoretical grid capacity needed to charge the buses is about 323 kW. However, the maximum grid peak load does not exceed 109 kW at any point in time. This is because the optimal charging behavior spreads out charging over a longer period, primarily during super-off-peak periods, to minimize demand charges. While the capacity demand is mitigated, the lack of solar energy increases the total energy pulled from the grid compared to other scenarios. Equally important, the “V2G peak”, defined as the maximum discharge rate from the buses to the grid, is 323 kW at any point in time.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, most of the discharge occurs during the later hours of the on-peak tier. It is conceivable that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak hours.

Economics: The total cost of ownership for the electric fleet in Scenario 1 over 20 years is detailed in Table 11 below.

Table 11: Total Cost of Ownership for Scenario 1

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	80.3%
Charging Stations – CAPEX	*	8.0%
Charging Stations – OPEX	*	0.9%
Solar PV – CAPEX	*	0%
Solar PV – OPEX	*	0%
Grid energy supply – OPEX	*	10.7%

** Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 4a from diesel to electric with vehicle-to-grid capabilities reduces the GHG emissions from the buses by about 82%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 2,282 MtCO2, compared to an estimate of 12,643 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for two reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits.

Energy flows: Figure 19 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show that the buses are charging from the grid primarily during super-off-peak hours, either overnight on weekdays or overnight and during the day on weekends. At the same time, the vehicles discharge during off-peak and on-peak periods on Friday, as well as during on-peak periods on weekends, when no further trips are scheduled.

Charging profiles: Figure 20 and Figure 21 focus on the bus charging and discharging profiles. Figure 20 shows the stack of charging/discharging profiles for every bus in Phase 4a, and Figure 21 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- Because there is no solar energy, the buses must charge solely from the grid.
- During weekdays, bus charging occurs after 5:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 109 kW, and maximum discharge rate reaches 323 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a rate of 109 kW. The buses benefit from cheap super-off-peak rates from 12:00 am to 5:00 am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 5:00pm and 12:00am. In other words, while this off-peak and on-peak charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct. By charging from 5:00 pm to 5:00 am,

the buses can charge at a slower rate and thus minimize demand charges overall.

  - In the middle of the day, between 10:00am and 12:00pm, some off-peak charging occurs. This is because some buses need a charging boost after their morning routes in order to complete their afternoon routes.

- On weekends (Saturday and Sunday), the buses charge at 109 kW during super-off-peak periods, from after midnight through the early afternoon hours.
- In terms of discharge, the buses mostly discharge to the grid during peak period on Friday, Saturday, and Sunday. The buses discharge less energy on Sunday than Saturday to maintain a state-of-charge needed for the routes on Monday.
  - As seen in Figure 21, there is some “bus-to-bus” charging, on Friday for example. In reality, this means that one bus is discharging to the grid while another is simultaneously pulling energy from the grid, resulting in a net zero expense. Since each bus has its unique trip schedule and therefore optimal charging schedule, such behavior is reasonable.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 80 MWh of electricity are discharged from the buses back to the grid to generate NEM credits.
- As shown in Figure 22, those credits fall under the three tiers: 80 MWh on-peak, 0 MWh off-peak, and 0 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership.
- For Scenario 1, the vehicles exhibit optimal operations by maximizing discharge during on-peak hours. On-peak credits are exactly matched to expenses, but no credits are generated during off-peak or super-off-peak hours. The ability to match credits with expenses depends on bus size, route and charging demands, and charger size.

Scenario 2: V2G; DERs

In Scenario 2, the same bus and charging infrastructure is used as Scenario 1, but with the ability to optimally select and size a solar PV system. First, we present some insights from Scenario 2. Then, we compare to the results from Scenario 1 (V2G only) and Task 2 (essential electrification with no V2G). ***As a reminder, in this scenario any and all electricity discharge back the grid is accounted for as NEM credit, regardless of whether it’s produced by solar or by the V2G-enabled bus.***

<u>Buses & Chargers:</u>

- 3 Lion C1 buses, 5 Lion D1 buses, 6 Lion D2 buses
- 9 Nuvve 19.2 kW L2 bi-directional chargers, 5 Proterra 30 kW bi-directional chargers

<u>Onsite DERs:</u> In Scenario 2, the optimization yields investment in a 293 kW rooftop PV system. The solar system produces about 398 MWh every year. About 27% of the solar energy is directly used for bus charging, while the remaining 73% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

<u>Grid infrastructure:</u> Adding the nameplate capacity of all required charging stations show that the theoretical grid capacity needed to charge the buses is about 323 kW. However, the maximum grid peak load does not exceed 138 kW at any point in time. In fact, in the summer, grid peak load does not exceed 120 kW; this is because there is more charging from solar PV in the middle of the day. Equally important, the “V2G peak”, defined as the maximum discharge rate from the buses to the grid, is 323 kW at any point in time.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier (in summer) and super-off-peak (in winter) tier. It is very likely that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak (summer) and super-off-peak (winter) hours.

<u>GHG Emissions:</u> Under this Scenario, GUHSD would reduce the GHG emissions from the buses by about 88%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,563 MtCO2, compared to an estimate of 12,643 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 1,563 MtCO2 factors in only 27% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

<u>Energy flows:</u> Figure 23 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how solar and grid energy is balanced throughout the week.

- During weekdays, the majority of solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. In the middle of the day, solar is used to charge the buses directly, when the buses are in the depot between their morning and afternoon trips.
- On weekends, the majority of solar is used to charge the buses, which then store this solar energy and discharge it back to the grid, mostly during on-peak and occasionally during super-off-peak.
- Both on weekdays and on weekends, grid energy is used to supplement bus charging, mostly after midnight and sometimes in the evenings when needed.

<u>Charging profiles:</u> Figure 24 and Figure 25 focus on the bus charging and discharging profiles. Figure 24 shows the stack of charging/discharging profiles for every bus in Phase 4a, and Figure 25 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- During weekdays, bus charging occurs after 6:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 138 kW, and maximum discharge rate reaches 323 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a rate not exceeding 138 kW. The buses benefit from super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 6:00pm and 12:00am. In other words, while this charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct.
    - In the middle of the day, between 10:00am and 12:00pm, significant off-peak charging occurs for the buses to recharge between their morning and afternoon trips. The majority of energy is supplied directly from solar PV.
- On weekends (Saturday and Sunday), the buses charge during the day, anytime from 6:00am and 4:00pm. The majority of charging is attributed to direct feed from solar PV and is supplemented with grid electricity in the afternoon. The buses charge again the evening, between 9:00pm and midnight.
- In terms of discharge, the buses display distinct optimal behaviors between the summer and

winter months.

- During summer months, the buses discharge during the peak period on Friday, Saturday, and Sunday. The discharging on Saturday is maximized since the buses are least constrained with trip schedules. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during on-peak hours, benefiting from the price differential and accumulating valuable on-peak credits.
- During winter months, the buses' discharge is more limited, mostly occurring on Sunday for a few hours during the super-off-peak period. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during super-off-peak hours, to balance NEM credits (which we explain more in next section). Because the effective cost of solar is even cheaper than super-off-peak grid electricity, this behavior makes sense; the economic benefit associated with it is small but positive, therefore still contributing to reducing costs.

NEM Credit Balance:

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 33 MWh of electricity are fed into the grid to generate NEM credits using vehicle to grid capabilities, and 290 MWh of electricity are fed into the grid to generate NEM credits using solar.
- As shown in Figure 26, those credits fall under the three tiers: 62 MWh on-peak, 180 MWh off-peak, and 81 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership. The results show that credits and expenses are completely and perfectly balanced for all three tiers; no net energy expense occurs.
- Figure 27 provides a more granular view of where the NEM credits originate: from solar PV or from V2G-enabled buses. First, it's apparent that solar PV contributes NEM credits in all 3 tiers: on-peak, off-peak, and super-off-peak. In contrast, V2G contributes NEM credits in only two tiers: on-peak and super-off-peak. While the solar PV NEM credits are rigid (dependent on solar generation profile), the V2G NEM credits are more flexible; while partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.

Comparing Scenario 2 (V2G; DERs) to Scenario 1 (V2G; no DERs):

Technology and Emissions:

Table 12: Technology and Emissions Comparison

Output	Scenario 2 Value (V2G; DERs)	Scenario 1 Value (V2G, no DERs)
Solar PV Size	293 kW	0 kW
Grid peak load	138 kW	109 kW
GHG emission reduction	88% reduction	82% reduction

- Adding onsite solar PV improves GHG emission reductions by about 6%. This is primarily due to the 108 MWh of solar energy used to directly charge the buses every year.
- Adding onsite solar PV leads to an increase in grid peak load, though the peak load with solar shrinks to 120 kW in summer months.

Major Takeaway: With V2G capabilities, there is a dynamic balance between the sizing of the solar system and the grid peak load, in order to minimize total cost of ownership. In detail, adding more solar: helps balance NEM credits; which requires balancing super-off-peak expenses and credits; which requires pulling less electricity from grid during super-off-peak tier after midnight; which may require shifting some of the charging from after midnight to later evenings; which may increase charging during later evenings; which may require increasing grid peak load.

- This dynamic between solar, grid peak load, overnight charging, and NEM credits is also evident in the results of Phase 3 and Phase 4a, but it is more pronounced in Phase 4a.

Economics:

Table 13: Total Cost of Ownership Comparison

Cost	Scenario 2 Value (V2G; DERs)	Scenario 1 Value (V2G, no DERs)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$890,152**	**$1,109,897**
Total costs	**$10,115,382**	**$10,335,127**

** Information redacted for confidentiality*

- The addition of solar results in an overall decrease in total energy costs by about $220,000. While the PV CAPEX and OPEX increases the TCO, this increase is more than offset by the lower cost of energy purchased from the grid.

Energy flows: Grid energy is used much in the same way with and without solar, to provide steady charging to buses overnight from 6:00pm to 5:00am. However, upon adding solar, the majority of midday charging is provided by solar PV, and the grid energy needed between the morning and after trips is relatively limited.

Charging profiles:

- During weekdays, Scenario 1 and 2 follow overall very similar charging profiles in the evenings and overnight, charging from the grid from 6:00pm to 5:00am. However, during the day from 10:00am to 12:00pm, there are a few key differences. Upon adding solar PV (scenario 2):
  - The majority of daytime charging can be fulfilled with solar energy.
  - The grid peak load is lower in the summer months, when solar is abundant. Buses charge more during off-peak hours between 10:00 am and 12:00 pm, then can charge more slowly overnight.
  - On Friday, the buses do not exhibit the “bus-to-bus” behavior explained in Scenario 1 (without solar), likely because solar energy is available to avoid charging from the grid.
- On weekends, midday charging without solar is more uniform than with solar; upon charging from solar, the buses follow the solar generation profile. However, without solar, the buses can charge at uniform rate from the grid.
- Both with and without solar, the buses discharge on Friday, Saturday, and Sunday, when less constrained by trip schedules and the need to charge. For Scenario 1 (no solar), buses optimally discharge almost exclusively during the most expensive on-peak hours to maximize

benefits. However, for Scenario 2 (with solar), buses optimally store then discharge the cheap solar energy during on-peak and super-off-peak hours; as a reminder, the levelized cost of solar energy is cheaper than the levelized cost of super-off-peak grid energy.

NEM Credit Balance:

- Both Scenarios 1 and 2 prioritize balancing the credits and the expenses in the more expensive billing tiers first. However, adding solar capacity allows for a much more balanced accounting of credits, leading to a reduction in energy expense and TCO for Scenario 2. Overall, 100% of energy drawn from the grid is offset by NEM credits in Scenario 2 (with solar), while 17% of energy drawn from the grid is offset by NEM credits in Scenario 1 (without solar).

Comparing Scenario 2 (V2G; DERs) to Task 2 (no V2G; DERs):

The comparison of the fleet operations with V2G (Scenario 2) and without V2G (earlier Task 2) entails using the same buses. Chargers in Scenario 2 are bi-directional, but were matched as closely to Task 2 as possible. In Scenario 2 (with V2G), five chargers were upgraded from 22.5 kW to 30 kW and 1 was upgraded from 7.7 kW to 19.2 to accurately reflect market availability for bi-directional chargers. The remaining eight chargers are 19.2 kW in both cases.

Table 14: Infrastructure and emissions comparison

Output	Scenario 2 Value (V2G, DERs)	Task 2 Value (no V2G, DERs)
Solar PV Size	293 kW	268 kW
Grid peak load	138 kW	132 kW
GHG emissions reduction	88% reduction	87% reduction

- Adding V2G capability to the fleet transition in Phase 4a does not result in major changes to GHG emissions reduction; the 1% improvement in emissions reduction with V2G is likely due to the chosen optimal solar system, which is slightly bigger.
- Grid peak load with V2G is about the same as without V2G, leading to the same total demand charge subscription fee while overall reducing energy costs (as seen in Table 15).

Table 15: Total cost of ownership comparison

Cost	Scenario 2 Value (V2G, DERs)	Task 2 Value (no V2G, DERs)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$890,152**	**$951,183**
Total costs	**$10,115,382**	**$9,636,739**

** Information redacted for confidentiality*

- Bus costs are the same with and without V2G.
- V2G-capable bi-directional chargers are more than double as expensive as one-directional conventional chargers, particularly because some chargers are slightly upgraded to reflect market availability.
- V2G reduces the total energy costs (from grid + solar) by almost 6%. While the cost of optimal

solar PV system is higher, the cost of grid energy supply is significantly lower due to better balancing of NEM credits.

- Unless the incremental cost of V2G hardware decreases significantly, the reduction in energy cost is unlikely to be sufficient to offset the increase in hardware cost, rendering the option of adding V2G capabilities the GUHSD fleet in Phase 4a economically unattractive.

Energy flows & charging profiles:

- During weekdays, the charging profiles for V2G and non-V2G fleet follow the same overall structure, patterns, and timing. The main difference is in the magnitude of charge (grid peak load) and magnitude of the solar profile.
- On weekends, the two cases charge differently due to technological differences, but with the same purpose - balancing NEM credits optimally.
    - In both cases, the buses charge from the grid during off-peak periods in the evening
    - Without V2G, solar energy feeds primarily back to the grid directly, resulting in off-peak NEM credits. In contrast, with V2G, solar energy feeds primarily to buses, which then discharge whenever needed – mostly on-peak period and occasionally super-off-peak – to optimize NEM credit balancing.

NEM Credit Balance:

- As explained before, V2G enables shifting some discharge, reshuffling the supply of solar energy from solar-to-grid into solar-to-bus-to-grid, to result in more valuable NEM credits.
- With and without V2G, the fleet is capable of offsetting all on-peak and off-peak energy expenses through solar. However, V2G improves the balancing of NEM credits in two ways:
    - V2G allows the credits to perfectly match, with no overgeneration and therefore no wasted credits. In contrast, without V2G, about 9% of the solar credits are wasted.
    - V2G closes the deficit in super-off-peak credits that exists without V2G. In one year, GUHSD would pay for 0 MWh of energy with V2G, compared to 52 MWh of super-off-peak energy without V2G.

Scenario 3: V2G; DERs; Upgraded Buses + Chargers

In Scenario 3, we upgrade to higher capacity buses and higher-powered chargers in order to test the sensitivity of V2G benefits to these variables. As in Scenario 2, solar PV is optimally selected. First, we present some insights from Scenario 3. Then, we compare the results of this Scenario 3 with upgraded buses+chargers to those of Scenario 2 with originally sized buses+chargers. ***As a reminder, in this scenario all bus routes remain constant, and therefore demand the same total energy consumption.***

Buses and Chargers:

- All buses are upgraded to 14 Thomas Jouley2 buses (226 kWh)
    - It is important to note that while we use the Thomas Jouley2, the bus range efficiencies (kWh/mi) are the same as in Scenario 1 and 2. The model is sensitive to bus efficiency, so we hold it constant to better understand the impact of battery size.
- All chargers are upgraded to Proterra 60 kW DCFC chargers. These chargers are modeled based on the Proterra 120 kW dual-port charger. We assume that each bus has a dedicated 60 kW port, and we assume simultaneous charging is allowed.

Onsite DERs: The optimization yields investment in a 293 kW rooftop PV system, which produces about 398 MWh every year. About 42% of the solar energy is directly used for bus charging, while the remaining 58% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

Grid infrastructure: Adding the nameplate capacity of all required charging stations show that the theoretical grid capacity needed to charge the buses is about 840 kW. However, the maximum grid peak load does not exceed 187 kW at any point in time. Equally important, the "V2G peak", defined as the maximum discharge rate from the buses to the grid, does reach the maximum rate of 840 kW.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier (in summer) and super-off-peak (in winter) tier. It is very likely that the discharge to the grid can occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak (summer) and super-off-peak (winter) hours.

GHG Emissions: Under this Scenario, GUHSD would reduce the GHG emissions from the buses by over 89%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,364 MtCO2, compared to an estimate of 12,643 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 1,364 MtCO2 factors in only 42% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

Energy flows: Figure 28 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how solar and grid energy is balanced throughout the week. During weekdays, the majority of daytime solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. In the middle of the day, solar is used to charge the buses directly, when the buses are in the depot between their morning and afternoon trips. On weekends, the majority of solar is used for day charging of the buses, which then discharge back to the grid during on-peak or super-off-peak hours. Both on weekdays and on weekends, grid energy is used to supplement bus charging, mostly after midnight and sometimes in the evenings when needed.

Charging profiles: Figure 29 and Figure 30 focus on the bus charging and discharging profiles. Figure 29 shows the stack of charging/discharging profiles for every bus in Phase 4a, and Figure 30 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- During weekdays, bus charging occurs after 5:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 187 kW, and maximum discharge rate reaches 840 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a maximum peak rate of 187 kW. The buses benefit from super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 6:00pm and 12:00am. In other words, while this charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct.
    - In the middle of the day, between 10:00am and 12:00pm, significant off-peak charging occurs for the buses to recharge between their morning and afternoon trips. The majority of energy is supplied directly from solar PV.
- On weekends (Saturday and Sunday), the buses charge during the day, anytime from 6:00am and 4:00pm. The majority of charging is attributed to direct feed from solar PV and is supplemented with small amount of grid electricity in the afternoon. The buses charge again the evening, between 9:00pm and midnight.

- In terms of discharge, the buses display distinct optimal behaviors between the summer and winter months.
    - During summer months, the buses discharge during the peak period on Friday, Saturday, and Sunday. The discharging on Friday is maximized since the buses are least constrained with trip schedules. In general, the buses use the abundant solar energy to charge. They then discharge during on-peak hours, benefiting from the price differential and accumulating valuable on-peak credits.
    - During winter months, the buses discharge during the limited hours of the super-off-peak period, mostly on Sunday and occasionally on Saturday. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during super-off-peak hours, to balance NEM credits (which we explain more in next section). Because the effective cost of solar is even cheaper than super-off-peak grid electricity, this behavior makes sense; the economic benefit associated with it is small but positive, therefore still contributing to reducing costs. In this particular case, the upgraded assets allow buses to generate enough super-off-peak NEM credits to completely offset super-off-peak energy expenses incurred during the week.
- As seen in Figure 30, there is some “bus-to-bus” charging, on Friday for example. In reality, this means that one bus is discharging to the grid while another is simultaneously pulling energy from the grid, resulting in a net zero expense. Since each bus has its unique trip schedule and therefore optimal charging schedule, such behavior is reasonable.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 38 MWh of electricity are fed into the grid to generate NEM credits using vehicle to grid capabilities, and 231 MWh of electricity are fed into the grid to generate NEM credits using solar.
- As shown in Figure 31, those credits fall under the three tiers: 49 MWh on-peak, 179 MWh off-peak, and 41 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership. The results show that credits and expenses are completely and perfectly balanced across all tiers; no net energy expense occurs under any tier. Also, there are no credit deficits and no overgeneration of credits in any tier.
- Figure 32 provides a more granular view of where the NEM credits originate: from solar PV or from V2G-enabled buses. First, it’s apparent that solar PV contributes NEM credits in all 3 tiers: on-peak, off-peak, and super-off-peak. In contrast, V2G contributes NEM credits in only two tiers: on-peak and super-off-peak. While the solar PV NEM credits are more rigid (dependent on solar generation profile), the V2G NEM credits are more flexible. While partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers.
    - Upgrading the buses and chargers enhances this ability further, resulting in perfect netting of energy expenses and credits. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.

Comparing Scenario 3 (V2G; DERs; Upgraded Buses+Chargers) to Scenario 2 (V2G; DERs; Original Buses+Chargers):

Technology and Emissions:

Table 16: Infrastructure and emissions comparison

Output	Scenario 3 Value (V2G; DERs; Upgraded Buses + Chargers)	Scenario 2 Value (V2G; DERs; Original Buses + Chargers)
Solar PV Size	293 kW	293 kW
Grid peak load	187 kW	138 kW
GHG emissions reduction	89%	88%

- Upgrading the buses and chargers in Phase 4a does not result in major changes to GHG emissions reduction; the 1% improvement in emissions reduction is likely due to the chosen optimal solar system, which is bigger.
- Upgrading the buses and chargers results in higher grid peak load as well as V2G peak. This has economic implications of increasing grid-capacity cost (demand charges). However, in this particular case, the increase in demand charge is within the optimization algorithm margin of error (0.4% change in total TCO), as we explain below.

Table 17: Total cost of ownership comparison

Cost	Scenario 3 Value (V2G; DERs; Upgraded Buses + Chargers)	Scenario 2 Value (V2G; DERs; Original Buses + Chargers)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$939,443**	**$890,152**
Total costs	**$13,520,711**	**$10,413,011**

** Information redacted for confidentiality*

- The total energy cost (from grid + solar) is not significantly higher in Scenario 3 than Scenario 2.
  - The cost of solar PV with upgraded buses + chargers is roughly the same as in Scenario 2 because there is enough solar energy produced by the 293 kW system to successfully arbitrage for NEM credits.
  - In both cases, all the cost of grid energy is formed of demand charges (kW); there is no cost associated with the energy itself (kWh) because the NEM credits perfectly offset all grid energy. Because Scenario 3 results in a slightly higher demand charge, the total grid energy OPEX increases. However, we note that this increase in demand charge is within the optimization algorithm margin of error (0.4% change in total TCO).
- Upgrading the buses and chargers doesn't significantly impact the total energy costs (combination of grid and solar), but it does result in a significant increase in CAPEX. Overall, the TCO for Scenario 3 (upgraded buses+chargers) is about 30% higher than that of Scenario 2 (original buses+chargers).

Energy flows & charging profiles:

- Throughout the week (both weekdays and weekends), the charging profiles for the original and the upgraded V2G fleets follow the same overall structure, patterns, and timing. The main difference is in the magnitude of charge (grid peak load) and discharge (V2G peak); the magnitude of charge and discharge is higher for upgraded buses and chargers.
- Buses demand the same amount of total energy needed to complete daily trips and fulfill mobility needs. However, upgraded buses and chargers can store and discharge more solar energy, providing more flexibility in how to reshuffle solar generation in a way that results in lowest possible total energy costs.
    - The solar system generates the same amount of total energy, some of which is sent back to the grid to generate credits and some of which directly charges the buses. Compared to the original fleet, a higher proportion of the solar energy is used for bus charging with upgraded buses + chargers (Scenario 3) during weekends, to reduce grid energy needs throughout the subsequent weekdays.

Main Takeaway: Compared to optimally sized buses, upgraded buses use more solar electricity to be directly charged during weekends. That energy is then stored and used on subsequent weekdays, therefore reducing the need for grid energy. Accordingly, the total NEM energy expenses across all tiers are lower for upgraded buses, as we explain in the next section.

- In Phase 3 (Scenario 3) and Phase 4b (Scenario 3), upgraded buses also store weekend solar energy for subsequent use throughout the week, but this behavior is more pronounced in Phase 4a.

NEM Credit Balance:

- With both originally sized buses + chargers (Scenario 2) and upgraded buses + chargers (Scenario 3), the fleet is capable of offsetting all on-peak, off-peak, and super-off-peak expenses, resulting in completely balanced credits and no energy expense for kWh purchased throughout the year.
- In both cases, we also see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.
- As discussed above, larger bus batteries act as storage for the low-cost solar energy on weekends, then redistribute the solar throughout the week to meet bus mobility demands while drawing less total energy from the grid. Comparing Figure 31 (Scenario 3) to Figure 26 (Scenario 2), we see this phenomenon manifest in lower total “expenses” in all three tiers of NEM. While NEM credits completely and totally balance expenses under both scenarios, upgraded buses and chargers (Scenario 3) draw overall fewer grid resources.
    - This effect is especially visible in the super-off-peak tier. Comparing Figure 31 to Figure 27 shows that much more solar PV is used for direct charging of upgraded buses during super-off-peak. Equally important, comparing Figure 31 to Figure 26 shows that the total NEM balance drops to almost half (81 to 41 MWh) for upgraded buses.

Figure 19: Energy Flows for Phase 4a Scenario 1 – Summer

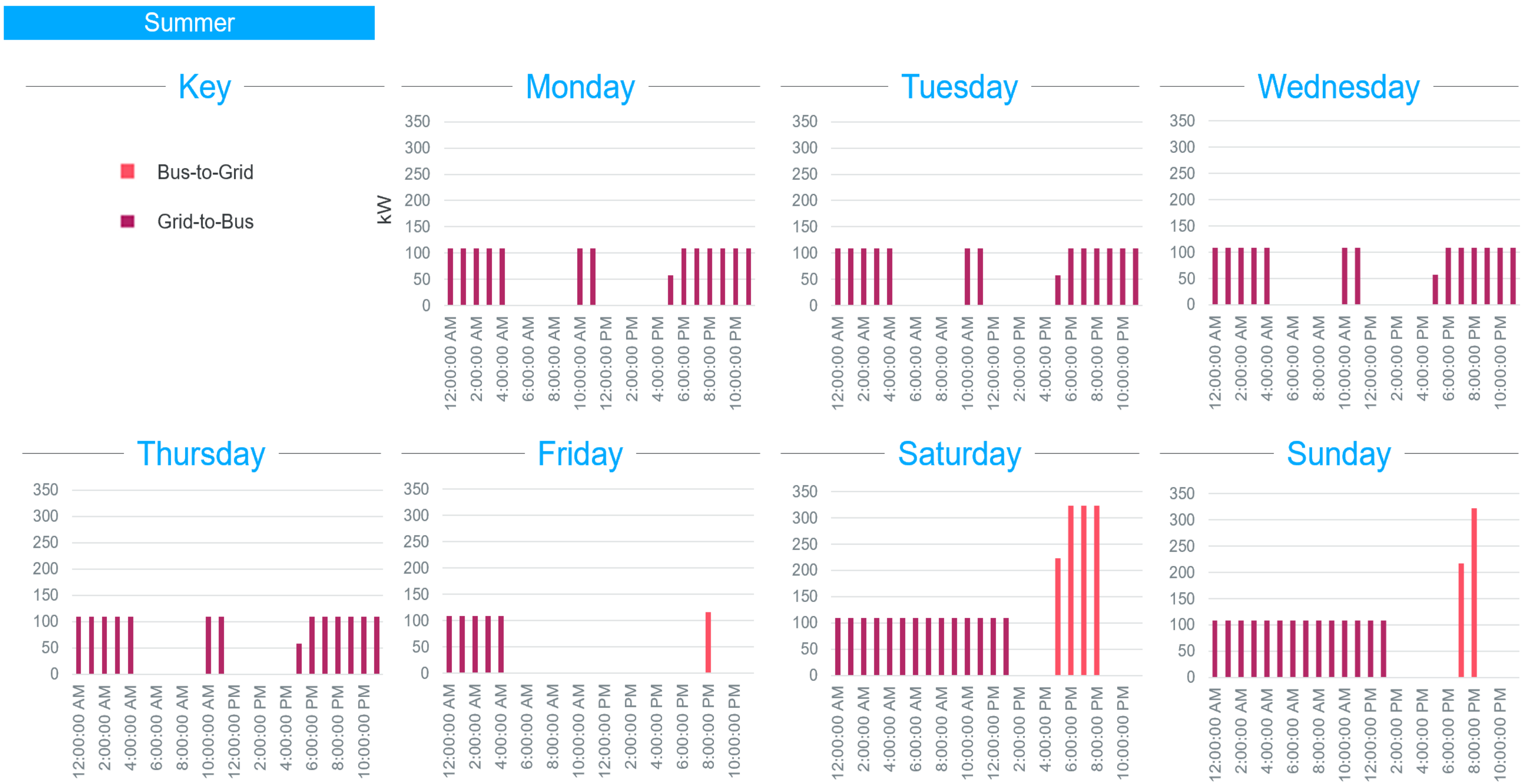


Figure 20: Charging Profiles for Phase 4a Scenario 1 – Summer

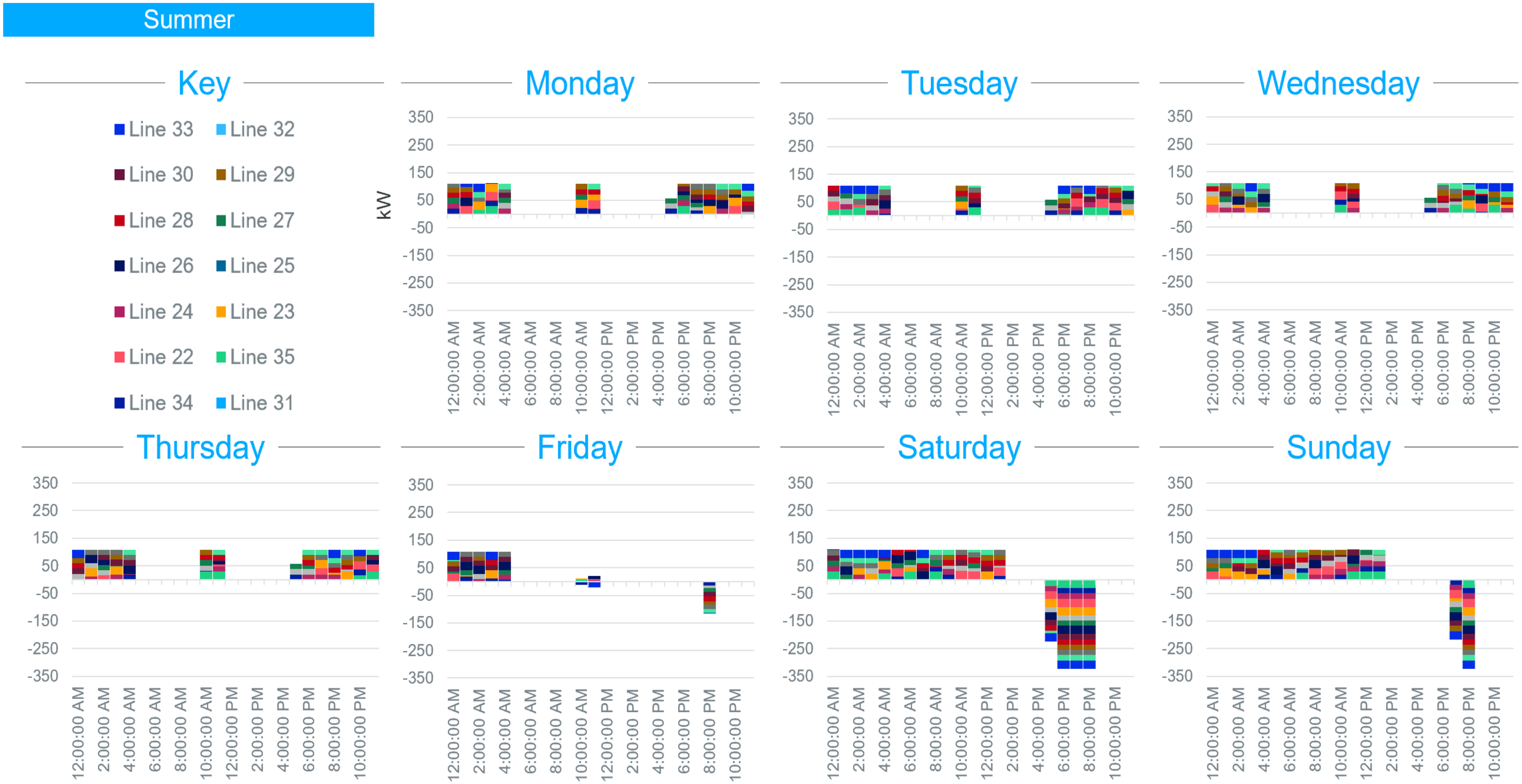


Figure 21: Sources of Energy for Bus Charging in Phase 4a Scenario 1 – Summer

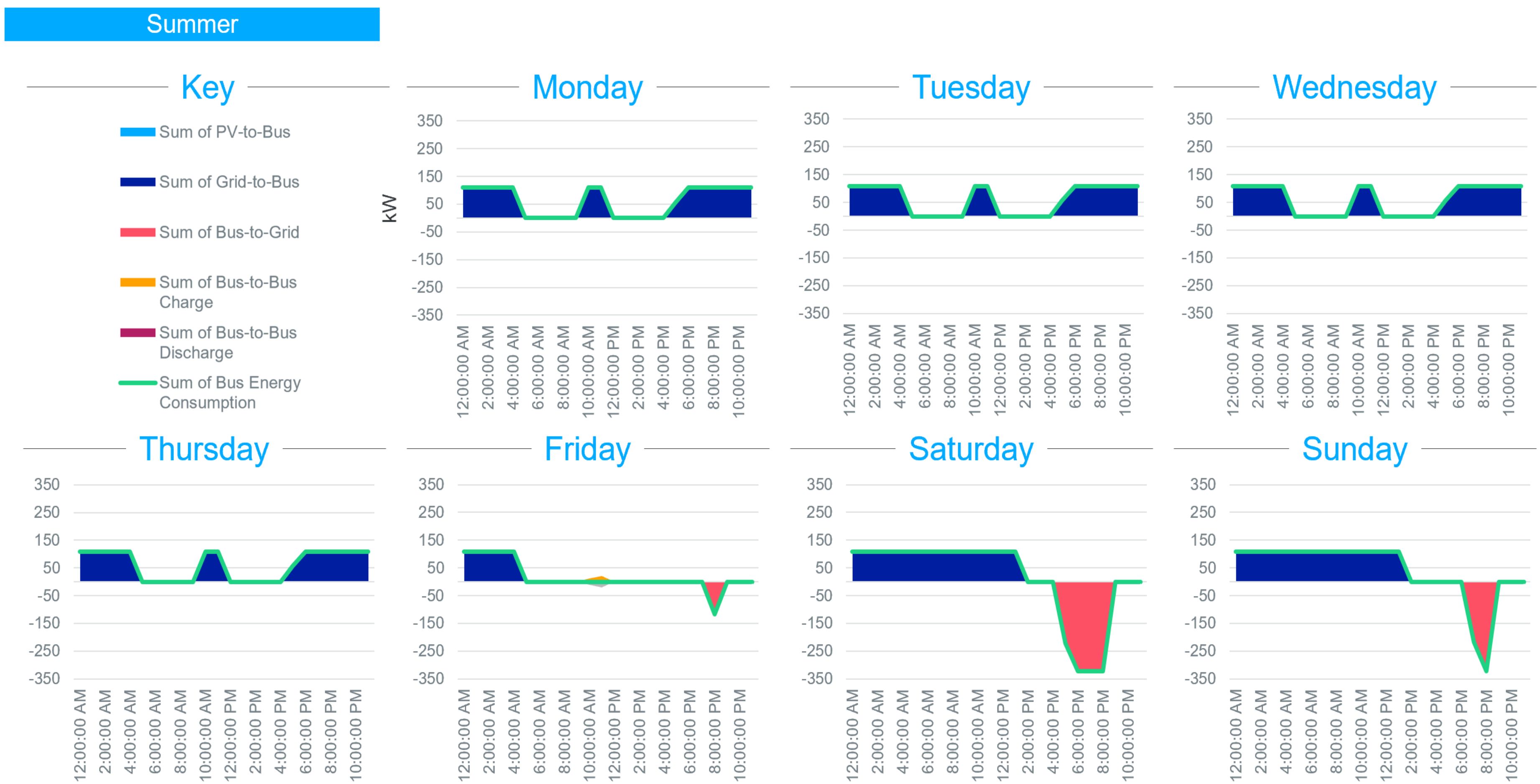


Figure 22: Tiered NEM Credit Balance for Phase 4a Scenario 1

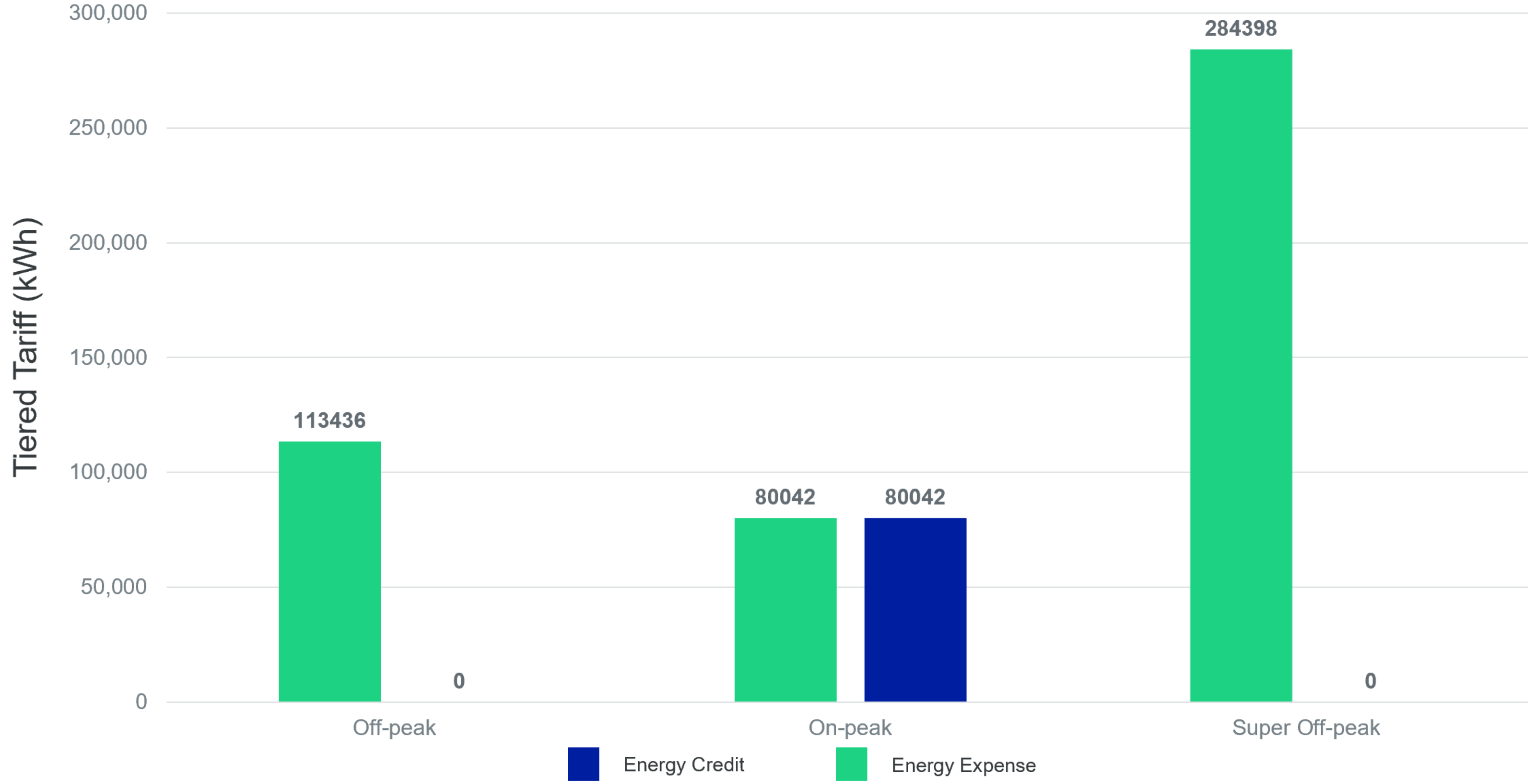


Figure 23: Energy Flows for Phase 4a Scenario 2 – Summer

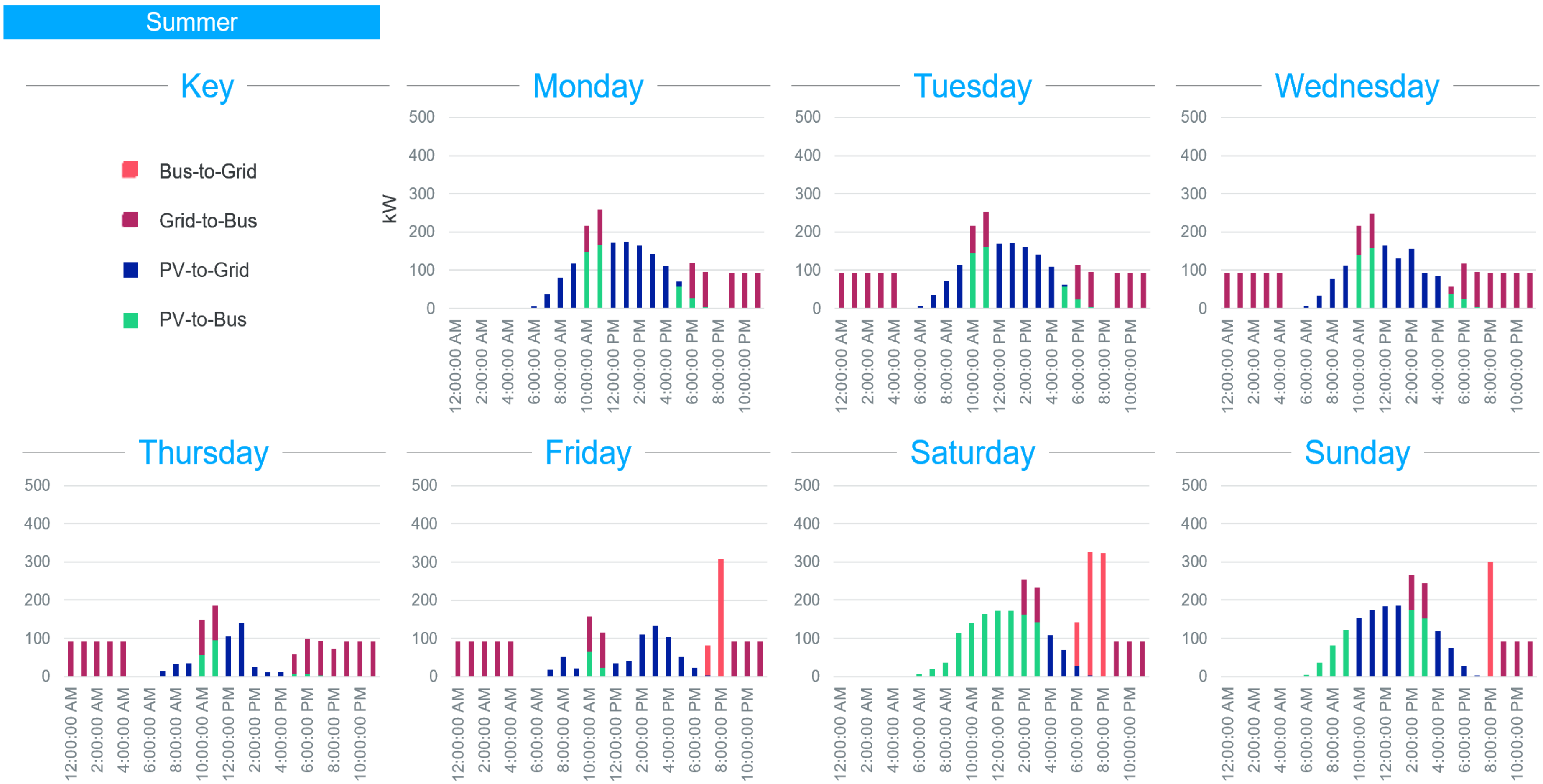


Figure 24: Charging Profiles for Phase 4a Scenario 2 – Summer

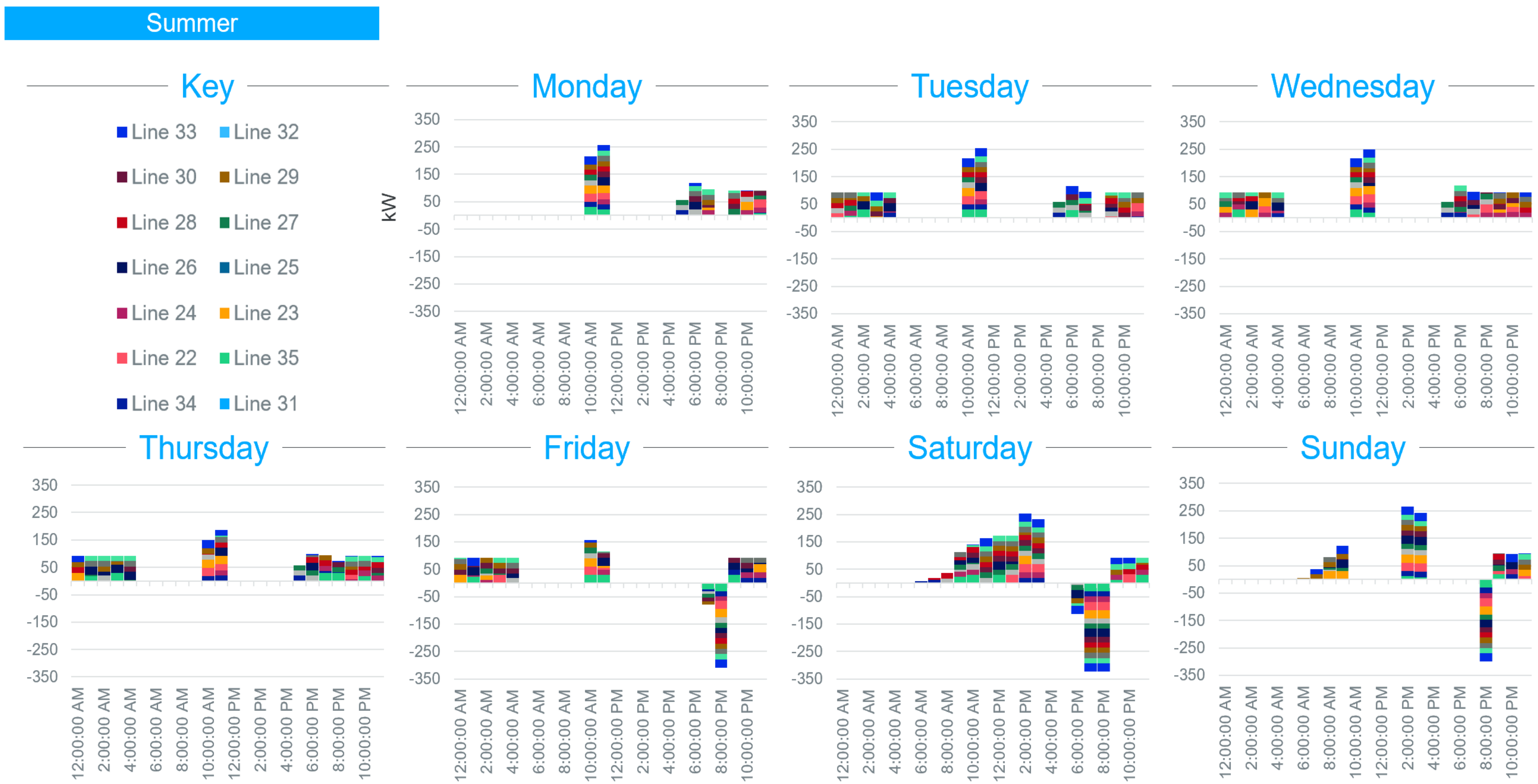


Figure 25: Sources of Energy for Bus Charging in Phase 4a Scenario 2 – Summer

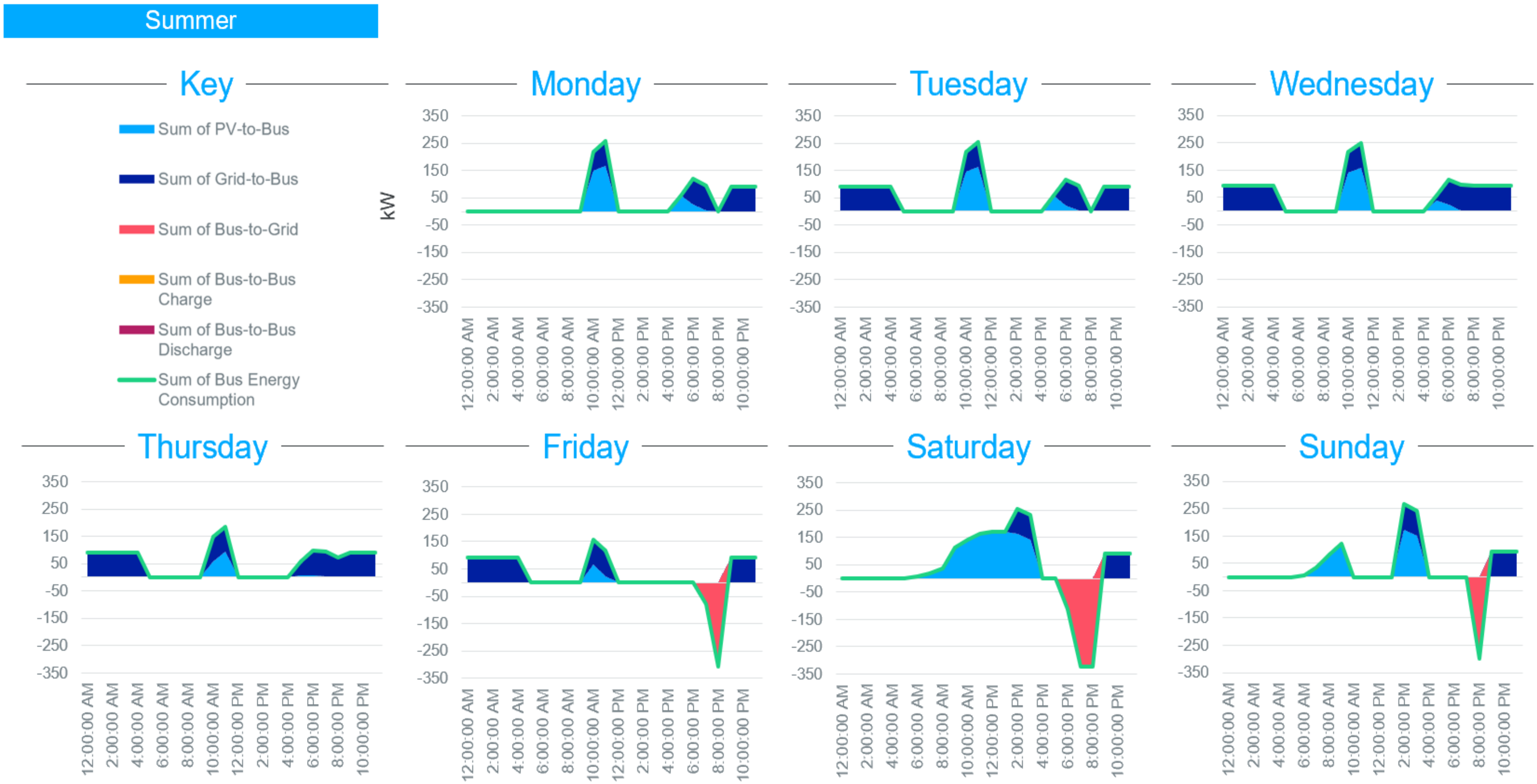


Figure 26: Tiered NEM Credit Balance for Phase 4a Scenario 2

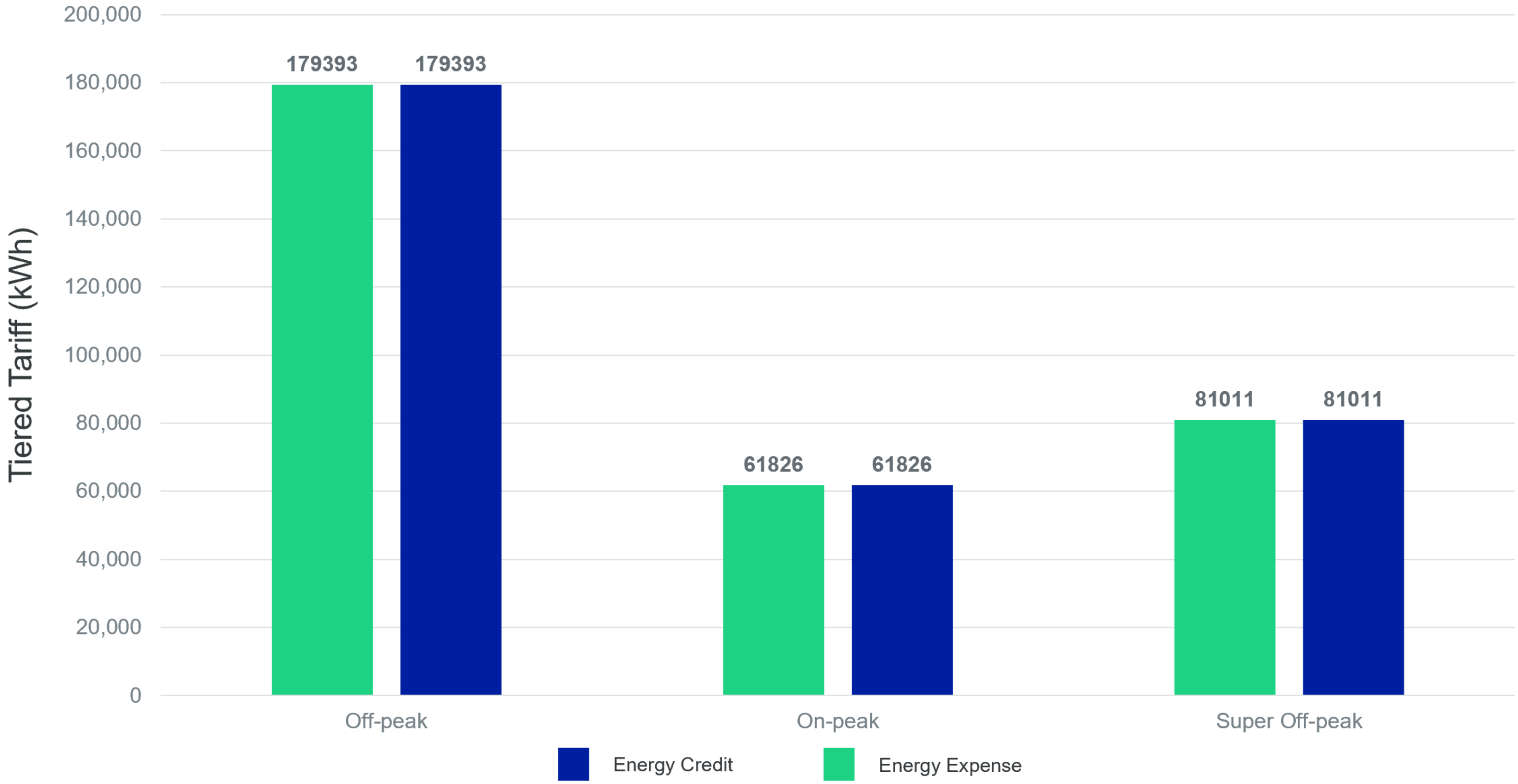


Figure 27: Solar Energy Generation and Consumption for Phase 4a Scenario 2

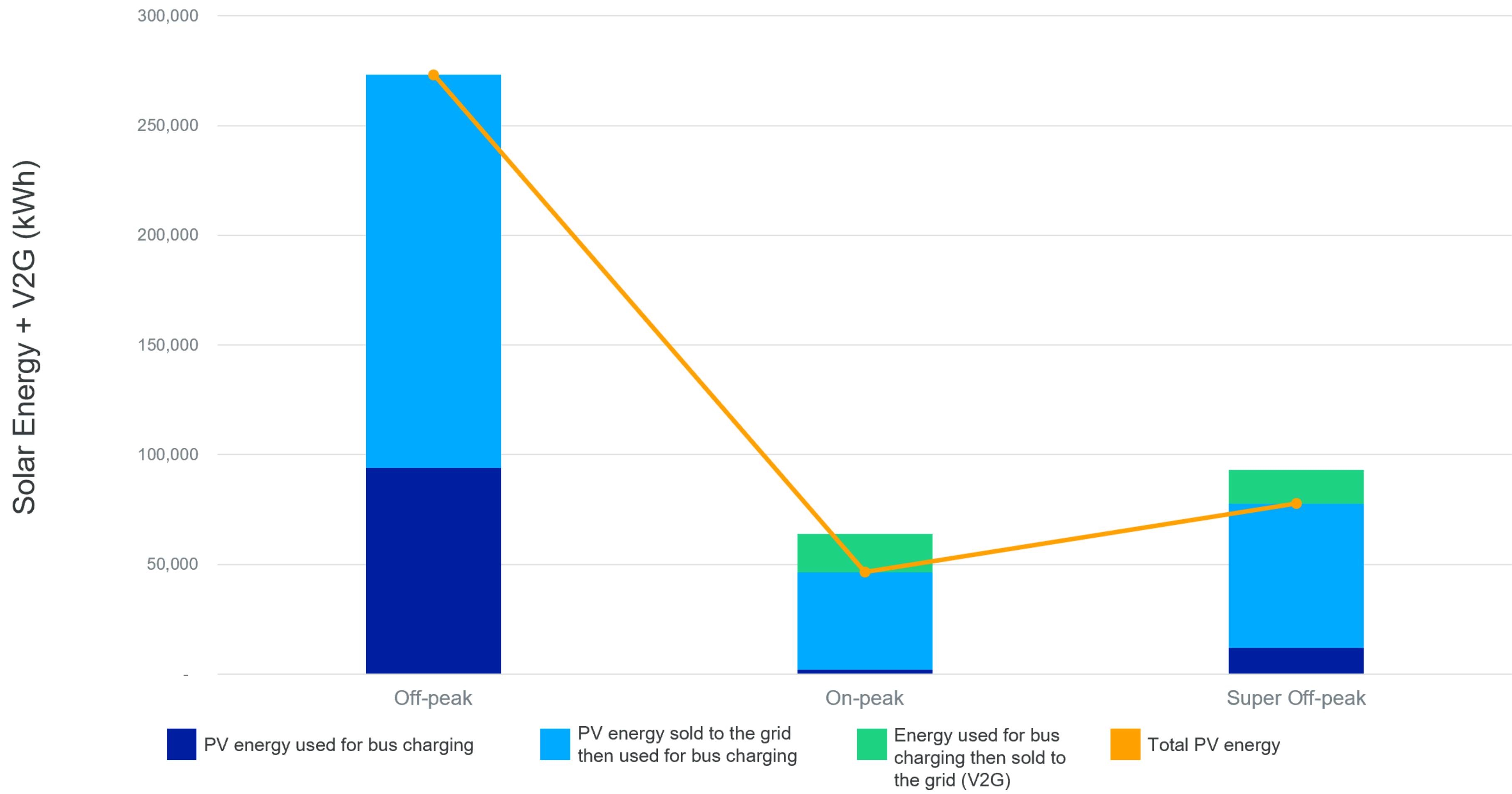


Figure 28: Energy Flows for Phase 4a Scenario 3 – Summer

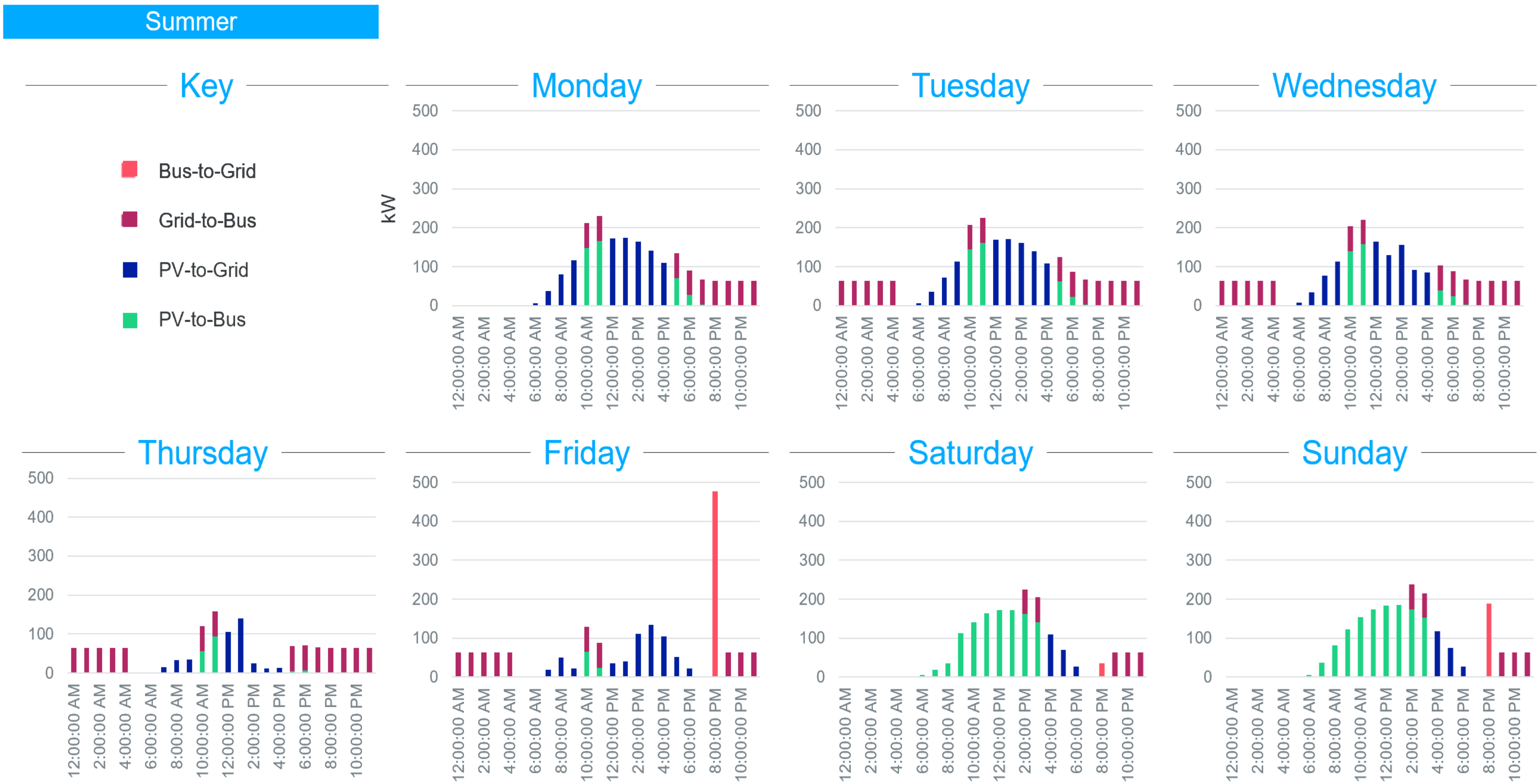


Figure 29: Charging Profiles for Phase 4a Scenario 3 – Summer

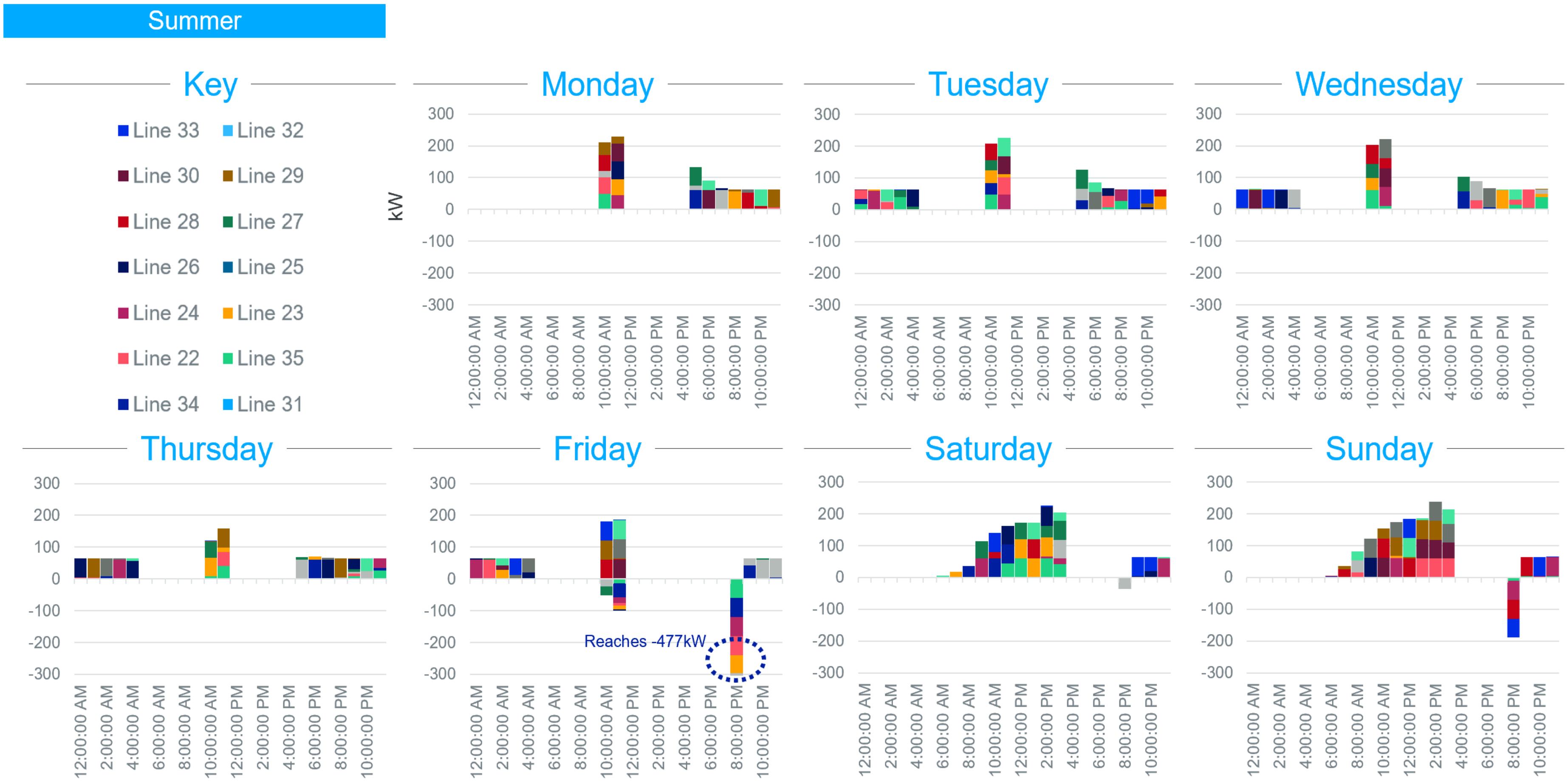


Figure 30: Sources of Energy for Bus Charging in Phase 4a Scenario 3 – Summer

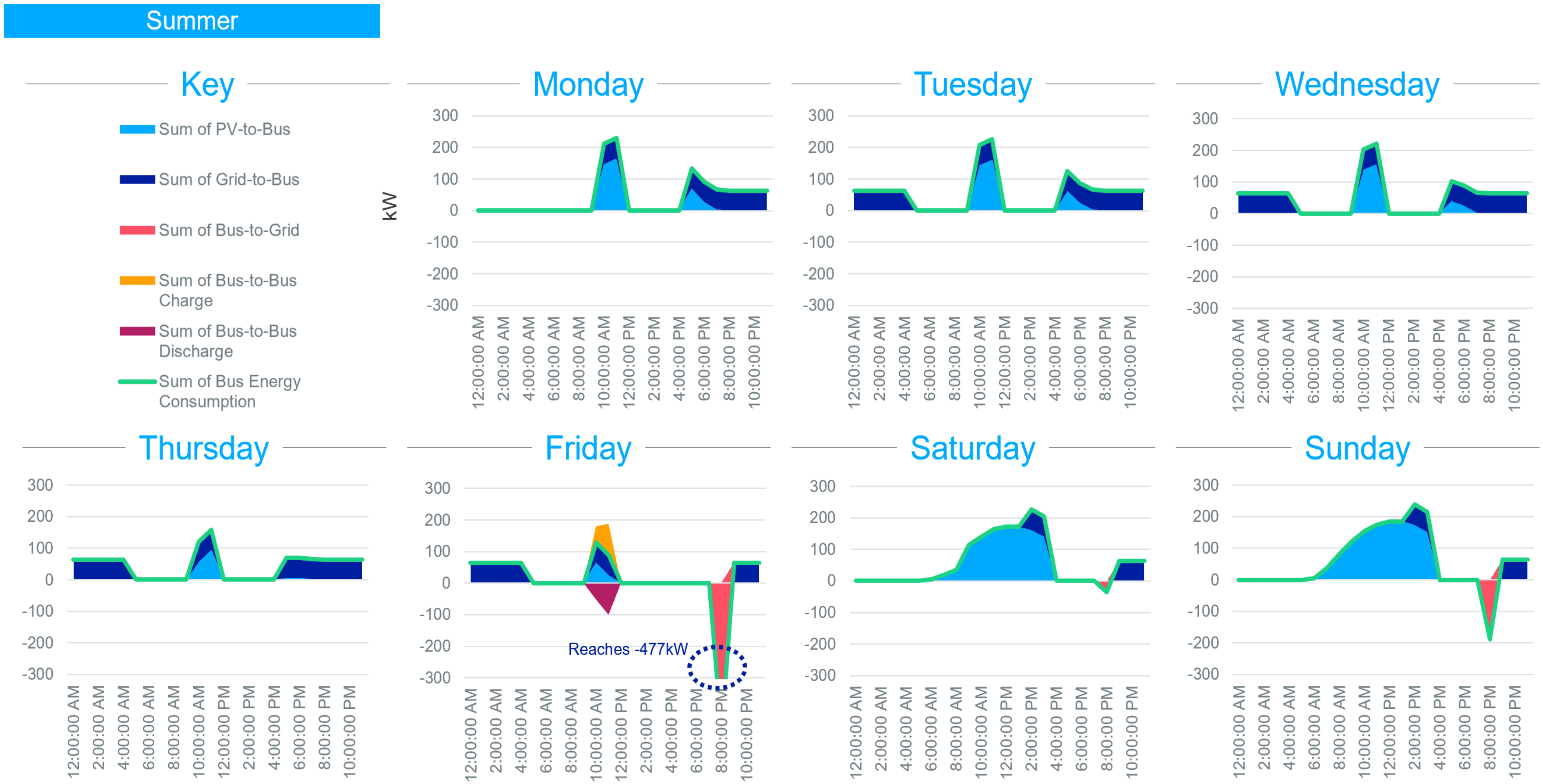


Figure 31: Tiered NEM Credit Balance for Phase 4a Scenario 3

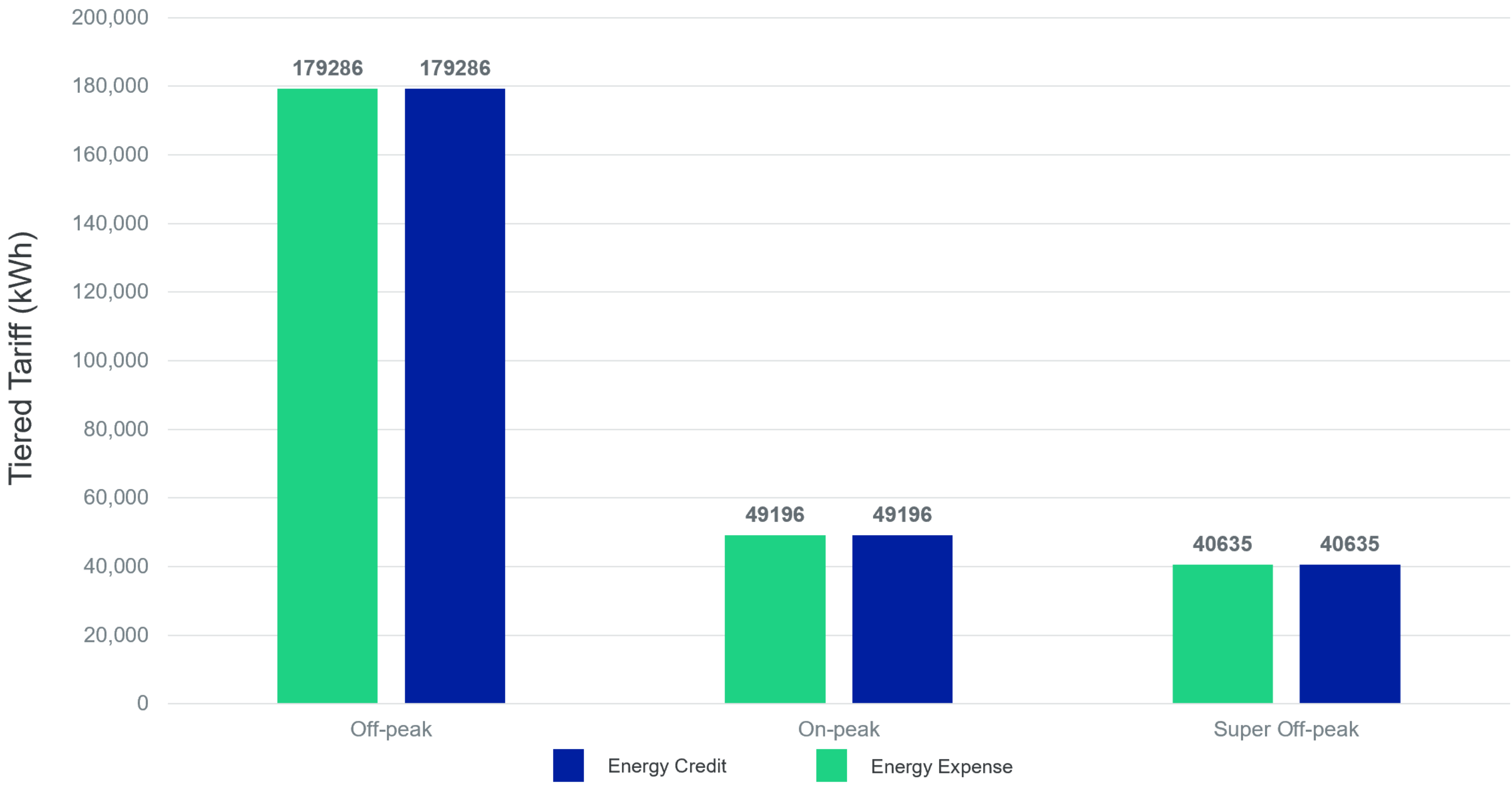
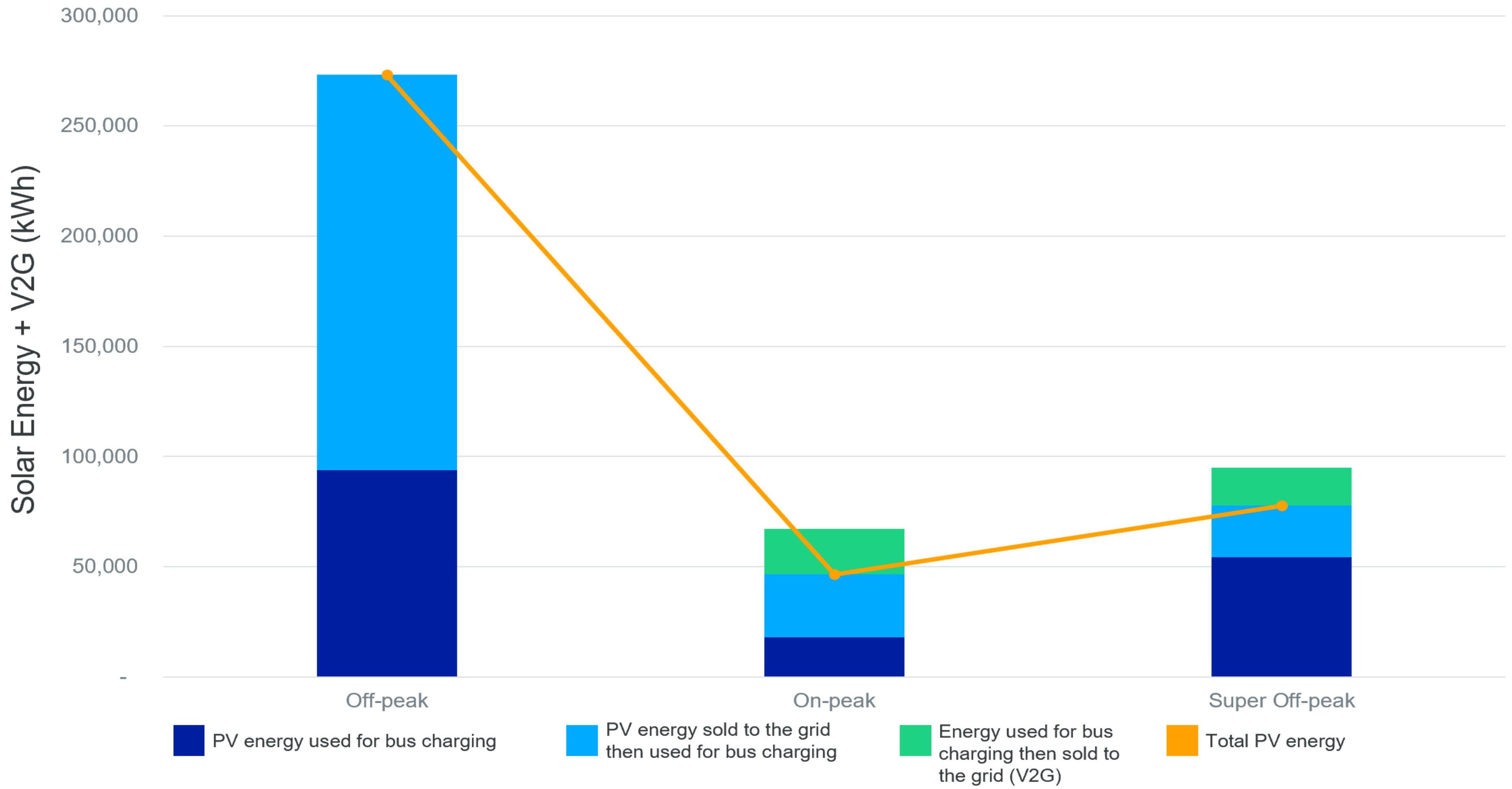


Figure 32: Solar Energy Generation and Consumption for Phase 4a Scenario 3



Phase 4b

To show how the optimal operations and economics of the fleet change with the introduction of V2G capabilities, we analyze Phase 4b using three different scenarios. These scenarios highlight the interaction between system variables like the size of the solar PV, bus battery capacity, and charger maximum nameplate capacity, as well as the sensitivity of the overall economics to these variables.

The Scenarios for Phase 4b are constructed as follows:

- Scenario 1: No DERs are allowed; buses and chargers are selected based on Task 2 (essential electrification without V2G); the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.
- Scenario 2: Solar is optimally selected; buses and chargers are selected based on Task 2 (essential electrification without V2G); the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.
- Scenario 3: Solar is optimally selected; buses and chargers are upgraded in battery size and charging rates, respectively, to increase V2G potential; the buses can discharge to the grid following the Tiered NEM credit accounting mechanisms.

Table 18. Bus and charger selection for Phase 4b

	Scenario 1: V2G; no DERs	Scenario 2: V2G; DERs	Scenario 3: V2G; DERs; Upgraded Buses + Chargers
Buses	1 Lion A2 bus (168 kWh)	1 Lion A2 bus (168 kWh)	15 Thomas C2 Jouley2 (226 kWh battery)
	5 Lion C1 buses (168 kWh battery)	5 Lion C1 buses (168 kWh battery)	
	7 Lion D1 buses (132 kWh battery)	7 Lion D1 buses (132 kWh battery)	
	2 Lion D2 buses (168 kWh)	2 Lion D2 buses (168 kWh)	
Chargers	Nuvve 19.2 kW bi-directional chargers	Nuvve 19.2 kW bi-directional chargers	Proterra 60 kW bi-directional chargers

In the following subsections, we provide a more granular description of the results for each Scenario, including comparison between charging and energy flow behavior for each run. We also compare the fleet performance with and without V2G.

Scenario 1: V2G; no DERs

Buses and Chargers:

- 1 Lion A2 bus, 5 Lion C1 bus, 7 Lion D1 buses, and 2 Lion D2 buses
- 15 Nuvve 19.2 kW L2 bi-directional chargers

Grid infrastructure: Adding the nameplate capacity of all required charging stations show that the theoretical grid capacity needed to charge the buses is about 288 kW. However, the maximum grid peak load does not exceed 123 kW at any point in time. This is because the optimal charging behavior spreads out charging over a longer period, primarily during super-off-peak periods, to minimize demand charges. While the capacity demand is mitigated, the lack of solar energy increases the total energy pulled from the grid compared to other scenarios. Equally important, the “V2G peak”, defined as the maximum discharge rate from the buses to the grid, is 288 kW at any point in time.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier. It is very likely that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak hours.

Economics: The total cost of ownership for the electric fleet in Scenario 1 over 20 years is detailed in Table 19 below.

Table 19: Total cost of ownership for Scenario 1

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	82.0%
Charging Stations – CAPEX	*	5.4%
Charging Stations – OPEX	*	0.7%
Solar PV – CAPEX	*	0%
Solar PV – OPEX	*	0%
Grid energy supply – OPEX	*	12.0%

* *Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 4b from diesel to electric with vehicle-to-grid capabilities reduces the GHG emissions from the buses by about 83%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 2,615 MtCO2, compared to an estimate of 14,905 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for two reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits.

Energy flows: Figure 33 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show that the buses are charging from the grid primarily during super-off-peak hours, either overnight on weekdays or overnight and during the day on weekends. At the same time, the vehicles discharge primarily during on-peak periods on weekends, when no further trips are scheduled.

Charging profiles: Figure 34 and Figure 35 focus on the bus charging and discharging profiles. Figure 34 shows the stack of charging/discharging profiles for every bus in Phase 4b, and Figure 35 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- Because there is no solar energy, the buses must charge solely from the grid.
- During weekdays, bus charging occurs after 5:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 123 kW, and maximum discharge rate reaches 288 kW.
    - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a rate of 123 kW. The buses benefit from cheap super-off-peak rates from 12:00 am to 5:00 am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 6:00pm and midnight. In other words, while this on-peak and off-peak charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct. By charging from 5:00 pm to 5:00 am, the buses can charge at a slower rate and thus minimize demand charges overall.
    - In the middle of the day, between 9:00am and 1:00pm, some off-peak charging occurs. This is because some buses need a charging boost after their morning routes in order to

complete their afternoon routes.

- On weekends (Saturday and Sunday), the buses charge at 123 kW during super-off-peak periods, from after midnight through the morning hours.
- In terms of discharge, the buses mostly discharge to the grid during peak period on Saturday and Sunday. The buses discharge less energy on Sunday than Saturday to maintain a state-of-charge needed for the routes on Monday.
  - As seen in Figure 35, there is some "bus-to-bus" charging, on Friday for example. In reality, this means that one bus is discharging to the grid while another is simultaneously pulling energy from the grid, resulting in a net zero expense. Since each bus has its unique trip schedule and therefore optimal charging schedule, such behavior is reasonable.

NEM Credit Balance:

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 92 MWh of electricity are discharged from the buses back to the grid to generate NEM credits.
- As shown in Figure 36, those credits fall under the three tiers: 89 MWh on-peak, 3 MWh off-peak, and 0 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership.
- For Scenario 1, the vehicles exhibit optimal operations by maximizing discharge during on-peak hours, followed by off-peak hours. On-peak credits are exactly matched to expenses, and on-peak credits are partially matched. The ability to match credits with expenses depends on bus size, route and charging demands, and charger size.

Scenario 2: V2G; DERs

In Scenario 2, the same bus and charging infrastructure is used as Scenario 1, but with the ability to optimally select and size a solar PV system. First, we present some insights from Scenario 2. Then, we compare to the results from Scenario 1 (V2G only) and Task 2 (essential electrification with no V2G). ***As a reminder, in this scenario any and all electricity discharge back the grid is accounted for as NEM credit, regardless of whether it's produced by solar or by the V2G-enabled bus.***

Buses & Chargers:

- 1 Lion A2 bus, 5 Lion C1 bus, 7 Lion D1 buses, and 2 Lion D2 buses
- 15 Nuvve 19.2 kW L2 bi-directional chargers

Onsite DERs: In Scenario 2, the optimization yields investment in a 309 kW rooftop PV system. The solar system produces about 420 MWh every year. About 39% of the solar energy is directly used for bus charging, while the remaining 61% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

Grid infrastructure: Adding the nameplate capacity of all required charging stations shows that the theoretical grid capacity needed to charge the buses is about 288 kW. However, the maximum grid peak load does not exceed 132 kW at any point in time. In fact, in the summer, grid peak load does not exceed 125 kW; this is because there is more charging from solar PV in the middle of the day. Equally important, the "V2G peak", defined as the maximum discharge rate from the buses to the grid, is 288 kW at any point in time.

- It is important to note that the demand charge is calculated based on the maximum *charge rate*, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier (in summer) and super-off-peak (in winter) tier. It is likely that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak (summer) and super-off-peak (winter) hours.

GHG Emissions: Under this Scenario, GUHSD would reduce the GHG emissions from the buses by about 88%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,823 MtCO2, compared to an estimate of 14,905 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 1,823 MtCO2 factors in only 39% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

Energy flows: Figure 37 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how solar and grid energy is balanced throughout the week.

- During weekdays, the majority of solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. In the middle of the day, solar is used to charge the buses directly, when the buses are in the depot between their morning and afternoon trips, and occasionally after they return from afternoon trips.
- On weekends, the majority of solar is used to charge the buses, which then store this solar energy and discharge it back to the grid, mostly during on-peak and occasionally during super-off-peak.
- Both on weekdays and on weekends, grid energy is used to supplement bus charging, mostly after midnight and sometimes in the evenings when needed.

Charging profiles: Figure 38 and Figure 39 focus on the bus charging and discharging profiles. Figure 38 shows the stack of charging/discharging profiles for every bus in Phase 4b, and Figure 39 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- During weekdays, bus charging occurs after 5:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 132 kW, and maximum discharge rate reaches 288 kW.
  - Between 6:00pm and 5:00am, the buses charge consistently from the grid at a rate of 105 kW. The buses benefit from super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 6:00pm and 12:00am. In other words, while this charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct.
  - In the middle of the day, between 9:00am and 1:00pm, significant off-peak charging occurs, for the buses to recharge between their morning and afternoon trips. The majority of energy is supplied directly from solar PV.
- On weekends (Saturday and Sunday), the buses charge during the day, anytime from 6:00am and 4:00pm. The majority of charging is attributed to direct feed from solar PV and is supplemented with grid electricity in the afternoon. The buses charge again the evening, between 9:00pm and midnight.
- In terms of discharge, the buses display distinct optimal behaviors between the summer and winter months.
  - During summer months, the buses discharge during the peak period on Friday,

Saturday, and Sunday. The discharging on Saturday is maximized, since the buses are least constrained with trip schedules. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during on-peak hours, benefiting from the price differential and accumulating valuable on-peak credits.

  - During winter months, the buses' discharge is more limited, mostly occurring on Sunday for a few hours during the super-off-peak period. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during super-off-peak hours, to balance NEM credits (which we explain more in next section). Because the effective cost of solar is even cheaper than super-off-peak grid electricity, this behavior makes sense; the economic benefit associated with it is small but positive, therefore still contributing to reducing costs.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 72 MWh of electricity are fed into the grid to generate NEM credits using vehicle to grid capabilities, and 256 MWh of electricity are fed into the grid to generate NEM credits using solar.
- As shown in Figure 40, those credits fall under the three tiers: 74 MWh on-peak, 181 MWh off-peak, and 73 MWh super-off-peak. Optimal charging requires energy credits to balance energy expense in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership. The results show that credits and expenses are completely and perfectly balanced for on-peak and off-peak tiers; no net energy expense occurs under these two tiers. The super-off-peak tier is partially balanced, with a credit deficit of about 37 MWh.
- Figure 41 provides a more granular view of where the NEM credits originate: from solar PV or from V2G-enabled buses. First, it's apparent that solar PV contributes NEM credits in all 3 tiers: on-peak, off-peak, and super-off-peak. In contrast, V2G contributes NEM credits in only two tiers: on-peak and super-off-peak. While the solar PV NEM credits are rigid (dependent on solar generation profile), the V2G NEM credits are more flexible; while partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.

Comparing Scenario 2 (V2G; DERs) to Scenario 1 (V2G; no DERs):

<u>Technology and Emissions:</u>

Table 20: Technology and emissions comparison

Output	Scenario 2 Value (V2G; DERs)	Scenario 1 Value (V2G, no DERs)
Solar PV Size	309 kW	0 kW
Grid peak load	132 kW	123 kW
GHG emission reduction	88% reduction	83% reduction

- Adding onsite solar PV improves GHG emission reductions by about 5%. This is primarily due to the 164 MWh of solar energy used to directly charge the buses every year.
- Adding onsite solar PV leads to an increase in grid peak load, though the peak load with solar shrinks to 125 kW in summer months.
  - The dynamic between solar, grid peak load, overnight charging, and NEM credits is described in detail in Phase 4a. In brief, it is advantageous to increase the grid peak load in Scenario 2 in order to balance NEM credits more effectively.

Economics:

Table 21: Total cost of ownership comparison

Cost	Scenario 2 Value (V2G; DERs)	Scenario 1 Value (V2G, no DERs)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$1,011,264**	**$1,261,343**
Total costs	**$10,294,931**	**$10,545,010**

** Information redacted for confidentiality*

- The addition of solar results in an overall decrease in total energy costs by about $250,000. While the PV CAPEX and OPEX increases the TCO, this increase is more than offset by the lower cost of energy purchased from the grid.

Energy flows: Grid energy is used much in the same way with and without solar, to provide steady charging to buses overnight from 6:00pm to 5:00am. However, upon adding solar, the majority of midday charging is provided by solar PV, and the grid energy needed between the morning and after trips is relatively limited.

Charging profiles:

- During weekdays, Scenarios 1 and 2 follow overall very similar charging profiles in the evenings and overnight, charging from the grid consistently from 6:00pm to 5:00am. However, during the day from 9:00am to 1:00pm, there are a few key differences. Upon adding solar PV (Scenario 2):
    - The majority of daytime charging can be fulfilled with solar energy.
    - The grid peak load is lower in the summer months, when solar is abundant. Buses charge more during off-peak hours between 9:00 am and 1:00 pm, then can charge more slowly overnight.
    - On Friday, the buses do not exhibit the “bus-to-bus” behavior explained in Scenario 1 (without solar), likely because solar energy is available to avoid charging from the grid.
- On weekends, midday charging without solar is more uniform than with solar; upon charging from solar, the buses follow the solar generation profile. However, without solar, the buses can charge at uniform rate from the grid.
- Both with and without solar, the buses discharge on Saturday and Sunday, when less constrained by trip schedules and the need to charge. With solar, there is also some discharge on Friday. For Scenario 1 (no solar), buses optimally discharge almost exclusively during the most expensive on-peak hours to maximize benefits. However, for Scenario 2 (with solar), buses optimally store then discharge the cheap solar energy during on-peak and super-off-peak hours; as a reminder, the levelized cost of solar energy is cheaper than the levelized cost of super-off-peak grid energy.

NEM Credit Balance:

- Both Scenarios 1 and 2 prioritize balancing the credits and the expenses in the more expensive billing tiers first. However, adding solar capacity allows for a much more balanced accounting of credits, leading to a reduction in energy expense and TCO for Scenario 2. Overall, 90% of energy drawn from the grid is offset by NEM credits in Scenario 2 (with solar), while 17% of energy drawn from the grid is offset by NEM credits in Scenario 1 (without solar).

Comparing Scenario 2 (V2G; DERs) to Task 2 (no V2G; DERs):

The comparison of the fleet operations with V2G (Scenario 2) and without V2G (earlier Task 2) entails using the same buses. Although the chargers have equivalent power rating (19.2 kW) in both cases, the chargers in Scenario 2 are bi-directional whereas the ones in Task 2 are not. Buses in Scenario 2 are matched as closely as possible to Task 2. We swap one Motiv & Colins (127 kWh) bus, which is not V2G-enabled, with a V2G-capable Lion A2 (168 kWh). The Lion A2 was chosen because it most closely matched the specifications in seating capacity and range.

Table 22: Infrastructure and emissions comparison

Output	Scenario 2 Value (V2G, DERs)	Task 2 Value (no V2G, DERs)
Solar PV Size	309 kW	301 kW
Grid peak load	132 kW	158 kW
GHG emissions reduction	88% reduction	87% reduction

- Adding V2G capability to fleet transition in Phase 4b does not result in major changes to GHG emissions reductions; the 1% improvement in emissions reductions with V2G is likely due to the chosen optimal solar system, which is slightly bigger.
- Grid peak load with V2G is lower than that without V2G. This can be attributed to the fundamental principle that adding V2G capabilities provide the fleet with additional flexibility to fulfill the bus energy needs, all while reducing energy costs; such flexibility can manifest in installing larger solar PV or reshuffling (stretching over longer periods) the charging schedules to reduce demand charges.

Table 23: Total cost of ownership comparison

Cost	Scenario 2 Value (V2G, DERs)	Task 2 Value (no V2G, DERs)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$1,011,264**	**$1,105,130**
Total costs	**$10,294,931**	**$10,002,745**

** Information redacted for confidentiality*

- Bus costs are slightly higher with V2G because one Motiv & Collins bus is exchanged with a V2G-capable Lion A2 bus.
- Although 19.2 kW chargers are used in both cases, V2G-capable bi-directional chargers are almost double as expensive as one-directional conventional chargers.
- V2G reduces the total energy costs (from grid + solar) by over 9%. While the cost of optimal solar PV system is slightly higher, the cost of grid energy supply is significantly lower, due to two reasons, both related to better balance: (i) reduced demand charges, and (ii) cheaper energy charges due to better balancing of NEM credits.

- Unless the incremental cost of V2G hardware decreases significantly, the reduction in energy cost is unlikely to be sufficient to offset the increase in hardware cost, rendering the option of adding V2G capabilities the GUHSD fleet in Phase 4b economically unattractive.

Energy flows & charging profiles:

- During weekdays, the charging profiles for V2G and non-V2G fleet are essentially identical.
- On weekends, the two cases charge differently due to technological differences, but with the same purpose - balancing NEM credits optimally.
    - In both cases, the buses charge from the grid during off-peak periods in the evening.
    - Without V2G, solar energy feeds primarily back to the grid directly, resulting in off-peak NEM credits. In contrast, with V2G, solar energy feeds primarily to buses, which then discharge whenever needed – mostly on-peak period and occasionally super-off-peak period– to optimize NEM credit balancing.

NEM Credit Balance:

- As explained before, V2G enables shifting some of the discharge, reshuffling the supply of solar energy from solar-to-grid into solar-to-bus-to-grid, to result in more valuable NEM credits.
- With and without V2G, the fleet is capable of offsetting all on-peak and off-peak energy expenses through solar. However, V2G improves the balancing of NEM credits in two ways:
    - V2G allows on-peak and off-peak credits to perfectly match, with no overgeneration and therefore no wasted credits. In contrast, without V2G, about 9% of the solar credits are wasted.
    - V2G narrows down the deficit in super-off-peak credits. In one year, GUHSD would pay for 37 MWh of super-off-peak energy with V2G, compared to 71 MWh of super-off-peak energy without V2G.

Scenario 3: V2G; DERs; Upgraded Buses + Chargers

In Scenario 3, we upgrade to higher capacity buses and higher powered chargers in order to test the sensitivity of V2G benefits to these variables. As in Scenario 2, solar PV is optimally selected. First, we present some insights from Scenario 3. Then, we compare the results of this Scenario 3 with upgraded buses+chargers to those of Scenario 2 with originally sized buses+chargers. ***As a reminder, in this scenario all bus routes remain constant, and therefore demand the same total energy consumption.***

Buses and Chargers:

- All buses are upgraded to 15 Thomas Jouley2 buses (226 kWh)
    - It is important to note that while we use the Thomas Jouley2, the bus efficiencies (kWh/mi) are the same as in Scenario 1 and 2. The model is sensitive to bus efficiency, so we hold it constant to better understand the impact of battery size.
- All chargers are upgraded to 15 Proterra 60 kW DCFC chargers. These chargers are modeled based on the Proterra 120 kW dual-port charger. We assume that each bus has a dedicated 60 kW port, and we assume simultaneous charging is allowed.

Onsite DERs: The optimization yields investment in a 337 kW rooftop PV system, which produces about 457 MWh every year. About 45% of the solar energy is directly used for bus charging, while the remaining 55% is fed into the grid and accounted for as NEM credits under the three distinct tiers.

Grid infrastructure: Adding the nameplate capacity of all required charging stations shows that the theoretical grid capacity needed to charge the buses is about 900 kW. However, the maximum grid peak load does not exceed 98 kW at any point in time. Equally important, the “V2G peak”, defined as the maximum discharge rate from the buses to the grid, does reach the maximum rate of 900 kW.

- It is important to note that the demand charge is calculated based on the maximum charge rate, not the maximum discharge rate. Today, nearly all the discharge occurs during the later hours of the on-peak tier (in summer) and super-off-peak (in winter) tier. It is very likely that the discharge to the grid could occur over a longer period of time at a lower rate to reduce the V2G peak; this would entail stretching bus discharge across more on-peak (summer) and super-off-peak (winter) hours.

<u>GHG Emissions:</u> Under this Scenario, GUHSD would reduce the GHG emissions from the buses by about 88%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,823 MtCO2, compared to an estimate of 14,905 MtCO2e from diesel. In fact, the GHG emissions from electric buses are probably an overestimate, and the real emissions could be lower, primarily for three reasons. First, the electric bus emissions do not consider the progressive decrease in the carbon intensity of the California grid over time due to higher penetration of renewables. Furthermore, the ability for buses to discharge stored solar energy during peak periods, when energy demand is ramping up and is often dirtier, can provide additional emissions benefits. Finally, the 1,823 MtCO2 factors in only 55% of the onsite solar PV generation used to directly charge the buses; it does not account for the solar energy that was generated and fed into the grid.

<u>Energy flows:</u> Figure 42 shows all energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how solar and grid energy is balanced throughout the week. During weekdays, daytime solar generation is fed back into the grid both in the morning and in the afternoon, while the buses are away completing their trips. Solar is also used to charge the buses directly when the buses are in the depot between their morning and afternoon trips and sometimes after completing trips. On weekends, the majority of solar is used for day charging of the buses, which then discharge back to the grid during on-peak or super-off-peak hours. Both on weekdays and on weekends, grid energy is used to supplement bus charging, in the evenings and into the early morning when needed.

<u>Charging profiles:</u> Figure 43 and Figure 44 focus on the bus charging and discharging profiles. Figure 43 shows the stack of charging/discharging profiles for every bus in Phase 4b, and Figure 44 shows the sources of electricity used to charge/discharge these buses. Some key takeaways:

- During weekdays, bus charging occurs after 5:00pm to about 5:00am, and in the middle of the day after the morning trips. The maximum charging rate reaches 98 kW, and maximum discharge rate reaches 900 kW.
    - Between 5:00pm and 5:00am, the buses charge consistently from the grid at a maximum peak rate of 98 kW. The buses benefit from super-off-peak rates from 12:00am to 5:00am. The model utilizes the Tiered NEM credits to allow on-peak and off-peak charging between 5:00pm and 12:00am. In other words, while this charging pulls electricity from the grid, it does not result in costly energy expense but is rather enabled by V2G and the Tiered NEM construct.
    - In the middle of the day, between 9:00am and 1:00pm, significant off-peak charging occurs, for the buses to recharge between their morning and afternoon trips. The majority of energy is supplied directly from solar PV.
- On weekends (Saturday and Sunday), the buses charge during the day, anytime from 6:00am and 4:00pm. The majority of charging is attributed to direct feed from solar PV and is supplemented with grid electricity in the afternoon. The buses charge again the evening, between 9:00pm and midnight.
- In terms of discharge, the buses display distinct optimal behaviors between the summer and winter months.

    - During summer months, the buses discharge during the peak period on Friday, Saturday, and Sunday. The discharging on Friday is maximized since the buses are least constrained with trip schedules. In general, the buses use the abundant solar energy to charge. They then discharge during on-peak hours, benefiting from the price differential and accumulating valuable on-peak credits.
    - During winter months, the buses discharge during the limited hours of the super-off-peak period, mostly on Sunday and occasionally on Saturday. In general, the buses use the abundant and cheap solar energy to charge, and then discharge during super-off-peak hours, to balance NEM credits (which we explain more in next section). Because the effective cost of solar is even cheaper than super-off-peak grid electricity, this behavior makes sense; the economic benefit associated with it is small but positive, therefore still contributing to reducing costs. In this particular case, the upgraded assets allow buses to generate enough super-off-peak NEM credits to completely offset super-off-peak energy expenses incurred during the week.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of credits and minimum total cost of ownership. In total, 60 MWh of electricity are fed into the grid to generate NEM credits using vehicle to grid capabilities, and 250 MWh of electricity are fed into the grid to generate NEM credits using solar.
- As shown in Figure 45, those credits fall under the three tiers: 66 MWh on-peak, 163 MWh off-peak, and 80 MWh super-off-peak. Optimal charging requires energy credits to balance energy expenses in each tier as closely as possible, to secure lowest energy cost and therefore lowest total cost of ownership. The results show that credits and expenses are completely and perfectly balanced across all tiers; no net energy expense occurs under any tier. Also, there are no credit deficits and no overgeneration of credits in any tier.
- Figure 46 provides a more granular view of where the NEM credits originate: from solar PV or from V2G-enabled buses. First, it's apparent that solar PV contributes NEM credits in all 3 tiers: on-peak, off-peak, and super-off-peak. In contrast, V2G contributes NEM credits in only two tiers: on-peak and super-off-peak. While the solar PV NEM credits are rigid (dependent on solar generation profile), the V2G NEM credits are more flexible. While partially constrained with their mobility needs, the buses can try to balance their charging and discharging behavior to optimize NEM credit accounting across all tiers.
    - Upgrading the buses and chargers enhances this ability further, resulting in perfect netting of energy expenses and credits. Because of that, we see that no solar credit is wasted; every unit of energy produced by the solar PV system is fully utilized and properly credited, to minimize total cost of ownership.

Comparing Scenario 3 (V2G; DERs; Upgraded Buses+Chargers) to Scenario 2 (V2G; DERs; Original Buses+Chargers):

<u>Technology and Emissions:</u>

Table 24: Infrastructure and emissions comparison

Output	Scenario 3 Value (V2G; DERs; Upgraded Buses + Chargers)	Scenario 2 Value (V2G; DERs; Original Buses + Chargers)
Solar PV Size	337 kW	309 kW
Grid peak load	98 kW	132 kW
GHG emissions reduction	88%	88%

- Upgrading the buses and chargers in Phase 4b does not result in major changes to GHG emissions reduction

- Upgrading the buses and chargers results in lower grid peak load but higher V2G peak. This has economic implications on grid-capacity cost (demand charges), but it also creates more flexibility to reduce the energy costs by optimizing NEM accounting. This trade-off is evident in the economic results below.

Table 25: Total Cost of Ownership Comparison

Cost	Scenario 3 Value (V2G; DERs; Upgraded Buses + Chargers)	Scenario 2 Value (V2G; DERs; Original Buses + Chargers)
Electric Buses – CAPEX	*	*
Charging Stations – CAPEX	*	*
Charging Stations – OPEX	*	*
Solar PV – CAPEX	*	*
Solar PV – OPEX	*	*
Grid energy supply – OPEX	*	*
Total energy costs: grid + solar	**$951,060**	**$1,011,264**
Total costs	**$14,430,990**	**$10,294,931**

** Information redacted for confidentiality*

- The total energy cost (from grid + solar) is slightly lower in Scenario 3 than Scenario 2.
    - The cost of solar PV with upgraded buses+chargers is higher because the size of the solar system selected is larger. Buses with larger batteries can store more cheap solar energy, and the high-powered chargers can discharge that energy at optimal times to avoid or offset more expensive grid electricity; effectively, upgrading the buses and chargers allow using more solar energy to arbitrage for NEM credits.
    - That increased ability to arbitrage and optimize NEM credits also impacts the grid energy OPEX. Compared to Scenario 2 with smaller buses and chargers, Scenario 3 with upgraded buses and chargers results in significantly lower grid energy OPEX. In fact, all the cost of grid energy is formed of demand charges (kW); there is no cost associated with the energy itself (kWh) because the NEM credits perfectly offsets all grid energy.
- While upgrading the buses and chargers slightly lowers the total energy costs (combination of grid and solar), it also results in significant increase in CAPEX. Overall, the TCO for Scenario 3 (upgraded buses+chargers) is about 40% higher than that of Scenario 2 (original buses+chargers).

<u>Energy flows & charging profiles:</u>

- Throughout the week (both weekdays and weekends), the charging profiles for the original and the upgraded V2G fleets follow the same overall structure, patterns, and timing. The main difference is in the magnitude of charge (grid peak load) and discharge (V2G peak).
    - On weekdays in the middle of the day, the magnitude of charge for upgraded buses+chargers (at about 300kW) is higher than that for original buses (at about 260kW). This trend reverses for charging during evening and early morning hours, where the magnitude of charging for upgraded buses (at about 98kW) is lower than that for original buses (at about 125 kW).
    - For discharging, we also notice slight discrepancy in the magnitude of discharging behavior between Friday, Saturday, and Sunday. The upgraded bus fleet discharges more on Fridays, whereas the originally sized fleet discharges more on weekends.

- Buses demand the same amount of total energy needed to complete daily trips and fulfill mobility needs. However, upgraded assets allow for more flexibility and energy-arbitrage opportunities.
    - A larger solar system generates overall more energy, some of which is sent back to the grid to generate credits and some of which directly charges the buses. Compared to original fleet, the upgraded fleet generates more energy from solar PV in all three tiers, and there is overall less energy pulled from the grid to charge buses. Additionally, a higher proportion of solar PV is used to charge the buses.
    - The upgraded buses and chargers can store and discharge more solar energy than the original ones, providing more flexibility in how to reshuffle solar generation in a way that results in lowest possible total energy costs.

Major takeaway: Upon upgrading the buses and chargers, there is a variety of ways by which the buses may choose to over-charge from solar beyond their mobility energy needs, to eventually reduce total energy costs and therefore TCO. One option is for the buses to overcharge directly from solar in the middle of the day on weekdays. Another option is for the buses to overcharge directly from solar throughout the day on weekends. Each overcharging option will have its own unique implication on the redistribution of charging and discharging profiles, as well as on the balancing of NEM credits and expenses across the various tiers, as we explain in the next section. However, all options for overcharging will result in lower energy supply from the grid, and therefore overall less NEM energy expenses.

<u>NEM Credit Balance:</u>

- With originally sized buses+ chargers (Scenario 2), the fleet is capable of offsetting all on-peak and off-peak energy expenses, but a deficit still exists in the super-off-peak tier where grid electricity is needed. However, upgrading the buses+chargers enables shifting additional solar energy supply into the super-off-peak tier, resulting in completely balanced credits in all three tiers and no energy expense for kWh purchased throughout the year.
- As discussed previously, larger bus batteries act as storage for the low-cost solar energy on weekends, then redistribute the solar throughout the week to meet bus mobility demands while drawing less total energy from the grid. Comparing Figure 45 (Scenario 3) to Figure 40 (Scenario 2), we see this phenomenon manifest in lower total “expenses” in all three tiers of NEM. While NEM credits completely and totally balance expenses under both scenarios, upgraded buses and chargers (Scenario 3) draw overall fewer grid resources.

Figure 33: Energy Flows for Phase 4b Scenario 3 – Summer

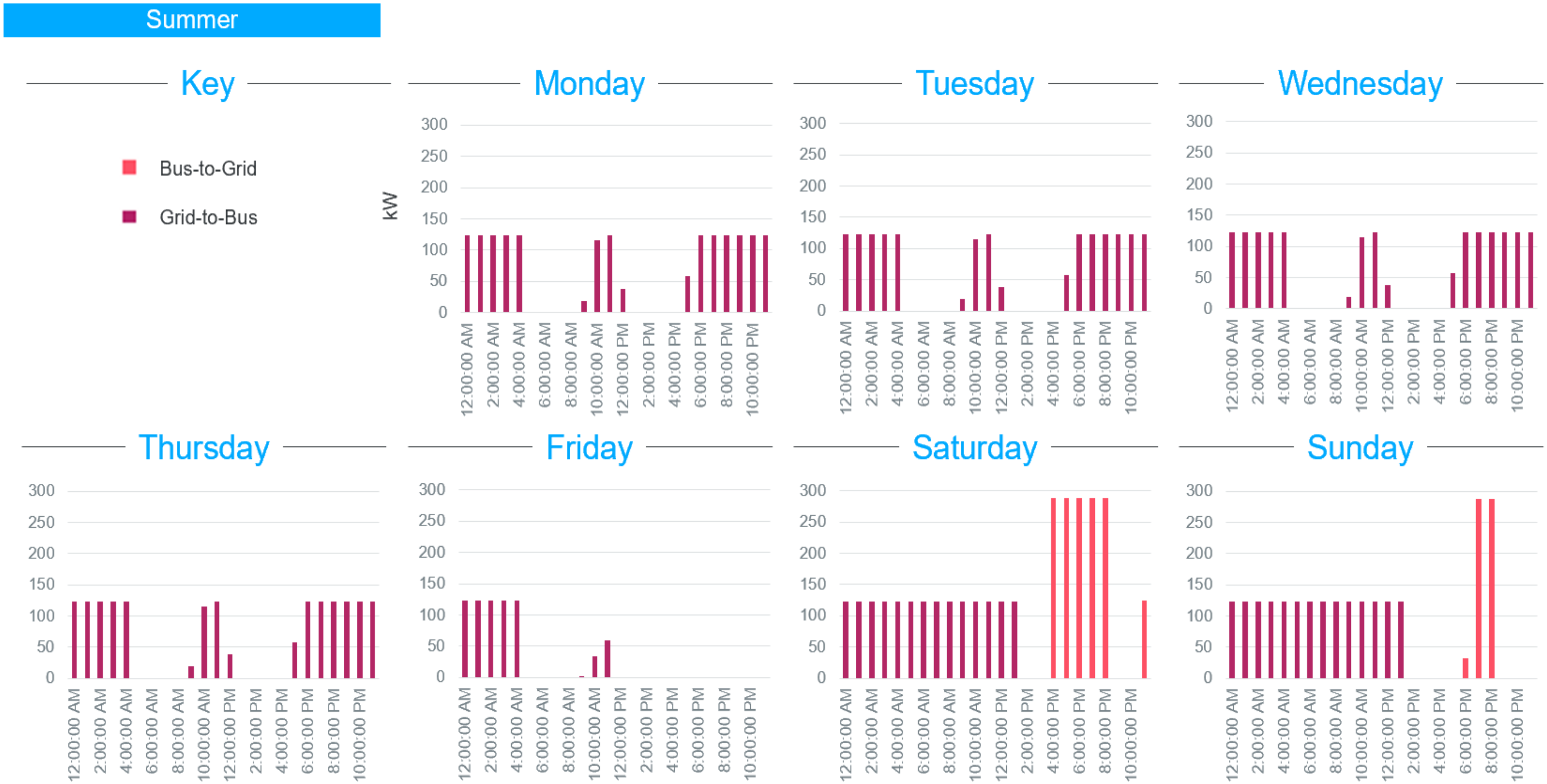


Figure 34: Charging Profiles for Phase 4b Scenario 1 – Summer

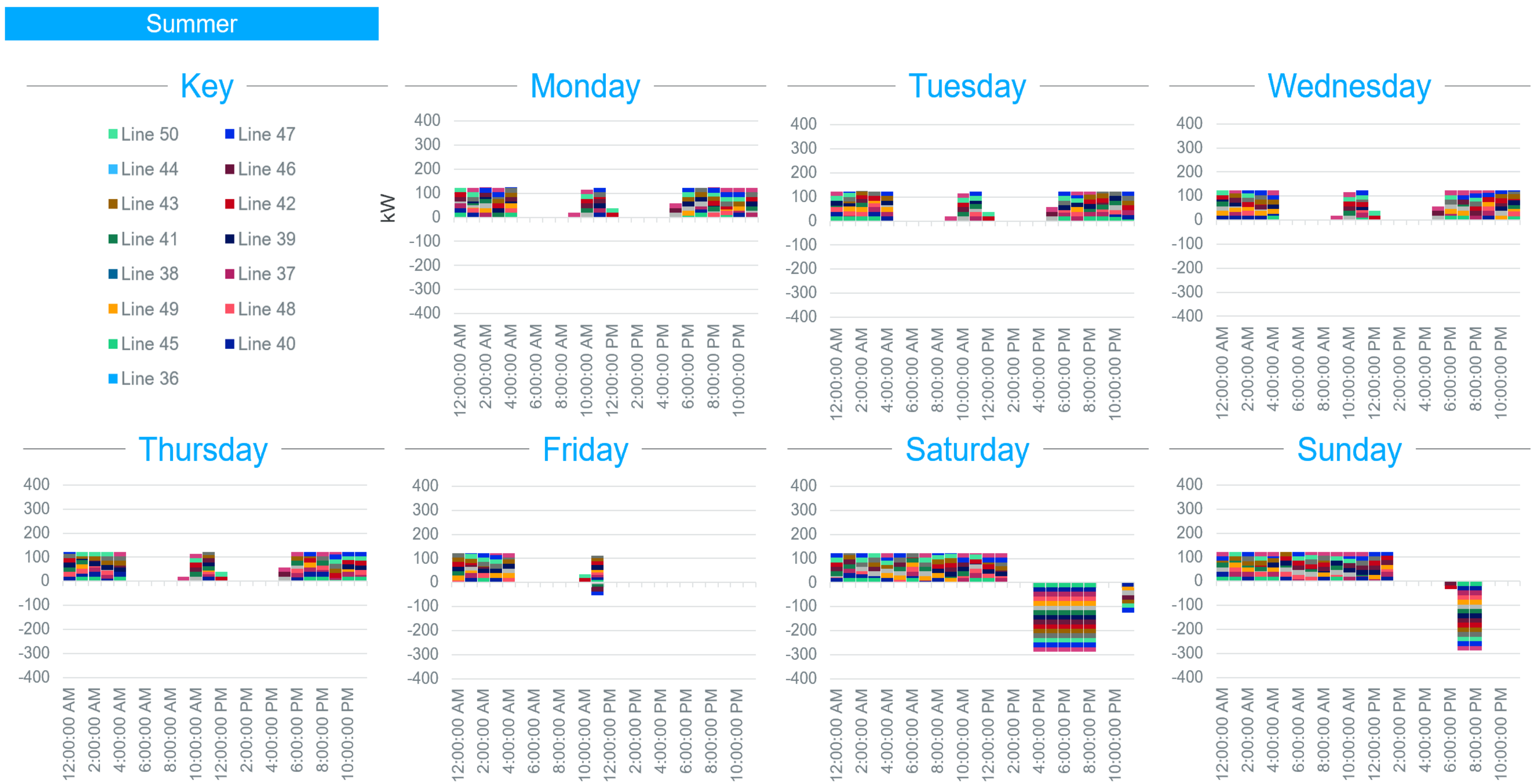


Figure 35: Sources of Energy for Bus Charging in Phase 4b Scenario 1 – Summer

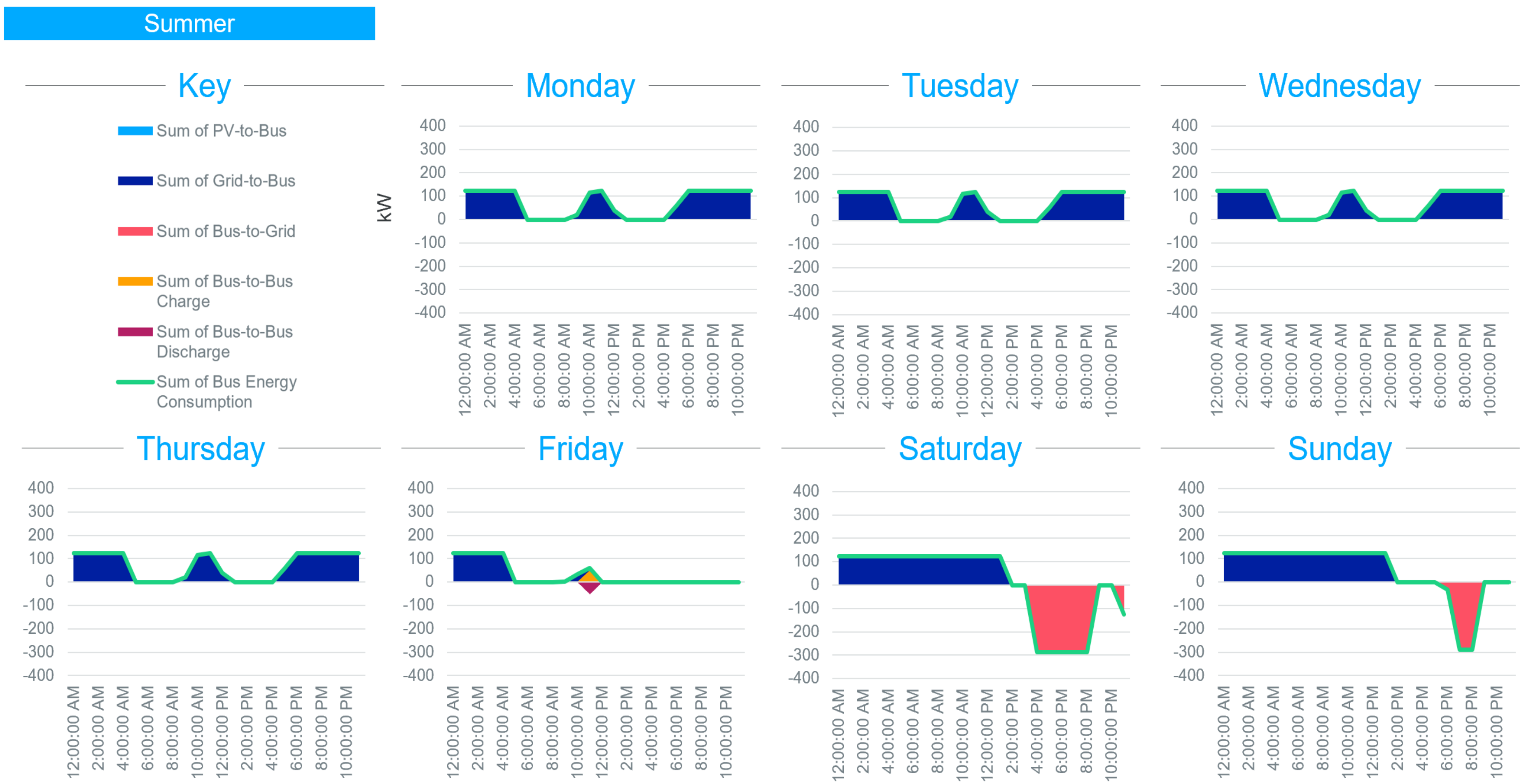


Figure 36: Tiered NEM Credit Balance for Phase 4b Scenario 1

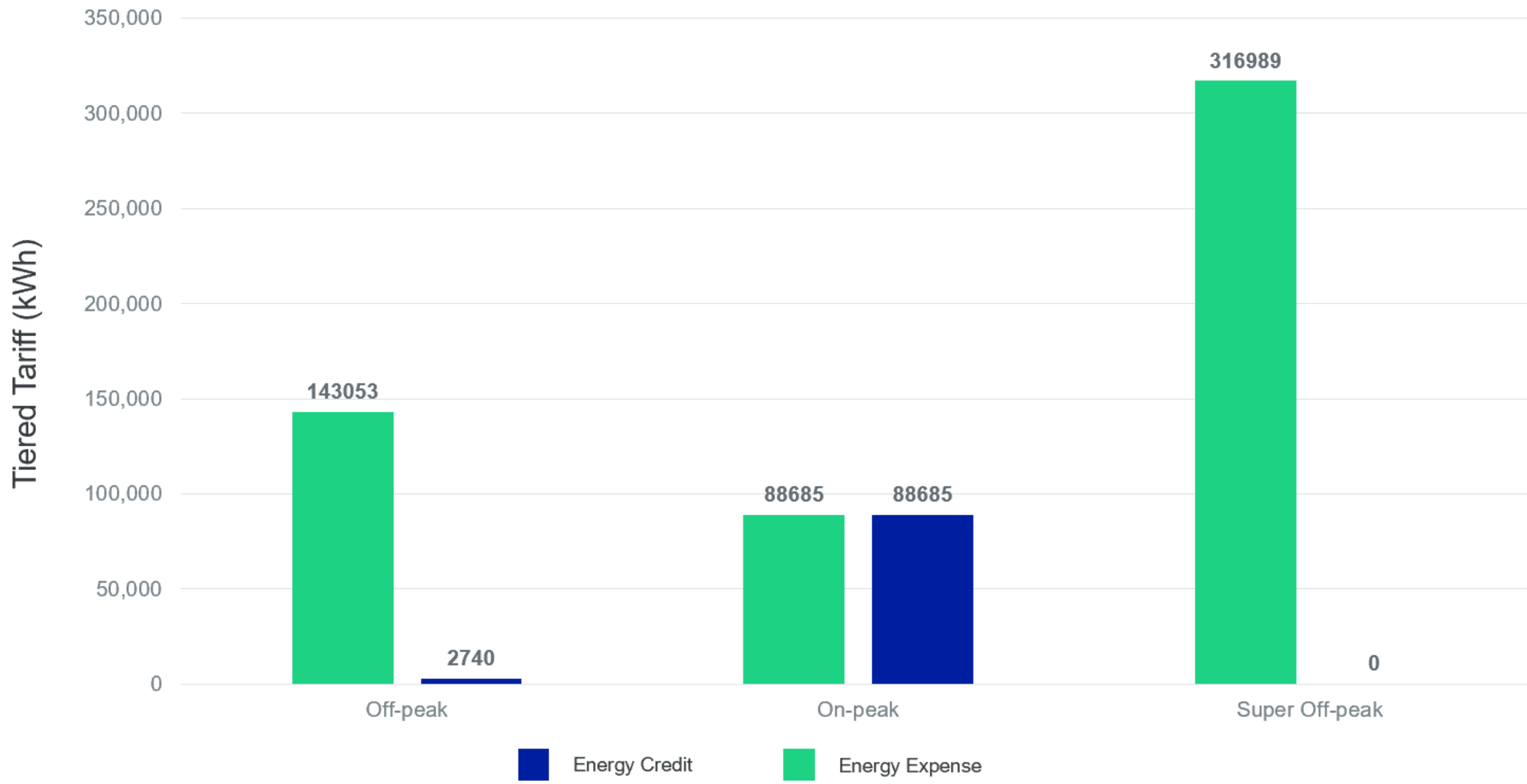


Figure 37: Energy Flows for Phase 4b Scenario 2 – Summer

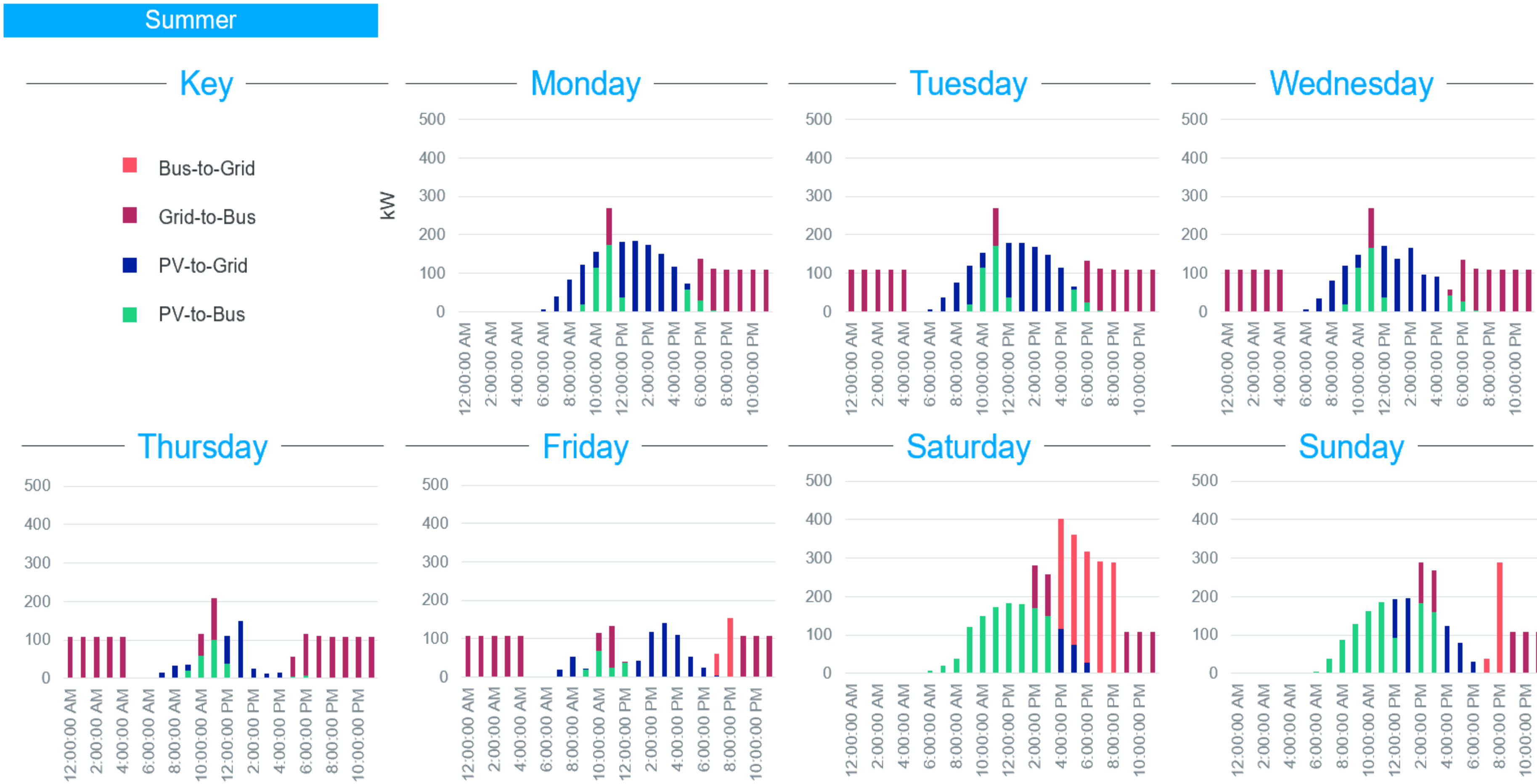


Figure 38: Charging Profiles for Phase 4b Scenario 2 – Summer

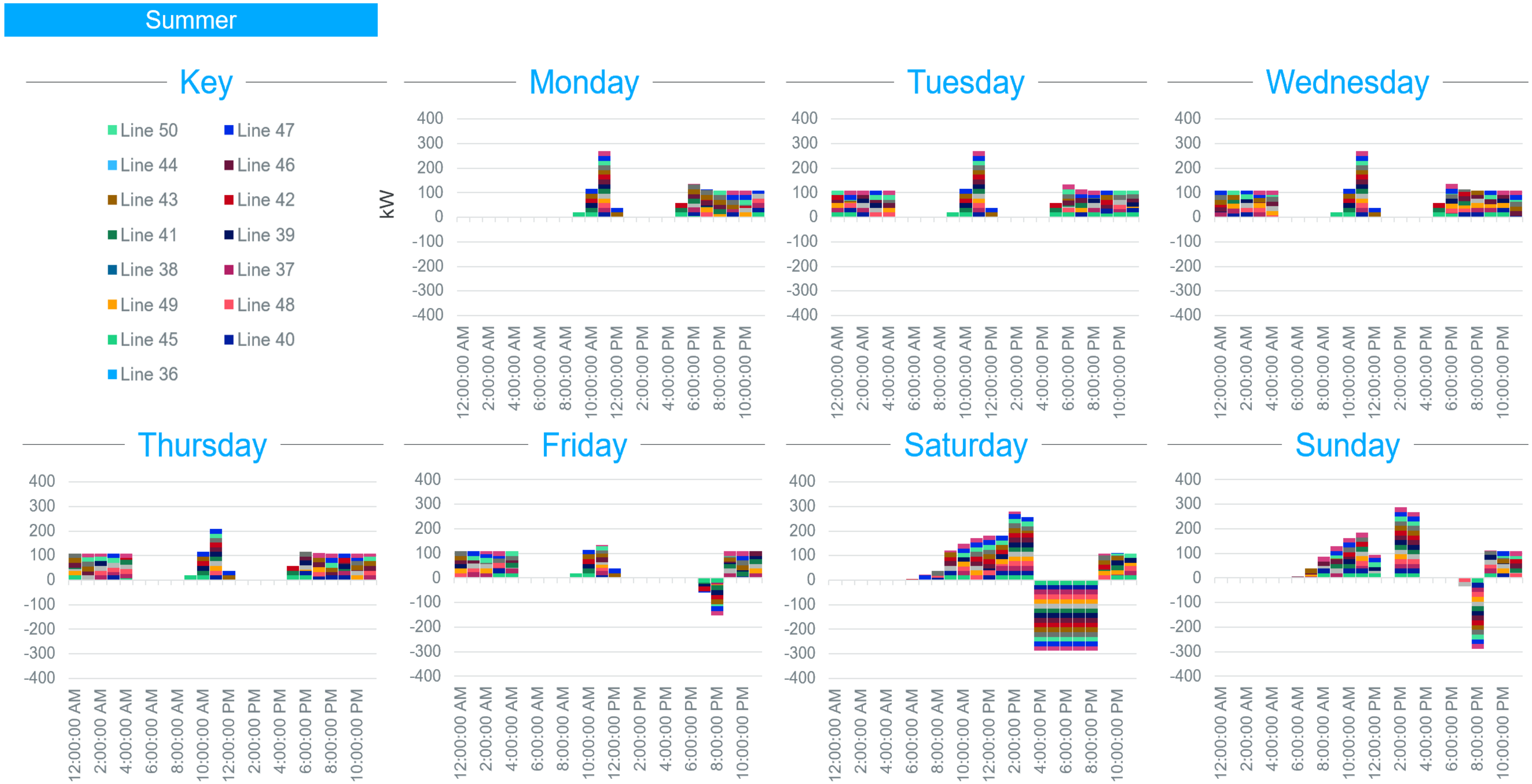


Figure 39: Sources of Energy for Bus Charging in Phase 4b Scenario 2 – Summer

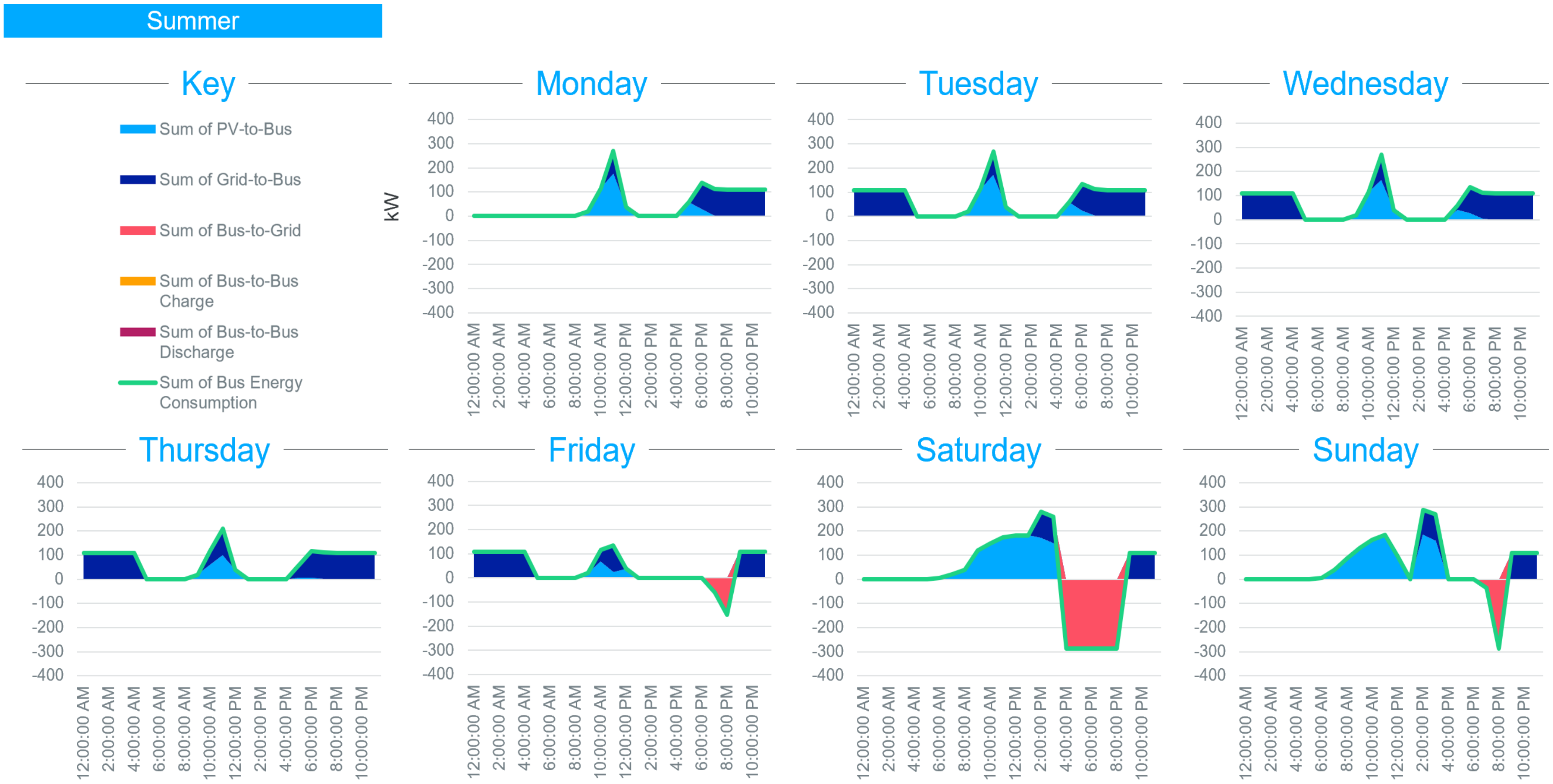


Figure 40: Tiered NEM Credit Balance for Phase 4b Scenario 2

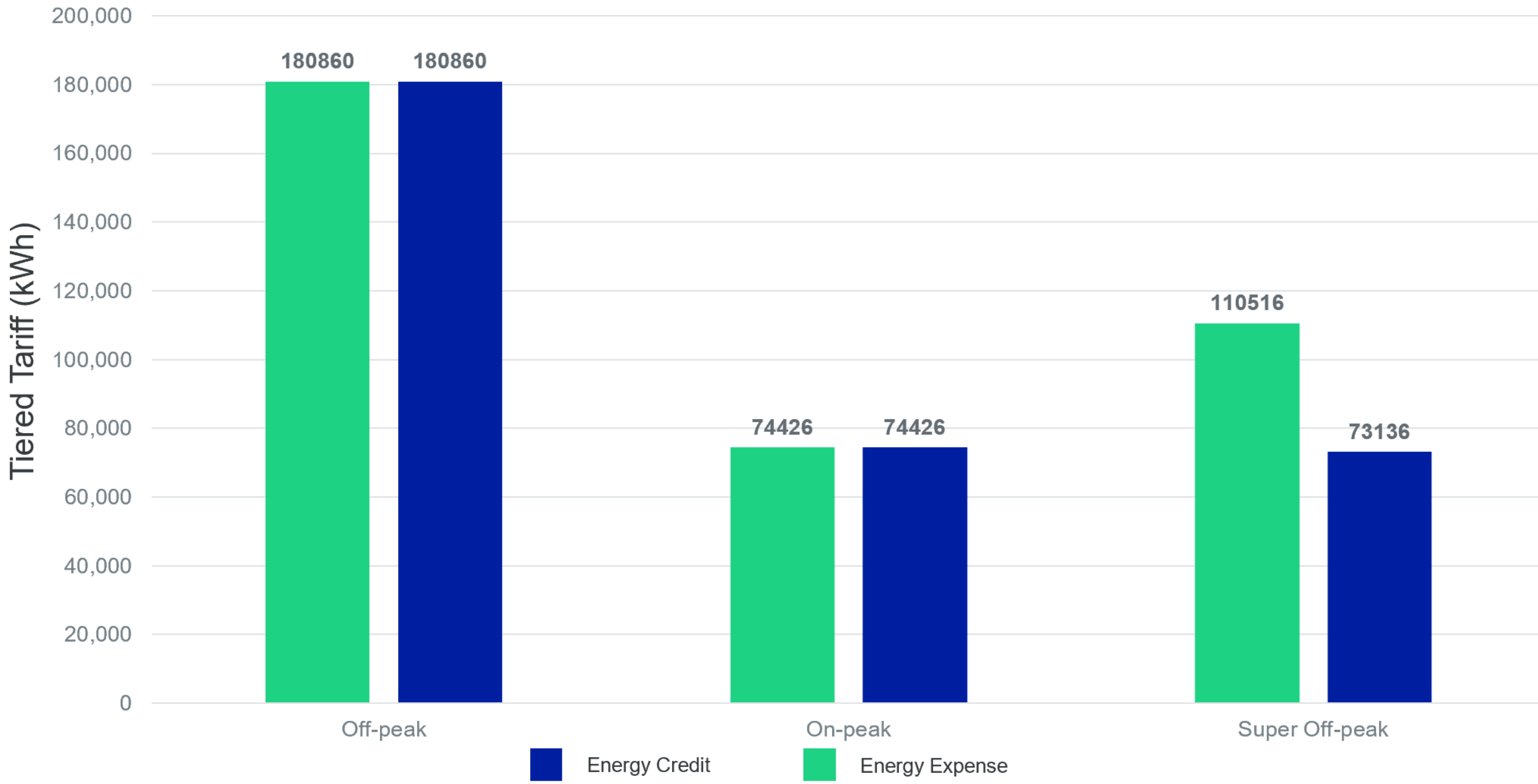


Figure 41: Solar Energy Generation and Consumption for Phase 4b Scenario 2

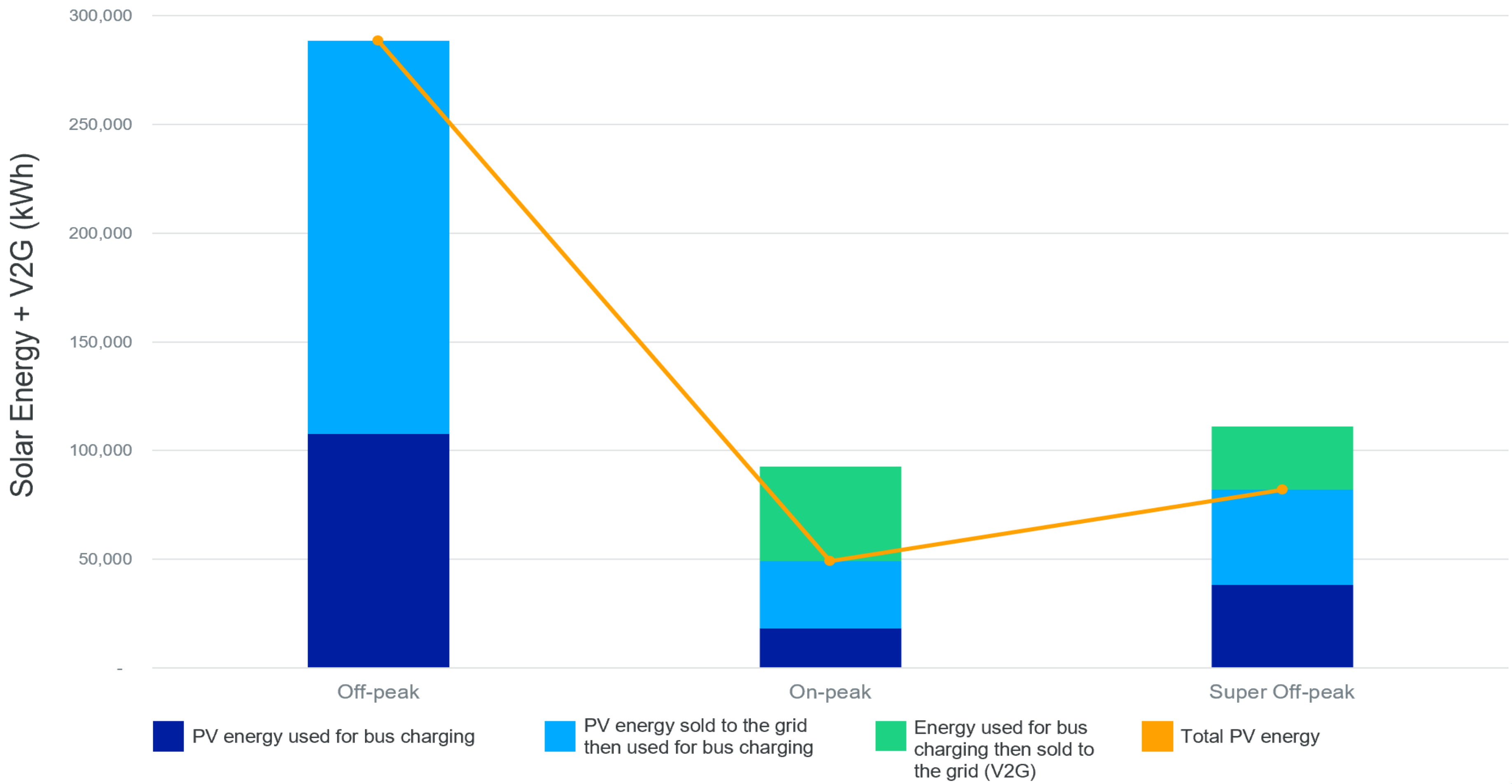


Figure 42: Energy Flows for Phase 4b Scenario 3 – Summer

Figure 43: Charging Profiles for Phase 4b Scenario 3 – Summer

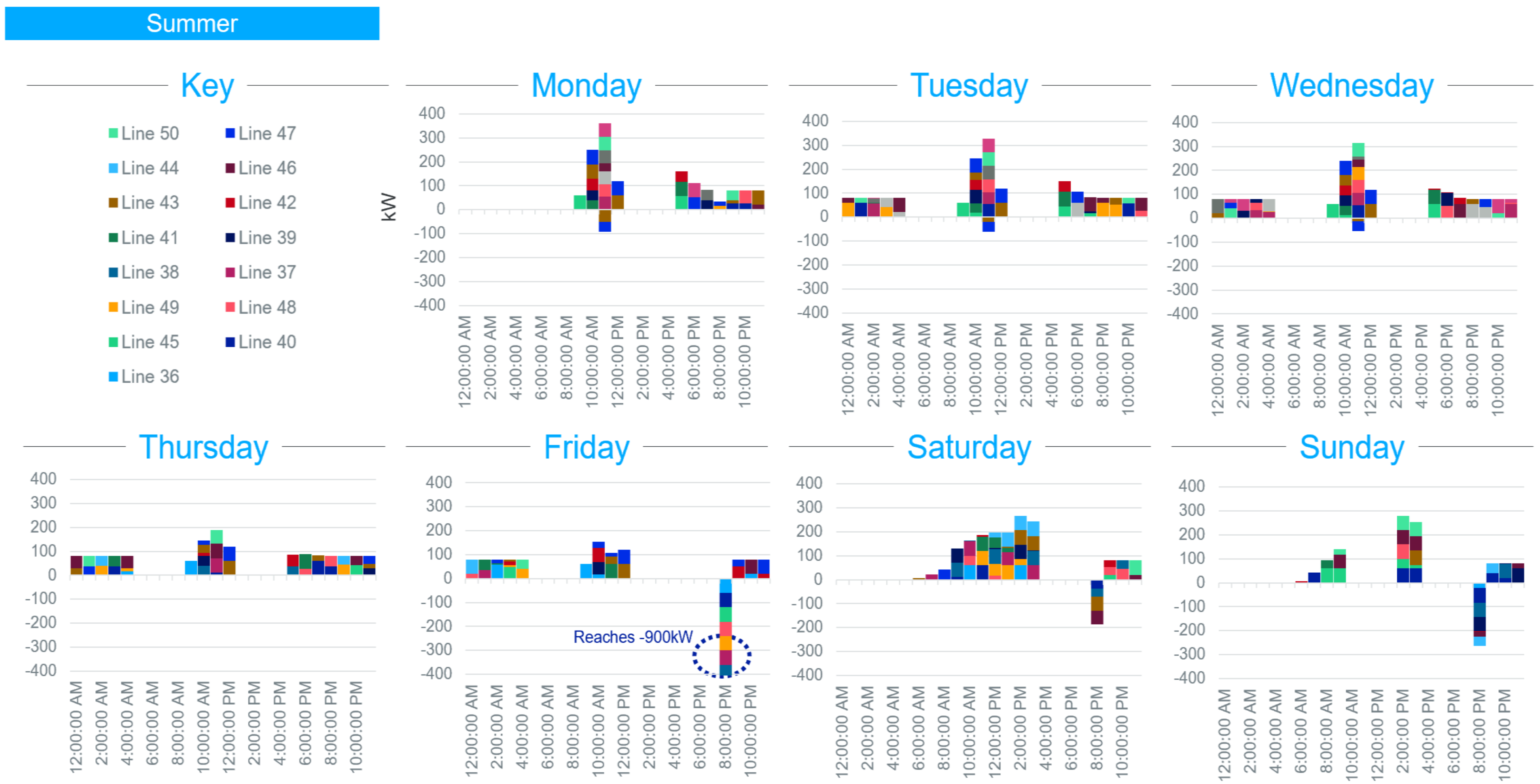


Figure 44: Sources of Energy for Bus Charging in Phase 4b Scenario 3 – Summer

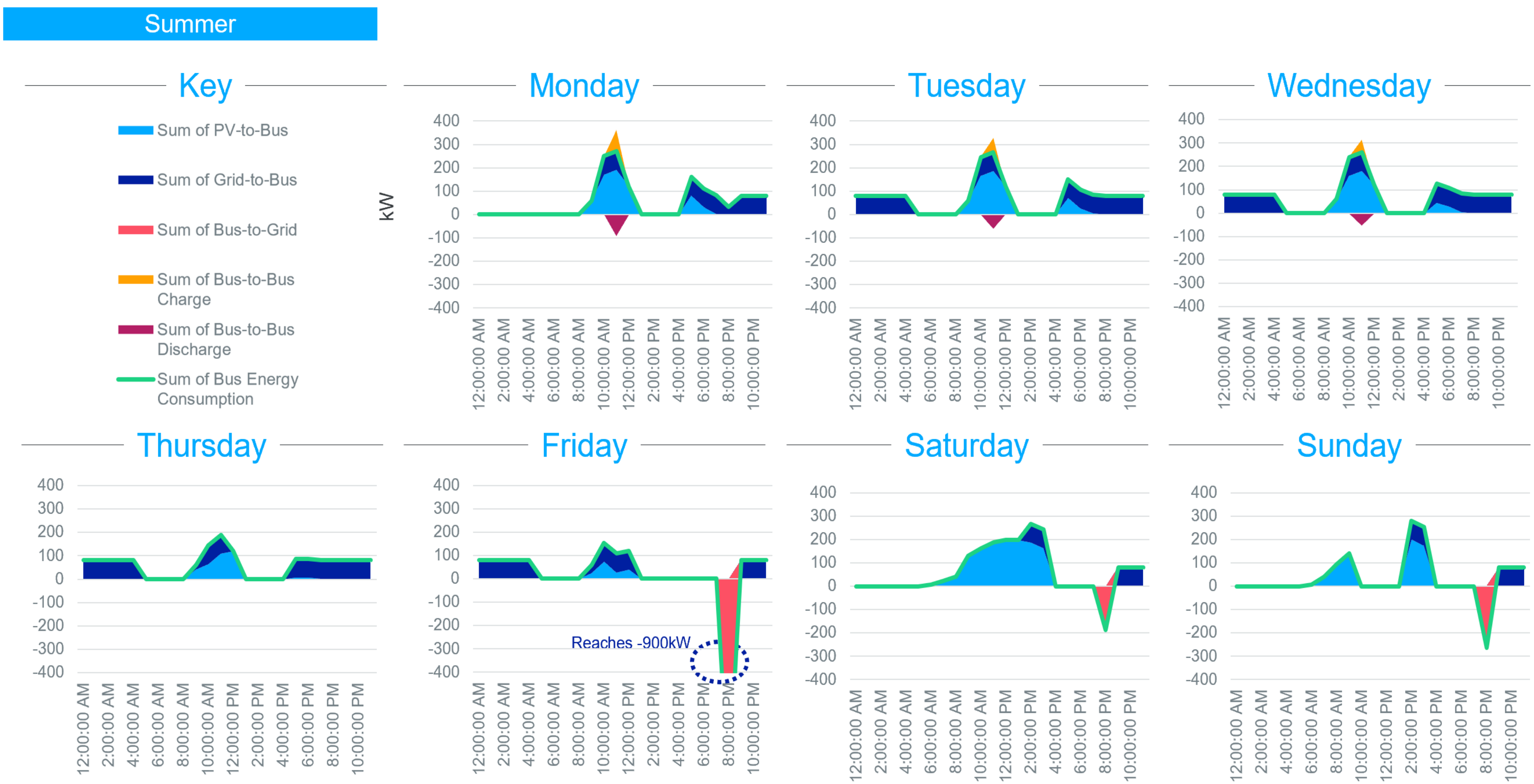


Figure 45: Tiered NEM Credit Balance for Phase 4b Scenario 3

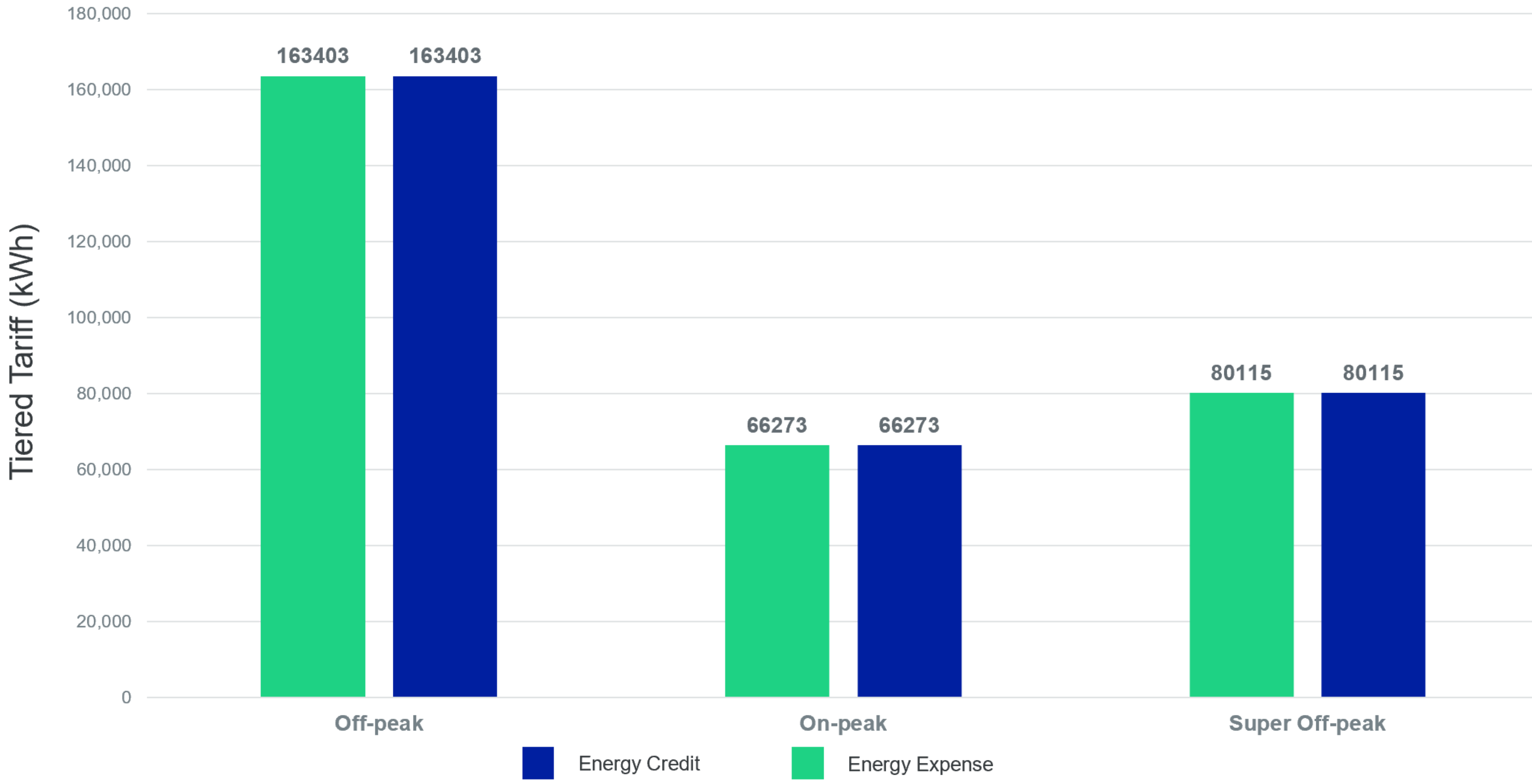
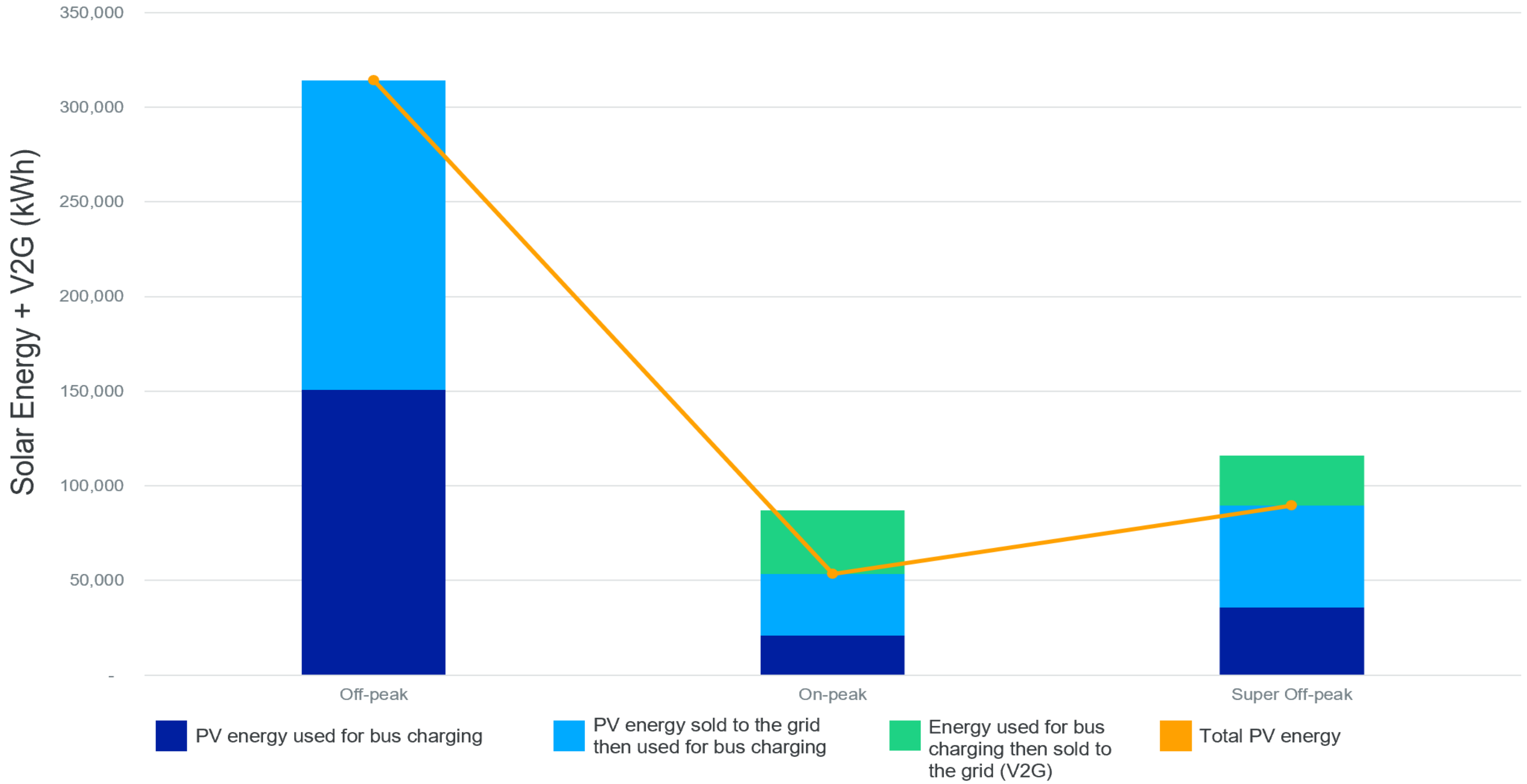


Figure 46: Solar Energy Generation and Consumption for Phase 4b Scenario 3



Procurement Guidelines & Recommendations

Based on detailed techno-economic analysis, current market and regulatory conditions make it economically challenging for GUHSD to move forward with the immediate implementation of V2G capabilities in their prospective electric bus fleet. For GUHSD to be able to deploy V2G functionalities in the school bus fleet cost-effectively – in such a way that reduces TCO – the following will be necessary:

- <u>Lower hardware costs:</u> The cost associated with V2G hardware, both the charging stations and the buses, needs to significantly decrease. Specifically, results show that the premium for bi-directional charging would need to decrease from about $1,140,000 to less than $224,000 in order to break-even, i.e. in order for the V2G-enabled savings in energy cost to fully offset the V2G-needed hardware costs. Due to the novelty of V2G applications, there are few options for bi-directional technologies in the US at present; in the future, an expanded market could result in more competitive pricing. Furthermore, manufacturers are actively developing modular EVSE and EV technologies that could significantly decrease the per-vehicle cost of bi-directional charging.
- <u>Higher benefits:</u> Given the incremental upfront costs needed, GUHSD should seek to stack several economic benefits from V2G. This might mean combining the participation in Emergency Load Reduction Program with the daily optimal fleet operations with solar and NEM to reduce energy costs, along with other potential revenue streams from grid-balancing services.
- <u>Additional grants, funding, and subsidies:</u> The value of enabling GUHSD fleet with V2G capabilities goes well above the economic benefits of energy savings and/or participating in Emergency Load Reduction Program (ELRP). There is significant benefit in piloting V2G school buses to test their ability to offer a portfolio of grid balancing services. In that light, GUHSD should seek public funding to support and subsidize their V2G efforts.
- <u>Proper NEM accounting mechanism:</u> Today, it is not clear how energy discharge from the buses will be compensated for by the local utility. For Grossmont to maximize the economic benefits from V2G, it's important that the School District and SDG&E to coordinate closely and to ensure favorable NEM accounting mechanisms for bus discharge to the grid. Given the nascent state of V2G deployment and the need to incentivize further deployments, the utility compensation mechanisms may need to be similar or perhaps even better than those set for solar PV today.

In terms of procurement guidelines, we recommend that GUHSD include the following questions and confirmations points in future RFP/Q process:

- While automakers have confirmed that modeled buses are V2G-capable, there are limited real-world examples of these buses using bi-directional capabilities. When issuing a competitive RFP, we recommend only selecting automakers whose vehicles have been tested and deployed for V2G use-cases.
- It is important to acquire concrete information on any technical restrictions or compatibility concerns with bi-directional charging stations. For example, it's important to confirm the maximum discharging rate in addition to the maximum charging rate.
- GUHSD should explore all warranty options, aiming to understand what is and is not included in them. Specifically, we recommend inquiring about any V2G warranties offered, or whether the use of V2G affects existing warranties.

SECTION 4. USE-CASE 2: USE V2G CAPABILITIES TO OPTIMIZE PARTICIPATION IN THE EMERGENCY LOAD REDUCTION PROGRAM (ELRP)

METHODOLOGY

This analysis aims to determine how much value GUHSD can generate through using V2G during ELRP events. Given this goal, the analysis is designed to answer the following three questions:

- What is the maximum level of participation for the GUHSD electric bus fleet in ELRP, without disturbing fleet operations?
- What is the economic value associated with this maximum participation for any given event?
- What scenarios provide a reasonable range of the total economic value that GUHSD can gain during the course of a year?

Modeling scenarios

Given the novelty and unpredictable nature of ELRP events, we created a range of scenarios to determine the realistic spectrum of revenue opportunities for GUHSD. The six scenarios represent three prospects (aggressive, moderate, and conservative), anchored by two different data sets related to wildfires and public safety power shutoffs (PSPS). Table 26 summarizes the six modeling scenarios, which are detailed in the text below.

Table 26: Description of the six modeling scenarios for the ELRP

	Anchored to Wildfires			Anchored to PSPS		
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total Event Days	**12**	**6**	**3**	**12**	**6**	**3**
Hours per Event	**5**	**4**	**3**	**5**	**4**	**3**
School Year Weekday	*4*	*2*	*2*	*9*	*4*	*2*
School Year Weekend	*2*	*1*	*0*	*3*	*2*	*1*
Summer Day	*6*	*3*	*1*	*0*	*0*	*0*

Scenarios are defined in a three-step process.

<u>Step 1</u>: We categorize the potential ELRP event days into three groups: School Year Weekday, School Year Weekend, and Summer Day. These three groups represent three fleet operation profiles that are relatively distinct from each other.

- School Year Weekday and Weekend:
  - During the School Year Weekday, buses are in operation until the later afternoon (around 4:00pm to 5:00pm in most cases), and then typically need to be charged in time to return to service the next day.
  - During the School Year Weekend, buses do not have operational duties, but their charging behavior is partially constrained by requirements to charge in time for scheduled operations on Monday morning.

    - We determine the state-of-charge of each bus when it arrives in the depot and is ready to participate in the event. The model then discharges the bus at the maximum rate allowed based on its associated charging station, until the event concludes or until the bus reaches a minimum state-of-charge (set at 10% of the total state-of-charge). Finally, the model checks the amount each bus is able to recharge overnight (between 9:00pm and 5:00am) and how much all buses in total can charge (to stay under the preset grid peak load).
    - The amount of energy (kWh) that the GUHSD fleet can contribute to an ELRP event is then the minimum of either:
        - The energy that all buses can discharge during an event
        - The energy that all buses can recharge (in addition to regularly scheduled charging) overnight after an event
- Summer Day:
    - On Summer Days, buses are assumed to be stationary and have no operations or charging responsibilities.
    - We assume, based on conservative estimates from GUHSD, that 40 buses can participate in ELRP events (all buses in Phases 3, 4a, and 4b). These 40 buses have a full state-of-charge at the beginning of the event, and there are no restrictions on how much time the buses need to recharge after the event. Each bus discharges at the maximum rate allowed by its associated charging station, until the event concludes or until the bus reaches a minimum state-of-charge.

Step 2: Each of these three groups of ELRP event days are then incorporated into three core modeling prospects. Given the nascency of the ELRP, there is no historical data on when, for how long, or how frequently ELRP events will occur. Therefore, through active discussion and collaboration with project partners, including SDG&E, we devised three prospects that cover a large range of possibilities. The most aggressive prospect looks at the maximum number of potential event days (12 days), each for the maximum number of hours (5 hours). The most conservative prospect looks at the estimated realistic worse case, with three days, of three hours each. We also created a moderate prospect, with six days, four hours each. These three prospects are listed in Table 27.

Table 27: Three core modeling prospects

	Aggressive	Moderate	Conservative
Total Event Days	**12**	**6**	**3**
Hours per Event	**5**	**4**	**3**

Step 3: For each of these three prospects, the next step is to determine how many days to include from each of the three event day groups. School Year Weekday and School Year Weekend events are simply divided to represent the share of weekdays ($5/7^{th}$) to weekend days ($2/7^{th}$). To determine how many events would take place during the School Year vs the Summer Days, we use two methodologies based on the likelihood of (i) wildfires and (ii) public safety power shutoffs (PSPS).

- Based on Wildfires: The ELRP was created in large part to help avoid issues that resulted from power disruptions during large wildfires. Therefore, we utilize historical data on wildfires in California to determine the months that are most likely to experience extreme fires (Figure 47). The probability of an ELRP event is then pinned to the average acres burned per month. Using this methodology, there is roughly equal probability that an ELRP event will occur during the School Year vs the Summer Days (Table 28).
- Based on PSPS: PSPS events are triggered by adverse weather conditions, which may present a dangerous situation to operate electric infrastructure. A main reason a PSPS may be called is

to help prevent potential wildfires. Figure 48 depicts the total PSPS events reported between 2013 and 2020 for major utilities in California. When pinned to PSPS data rather than wildfire data, there is a much higher probability that ELRP events will occur during the School Year. In fact, as shown in Table 29, the PSPS data indicates that practically all ELRP events will occur during the School Year.

Table 28: Estimated acres burned by School Year vs Summer Day

Period	Event Probability
School Year	**49%**
School Weekday	*35%*
School Weekend	*14%*
Summer Day	**51%**

Table 29: Estimated PSPS events by School Year vs Summer Day

Period	Event Probability
School Year	**97%**
School Weekday	*69%*
School Weekend	*28%*
Summer Day	**3%**

Inputs and assumptions

The ELRP modeling is designed with the baseline conditions used in the Use-case 1, Scenario 2 analysis, assuming operations with V2G and DERs for the GUHSD fleet in Phases 3, 4a, and 4b. This is used as the baseline, since it provides the specific buses and charging infrastructure that would be minimally needed to utilize V2G. Additional inputs and assumptions are listed below.

Scenario inputs: the six scenarios considered in the ELRP analysis are based on different combinations of the following inputs:

- Total number of event days (# days): Modeled 12, 6, and 3 days, based on discussions with SDG&E on the expected frequency of ELRP event days in a given year. The range of 3 – 12 days captures the expected low and high extreme.
- Type of event days**:** Modeled School Year Weekday, School Year Weekend, and Summer Day, based on the two methodologies described above related to wildfires and PSPS events.
- Event duration (# hours): Modeled 5, 4, and 3 hours per event. This assumes that GUHSD can control bus charging/discharging to respond within any of these time periods.

Additional inputs: below is a list of other inputs used to create the model:

- Grid peak load (kW): This value is taken from the Use-case 1 analysis (operating with V2G and DERs) and is 375 kW for the whole fleet in Phases 3, 4a, and 4b (see below sensitivity analysis for how we examined changes to this input).
- Bus trip schedules: Schedules are based on GUHSD-provided data.
- State-of-Charge (kWh/bus/hour): Based on results from Use-case 1 – Scenario 2, which assumes the fleet is operating with V2G and DERs.
- Types of buses and charging stations (makes and models): Based on results from Use-case 1 – Scenario 2, which assumes the fleet is operating with V2G and DERs.

Additional assumptions: below is a list of additional assumptions that guide the model:

- Buses cannot participate in an ELRP event while they are out of the depot.
- ELRP events always start at 4:00pm.
- Any discharge that takes place during an ELRP event (including V2G discharge that would occur even if there is no ELRP event) will be recharged during the overnight period following the event (between 9:00pm and 5:00am).
- Aside from their existing optimal daily charging/discharging behavior, based on Use-case 1 – Scenario 2, buses will not be participating in other grid balancing programs or events (e.g., critical peak pricing) that might impact their operations.

Conservative assumptions: The model is designed to take a conservative approach through the various stages of analyzing Grossmont fleet's participation in ELRP. Below are a list of measures and assumptions that highlight the conservative nature of the modeling:

- Only 40 buses (Phase 3, 4a, and 4b) will participate on a Summer Day during ELRP events; as with Use-case 1, we assume no buses from Phases 1 and 2 will be able to participate in V2G activities, and therefore will not be able to generate revenue in ELRP events.
- Bus schedules include time buffers (consistent with Use-case 1 and Task 2), which limit the time that buses are available in the depot for discharging during an event.
- Buses must maintain their originally scheduled charging sessions during an ELRP event. In other words, buses will not maximize ELRP participation by delaying already scheduled charging (see sensitivity analysis for exploration of results when this assumption is disregarded).
- Buses will not discharge below a minimum state-of-charge (set at 10%).
- Overnight charging is limited so that the fleet does not exceed the preset grid peak load.

RESULTS

Findings

The findings in this section provide the estimated net revenue associated with the different ELRP scenarios. Net revenue represents the gross revenue (the compensation GUHSD receives for participating in ELRP events) minus the costs associated with participating in the ELRP events (the cost to recharge the discharged energy in the buses after an event). The net revenue does not include any capital expenses, most notably the incremental cost to upgrade buses and charging infrastructure to be V2G-capable.

Summer Days demonstrate the highest net revenue, followed by School Year Weekends and School Year Weekdays, respectively. Table 30 shows the averages for each of these three event categories. For example, the average 5-hour event during a School Year Weekday is estimated to provide around $600 in new revenue.

- For Summer Days, buses have the highest net revenue generation during an ELRP event since there are no limitations imposed by trip schedules or charging times.
- For School Year Weekends, many buses have sufficient amounts of stored energy to discharge throughout the entire ELRP event duration. However, participation on the weekend is partially limited on Sunday by the amount of charge the buses can recover during the overnight periods after an event.
- For School Year Weekdays, buses have the lowest net revenue since buses are in operation before and partially during ELRP events. Many buses are still completing their afternoon trips

when an ELRP event starts and are not able to participate. Then, upon returning to the depot, the buses participate but do not have full batteries to discharge.

The impact of changing the duration of an event day differs for each of the three categories.

- For School Year Weekdays, net revenue decreases in a non-linear fashion with ELRP event duration. The difference between a 5-hour and 4-hour event day is approximately $13 ($601 minus $588), while the difference between a 4-hour and 3-hour event day increases to $223 ($588 minus $365). 4-hour ELRP events seem to be the sweet spot for fleet participation, since they produce the most net revenue per hour. For shorter events, some buses' participation in ELRP is limited since they are finishing their daily afternoon trips. For longer events, some buses would have already exhausted the residual energy in their batteries and cannot provide more energy. At the 4-hour mark, however, most buses have time to return to the depot and discharge their spare energy to the grid.
- For School Year Weekends, each decrease in an hour of event duration is roughly linear to the decrease in net revenue. This occurs since buses have high state-of-charge at the start of the event, and (in most cases) will be able to discharge at a constant pace each hour of the event without reaching their minimum charge.
- For Summer Days, each decrease in an hour of event duration is roughly linear to the decrease in net revenue. As with School Year Weekend events, this occurs since buses have high state-of-charge at the start of the event, and (in most cases) will be able to discharge at a constant pace each hour of the event without reaching their minimum charge.

Table 30: Average net revenue for each event day category, per duration of event

	School Year Weekday	School Year Weekend	Summer Day
5-hour Event Day	$601	$2,573	$3,582
4-hour Event Day	$588	$2,335	$2,950
3-hour Event Day	$365	$1,987	$2,219

Table 31 shows the net annual revenue for each of the six scenarios.

Table 31: Annual net revenue by scenario

	Anchored to Wildfires			Anchored to PSPS		
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total Event Days	**12**	**6**	**3**	**12**	**6**	**3**
Hours per Event	**5**	**4**	**3**	**5**	**4**	**3**
Net Revenue per Year	**$29,041**	**$12,362**	**$2,949**	**$13,127**	**$7,024**	**$2,717**
% Revenue School Weekday	8%	10%	25%	41%	34%	27%
% Revenue School Weekend	18%	19%	0%	59%	66%	73%
% Revenue Summer Day	74%	72%	75%	0%	0%	0%

- In general, the scenarios project a range of annual net revenue from slightly under $3,000 on the low end to around $30,000 in the most aggressive scenario. The moderate scenarios project annual net revenue roughly in the $7,000 to $12,000 range.
- The scenarios anchored to wildfire data demonstrate a higher net revenue potential than those anchored by PSPS events. This occurs because the wildfire data indicates a higher likelihood of events happening during the Summer Days, which (as described above) is the category with the

highest revenue potential. By contrast, the PSPS data indicate no ELRP events would likely occur during the school's summer period.

Sensitivity analyses

To better understand the outcomes of the model and guide recommendations, we conduct sensitivity analyses on two modeling assumptions. First, we explore the influence of changing the grid peak load, which allows for more charging to take place across the system at the same time. Second, we explore the impact of allowing already scheduled charging to be delayed during an ELRP event. The sections below provide key takeaways from both analyses.

Increasing grid peak load

As described above, the grid peak load is the maximum amount of load (in kW) that the depot facility can allow at any given time. Typically, it is economically advantageous to minimize the grid peak load since SDG&E levies demand charges proportional to the grid peak load.

The ELRP provides a strong economic incentive ($1 per kWh) to discharge during an event, but discharges during the School Year Weekend period are expected to be constrained by the ability to recharge at night. Increasing the grid peak load would allow for more opportunities to charge the buses after an ELRP event. Therefore, we explore if, and to what extent, GUHSD could increase ELRP net revenue by increasing the grid peak load.

We first examine the impact on net revenue by increasing the grid peak load across each of the three types of event days. Table 32 shows the net revenue associated with 25 kW increases in the grid peak load. We chose 25 kW as the measuring increment since SDG&E rate structure increases demand charges for each 25 kW.

Table 32: Sensitivity of increasing the grid peak load per event category and per event duration on net revenue (rows with changing data highlighted)

	Increase in kW Over Original Grid Peak Load	0	25	50	75	100	125
School Year Weekday	5-hour Event Day	$601	$601	$601	$601	$601	$601
	4-hour Event Day	$588	$588	$588	$588	$588	$588
	3-hour Event Day	$365	$365	$365	$365	$365	$365
School Year Weekend	5-hour Event Day	$2,573	$2,663	$2,843	**$2,985**	$2,985	$2,985
	4-hour Event Day	$2,335	$2,425	**$2,552**	$2,552	$2,552	$2,552
	3-hour Event Day	$1,987	$1,987	$1,987	$1,987	$1,987	$1,987
Summer Day	5-hour Event Day	$3,582	$3,582	$3,582	$3,582	$3,582	$3,582
	4-hour Event Day	$2,950	$2,950	$2,950	$2,950	$2,950	$2,950
	3-hour Event Day	$2,219	$2,219	$2,219	$2,219	$2,219	$2,219

As seen in Table 32, increasing the grid peak load during the School Year Weekdays and Summer Days does not change the net revenue of those event days. Those days are constrained by the available energy to discharge not by the ability to recharge at night, so increasing the ability to charge at night will not impact net revenue. However, School Year Weekend events can increase net revenue by increasing the grid peak load for 5-hour and 4-hour event days. The maximum realized net revenue differs depending on the duration of the ELRP event. A 5-hour School Weekend event can maximize net revenue when 75 kW are added to the grid peak load, while a 4-hour event can maximize revenue once 50 kW are added to the grid peak load.

Table 33 examines the impact of increasing the grid peak load by 50 kW (the amount that would maximize net revenue for a 4-hour School Year Weekend event). In all scenarios except for Scenarios 3 and 6, increasing the grid peak load by 50 kW would provide additional net revenue through the ELRP program. In the two most aggressive scenarios (Scenario 1 and Scenario 4), adding 50 kW to the grid peak load would increase annual net revenue over the baseline case, by $333 and $499, respectively. Overall, while positive, the net improvement in ELRP economics by expanding grid peak load are modest, at or below 4%.

Table 33: Estimated net revenue from increasing grid peak load by 50 kW

		Anchored to Wildfires			Anchored to PSPS		
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Scenarios	Total Days	12	6	3	12	6	3
	Hours	5	4	3	5	4	3
Baseline	Net Revenue per Year	$29,041	$12,362	$2,949	$13,127	$7,024	$2,717
Additional 50 kW Added to the Grid Peak Load	Net Revenue per Year*	$29,373	$12,475	$2,949	$13,626	$7,250	$2,613
	Difference in Net Revenue per Year between Baseline and 50 kW Added	**$333**	**$113**	**$0**	**$499**	**$226**	**-$104**

** Additional demand charge for each School Year Weekend event subtracted from totals*

Table 33 assumes that demand charges for 50 kW will be levied separately for each of the School Year Weekend event days. Each of these demand charges will increase costs by $103.61 for each 25-kW increment, or a total of $207.22 for a 50-kW increase. The maximum expense for demand charges would be in Scenarios 1 and 4, where monthly demand charges would be imposed two times (for Scenario 1) and three times (for Scenario 4), respectively.

Shifting event-time charging

The second sensitivity analysis examines the impact of shifting charging originally scheduled during the ELRP events, into later in the night after the ELRP event is complete. By doing so, GUHSD participation in, and compensation for, the ELRP would entail both (i) dropping the charging load (shifting load from positive to zero) as well as (ii) discharging the buses' batteries (shifting load from zero to negative). In the baseline case, only the value of (ii) was accounted for.

The modeling follows a similar approach to the one described before. However, in this case, we need to account for the ability of each bus to recharge overnight to compensate not only for the ELRP discharging (ii) but also for the ELRP deferred charging (i). The amount of energy (kWh) that the GUHSD fleet can contribute to an ELRP event is then the minimum of either:

- The energy that all buses can discharge and defer-charge during an event
- The energy that all buses can recharge overnight after an event

Table 34 shows the results from shifting the event-time charging to the night after the event. There are three main findings:

- Net revenue on School Year Weekends and Summer Days is not impacted by shifting event-time charging. No charging is scheduled during event days on School Year Weekends or

Summer Days. Since no charging occurs, there is no charging to shift, and therefore this sensitivity analysis does not result in any changes to the net revenue.

- School Year Weekdays increase their net revenue for all time durations. Each event day on a School Year Weekday increases net revenue by over $220. This occurs since School Year Weekdays have charging that is planned during ELRP events, which can be shifted (in part) to spare charging capacity available during the overnight hours.
- The relative improvement of shifting charging schedules is largest for event days with shorter durations. School Year Weekday 3-hour events experience the highest increase in net revenue ($336) by shifting event-time charging. School Year Weekday 4-hour events have the second highest increase in net revenue ($226), followed closely by 5-hour events ($223). Unlike 4-hour and 5-hour events, 3-hour events are not constrained by the ability to recharge at night. Therefore, the majority of the shifted charging during a 3-hour event is able to generate net revenue during an event, while the benefit of shifting charging is capped on 4-hour and 5-hour events by the constrained ability to recharge at night.

Table 34: Sensitivity of shifting event-time charging per event category and per event duration on net revenue (columns with changing data highlighted)

		School Year Weekday	School Year Weekend	Summer Day
Baseline	5-hour Event Day	$601	$2,573	$3,582
	4-hour Event Day	$588	$2,335	$2,950
	3-hour Event Day	$365	$1,987	$2,219
Shifting Event-time Charging	5-hour Event Day	$824	$2,573	$3,582
	4-hour Event Day	$814	$2,335	$2,950
	3-hour Event Day	$701	$1,987	$2,219
Increased Net Revenue from Shifting Event-time Charging	**5-hour Event Day**	**$223**	**$0**	**$0**
	4-hour Event Day	**$226**	**$0**	**$0**
	3-hour Event Day	**$336**	**$0**	**$0**

Table 35 shows the impact of shifting event-time charging on the six scenarios.

- Shifting event-time charging increases annual net revenue in all six scenarios, by around $450 to $2,000.
- This increase is directly related to the number of School Year Weekdays in each scenario, since (as described above) only School Year Weekdays are sensitive to shifting event-time charging.
- The scenarios that are anchored to PSPS events increase net revenue more than the scenarios anchored to wildfires. This occurs because PSPS-anchored scenarios include only School Year events, and therefore more School Year Weekday events.

Table 35: Estimated net revenue from shifting event-time charging

		Anchored to Wildfires			Anchored to PSPS		
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Scenarios	Hours	5	4	3	5	4	3
	Total Days	12	6	3	12	6	3
	School Year Weekday	*4*	*2*	*2*	*9*	*4*	*2*
	School Year Weekend	*2*	*1*	*0*	*3*	*2*	*1*
	Summer Day	*6*	*3*	*1*	*0*	*0*	*0*
Baseline	Net Revenue per Year	$29,041	$12,362	$2,949	$13,127	$7,024	$2,717
Shifting Event-time Charging	Net Revenue per Year	$29,933	$12,813	$3,622	$15,135	$7,927	$3,390
	Difference in Net Revenue per Year between Baseline and Shifting Event-time Charging	**$892**	**$451**	**$673**	**$2,008**	**$903**	**$673**

Procurement guidelines and recommendations

Based on the results from the analysis, we recommend the following three actions related to the ELRP:

Recommendation 1: Participate in the ELRP if installing V2G-capable chargers

- At today's costs of V2G technologies, participation in the ELRP is unlikely to generate enough net revenue to singlehandedly pay for the incremental CAPEX increase to convert buses and charging infrastructure to be V2G capable. Table 36 indicates the expected incremental cost increases, and Table 37 shows the estimated net revenue generated from the ELRP over a 20-year period (the same period used for TCO analysis). Even under the most aggressive ELRP scenario, the incremental cost to procure V2G infrastructure is roughly $500,000 more than the 20-year net revenue generated from the ELRP ($1,087,554 vs $580,814).
    - As V2G costs come down in the future, either due to market maturity or public subsidies, the economics become much more favorable.
- However, if GUHSD decides to invest in V2G-enabled buses and chargers (for the myriad of other environmental, safety, and potential future economic opportunities associated with the technology), the ELRP can provide a steady stream of annual net revenue with minimal additional investment and effort required from GUHSD.
- Participating in the ELRP may also prove more economically advantageous in the future than it is currently. The ELRP was recently initiated as a response to growing wildfires and emergency grid instabilities. Given the increasing effects of Climate Change and current forecasts, these issues and the need for emergency load reduction may increase in future years. Participating in the program now will provide GUHSD with a better understanding of how the novel program functions and how it may change over time. If wildfires and PSPS events become more prevalent, it is possible that the ELRP may expand to include more event days, longer event durations, and/or larger economic incentives.

Table 36: Incremental CAPEX increase required to install V2G-capable buses and chargers, per phase

	Phase 3	Phase 4a	Phase 4b	**Total**
Electric Buses – CAPEX	*	*	*	*
Charging Stations – CAPEX	*	*	*	*
Total	*	*	*	**$1,087,554**

** Information redacted for confidentiality*

Table 37: Estimated net revenue from the ELRP over 20-year period, per scenario

	Anchored to Wildfires			Anchored to PSPS		
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total Event Days	12	6	3	12	6	3
Hours per Event	5	4	3	5	4	3
20 Year Total Net Revenue*	**$580,814**	**$247,238**	**$58,981**	**$262,544**	**$140,473**	**$54,339**

** Net revenue conservatively represents the baseline analysis and is not adjusted for inflation*

<u>Recommendation 2: Once the fleet is fully electrified, consider exceeding grid peak load by 50 kW if ELRP events are more likely to occur on School Year Weekends</u>

- As described in the sensitivity analysis above, increasing the grid peak load during School Year Weekends will allow GUHSD to generate more net revenue from those events. Adding 50 kW to the grid peak load for School Year Weekend events that last at least four hours will increase annual revenue by between roughly $100 and $500, based on the six scenarios.
- These revenue increases are modest relative to the total net revenue estimates, but actual real-world results may be more favorable since the model is based on many conservative assumptions (outlined above). Increasing the grid peak load by 50 kW will allow GUHSD to explore this cost saving potential, with little financial risk (50 kW in additional demand charges costs roughly $200).
- The model currently predicts grid peak load increases will not generate increased net revenue for School Year Weekdays and Summer Days. However, GUHSD should examine the results from the real-world implementation of the ELRP program, to determine if grid peak load increases may allow for more net revenue during future School Year Weekdays, as fleet operations and ELRP guidelines may change in the future.

<u>Recommendation 3: Delay planned charging during an ELRP event until the after-midnight period following the event</u>

- Shifting event-time charging to the overnight period after School Year Weekday events can increase annual net revenue by roughly $450 to $2,000, based on the six analyzed scenarios. This increased net revenue does not require any additional capital or operational expenses to implement.
- However, not every bus can forgo all charging during an event without creating constraints on the ability to adequately charge the buses overnight. Therefore, GUHSD should carefully consider the requirements and capacity for overnight charging and properly calibrate the amount of charging to shift outside of an ELRP event, to ensure all buses are adequately charged by the morning.

Broadly, we also make the following overarching recommendations:

- GUSHD should coordinate closely with SDG&E on (a) the ability to increase grid peak load allowance and (b) the ability to be properly compensated for shifting the event-time charging.

- Combining (a) the ability to increase grid peak load allowance with (b) the ability to shift event-time charging can open future opportunities and result in potentially significant additional value for GUHSD, that exceeds the benefits of implementing both measures separately.

Figure 47: Average acres burned by wildfire in California, between 2008 and 2019 (source: CalFire)

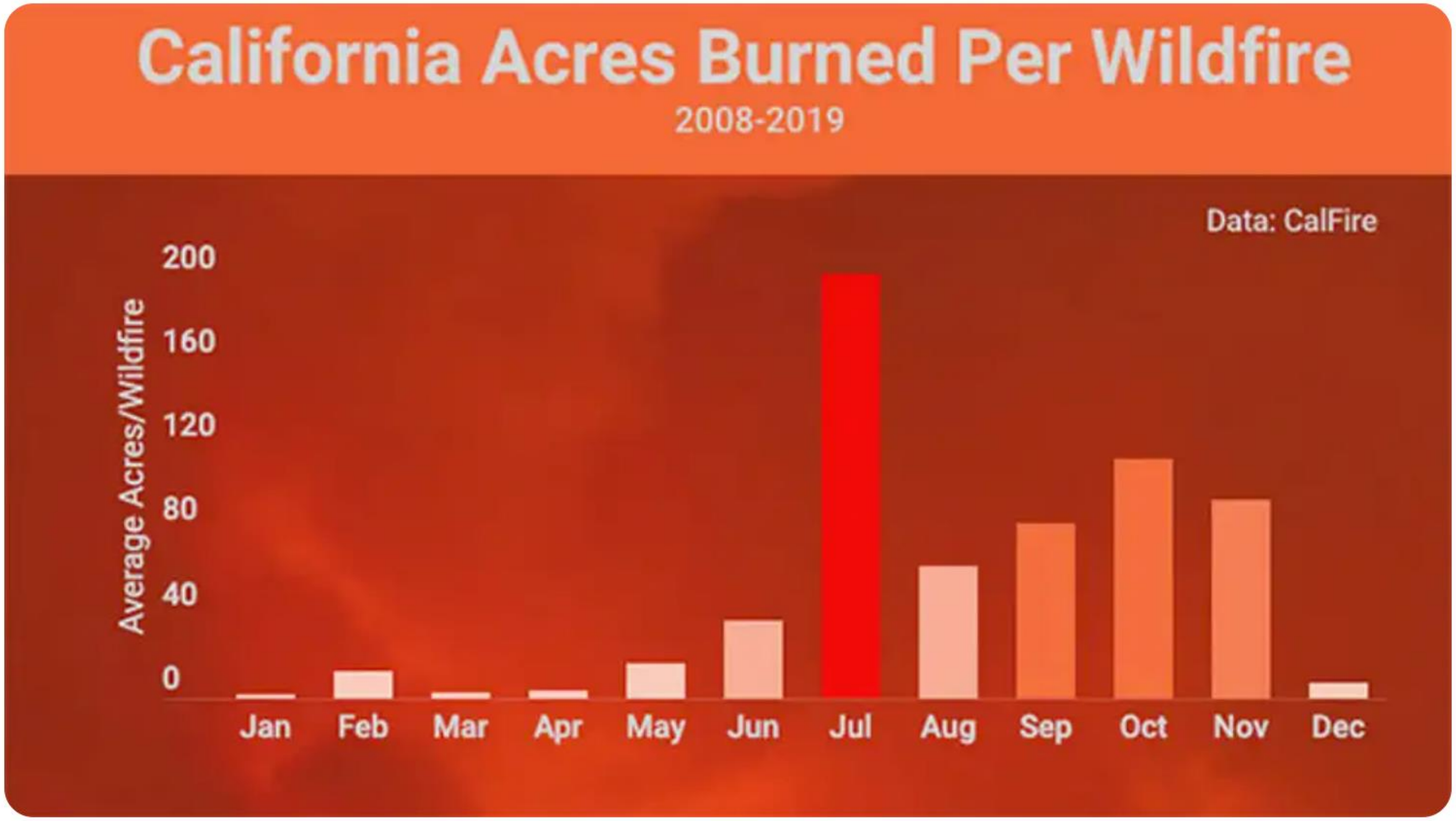
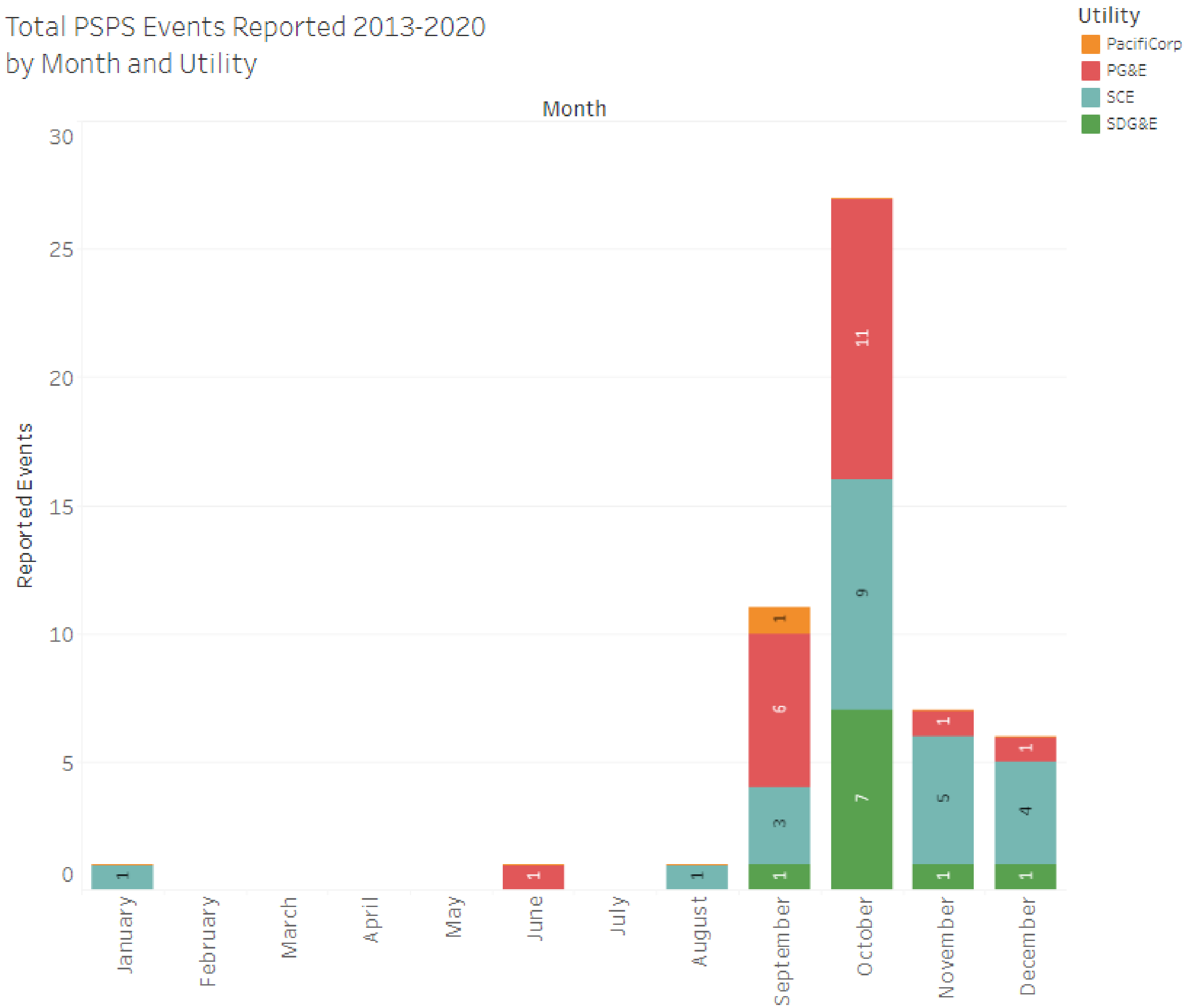


Figure 48: Total PSPS events reported by major utilities in California, between 2013 and 2020 (source: PSE)



APPENDIX

Figure 49: Energy Flows for Phase 3 Scenario 1 – Winter

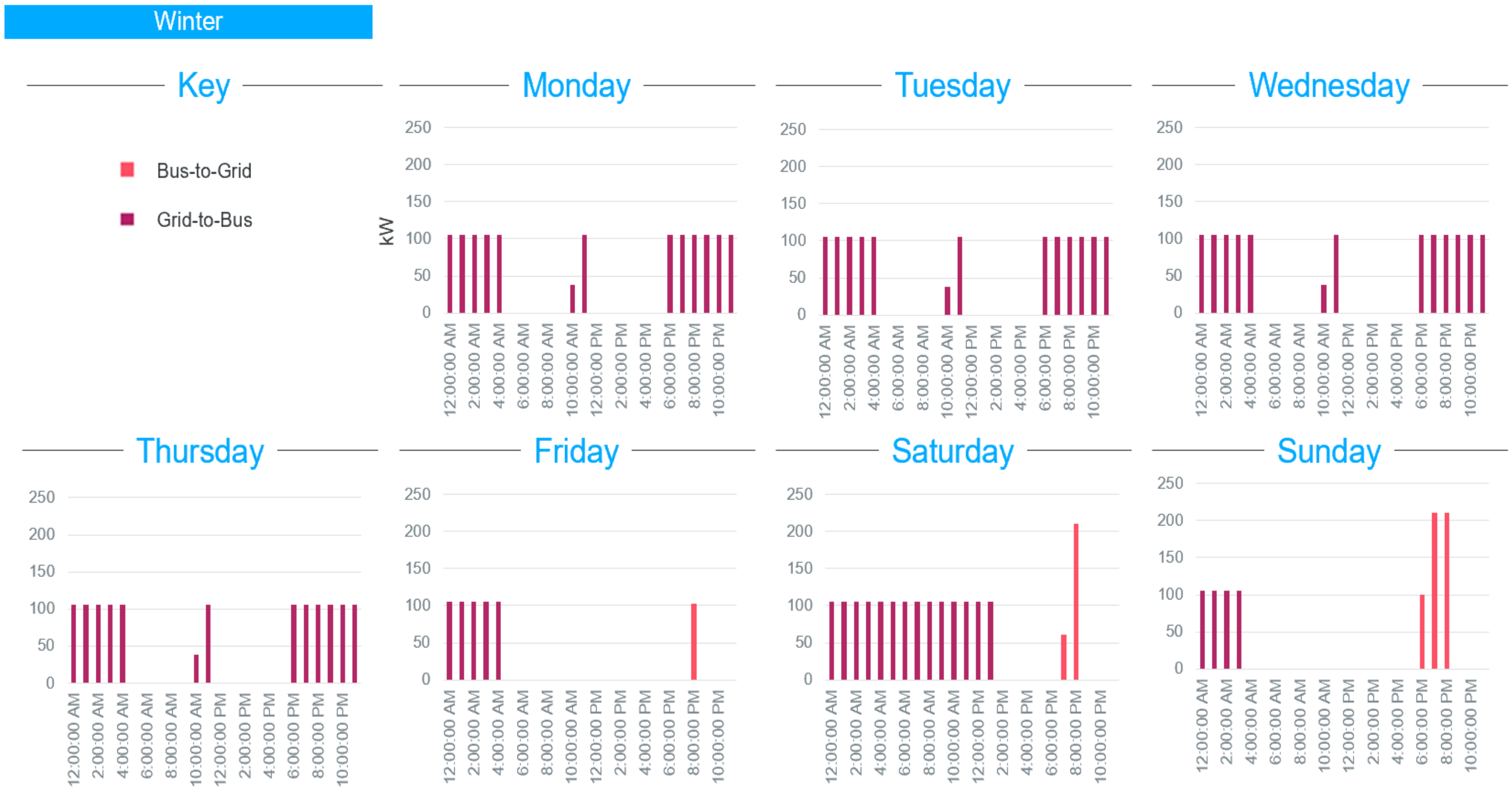


Figure 50: Charging Profiles for Phase 3 Scenario 1 – Winter

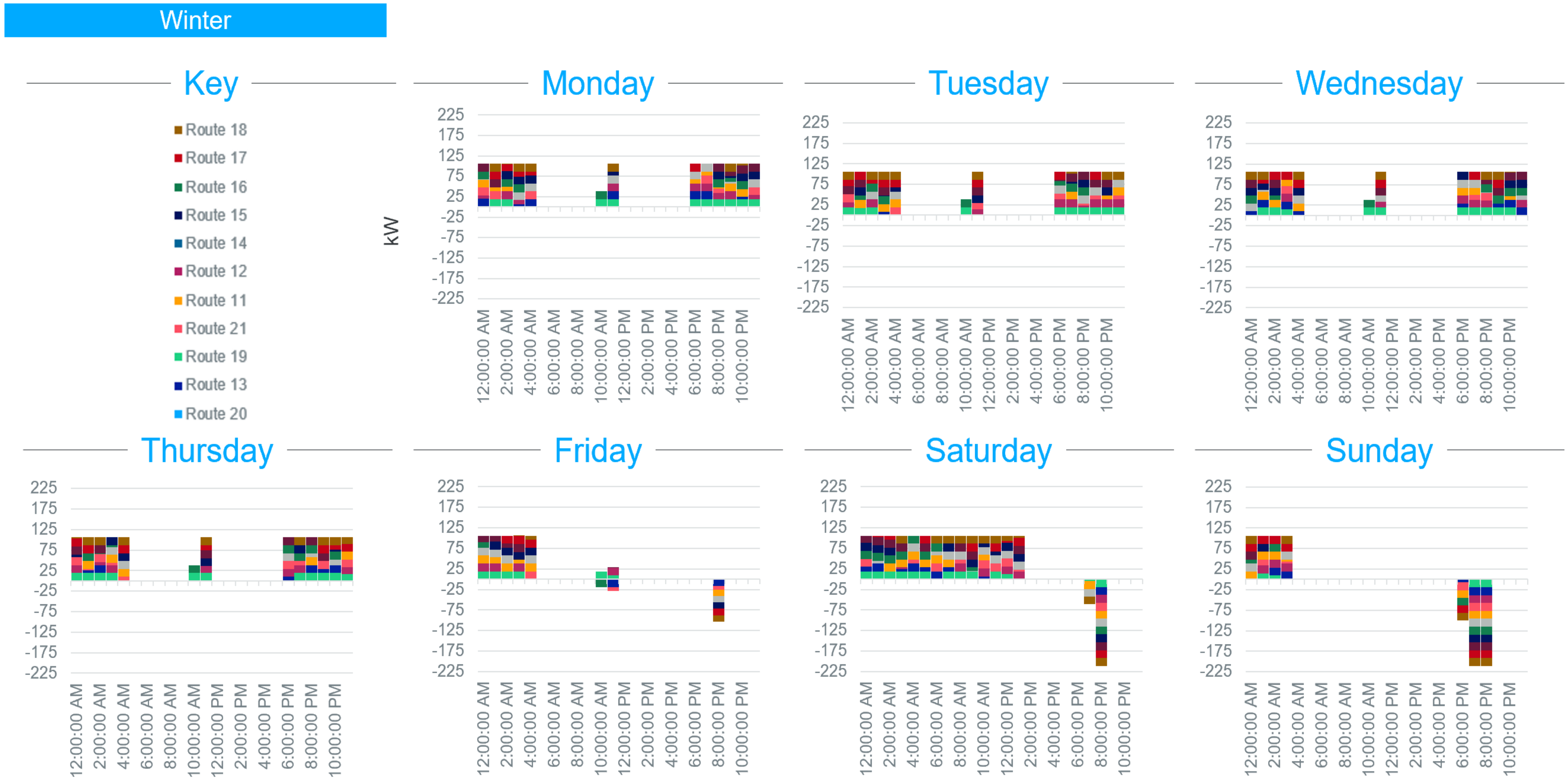


Figure 51: Sources of Energy for Bus Charging in Phase 3 Scenario 1 – Winter

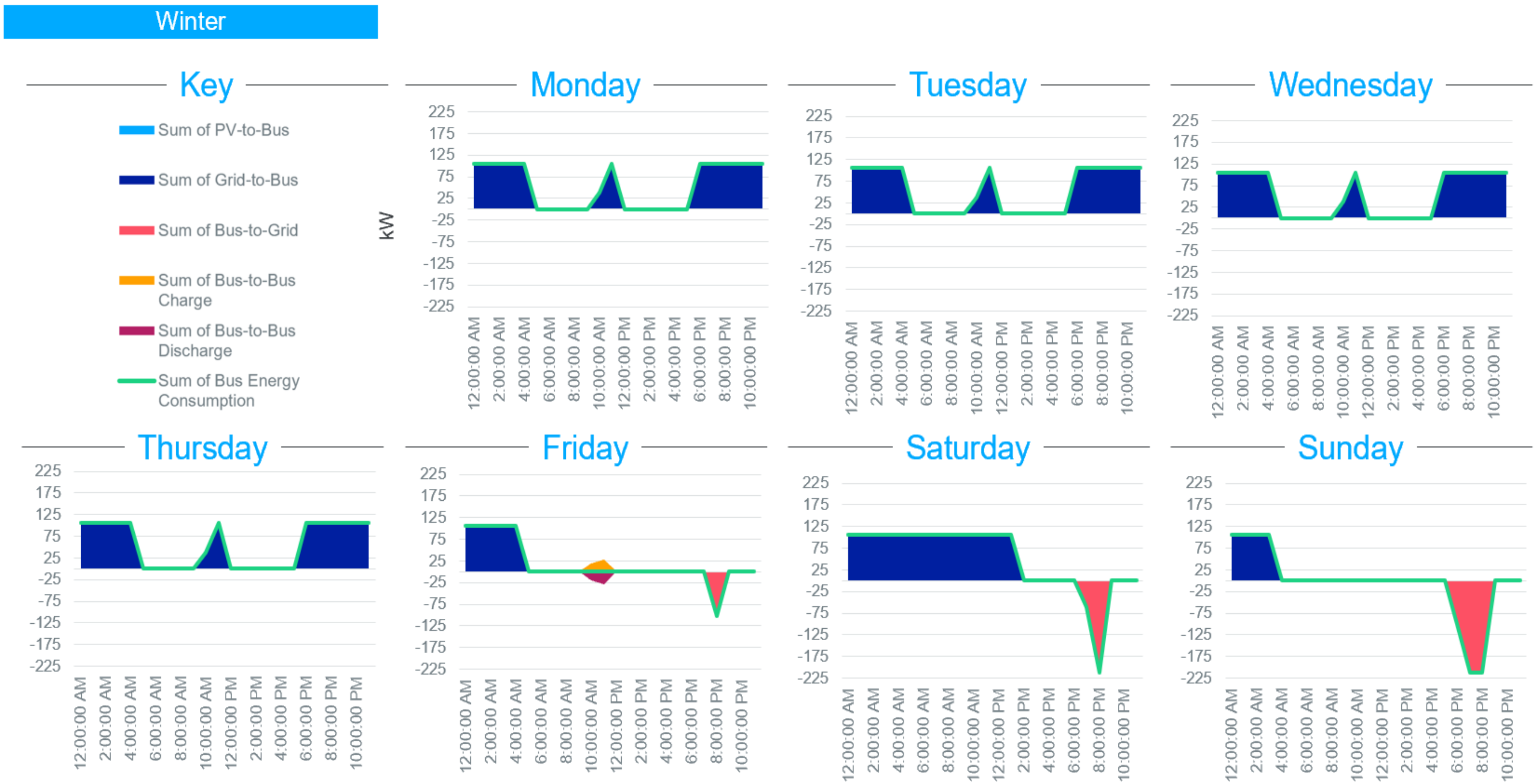


Figure 52: Energy Flows for Phase 3 Scenario 2 – Winter

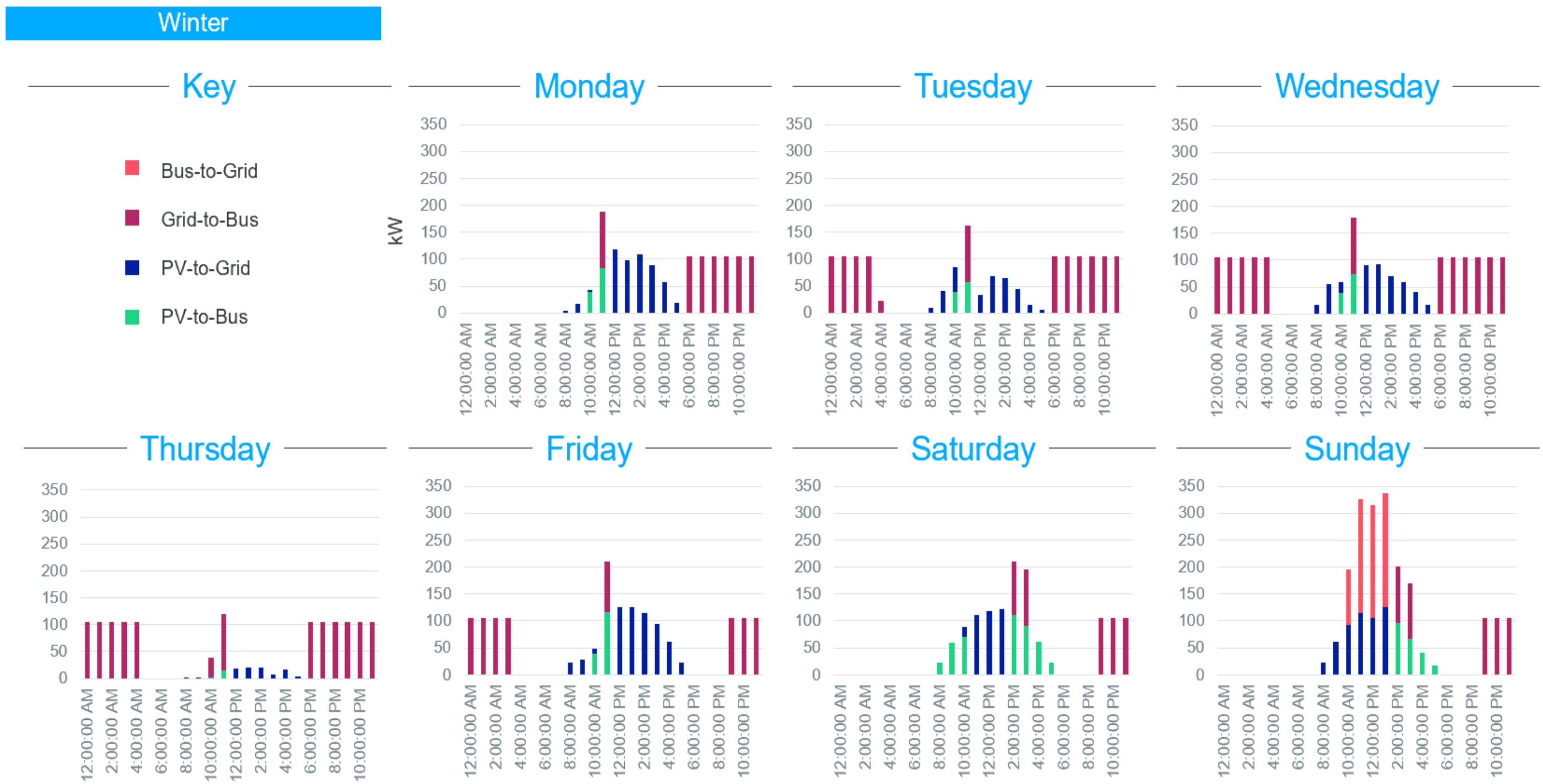


Figure 53: Charging Profiles for Phase 3 Scenario 2 – Winter

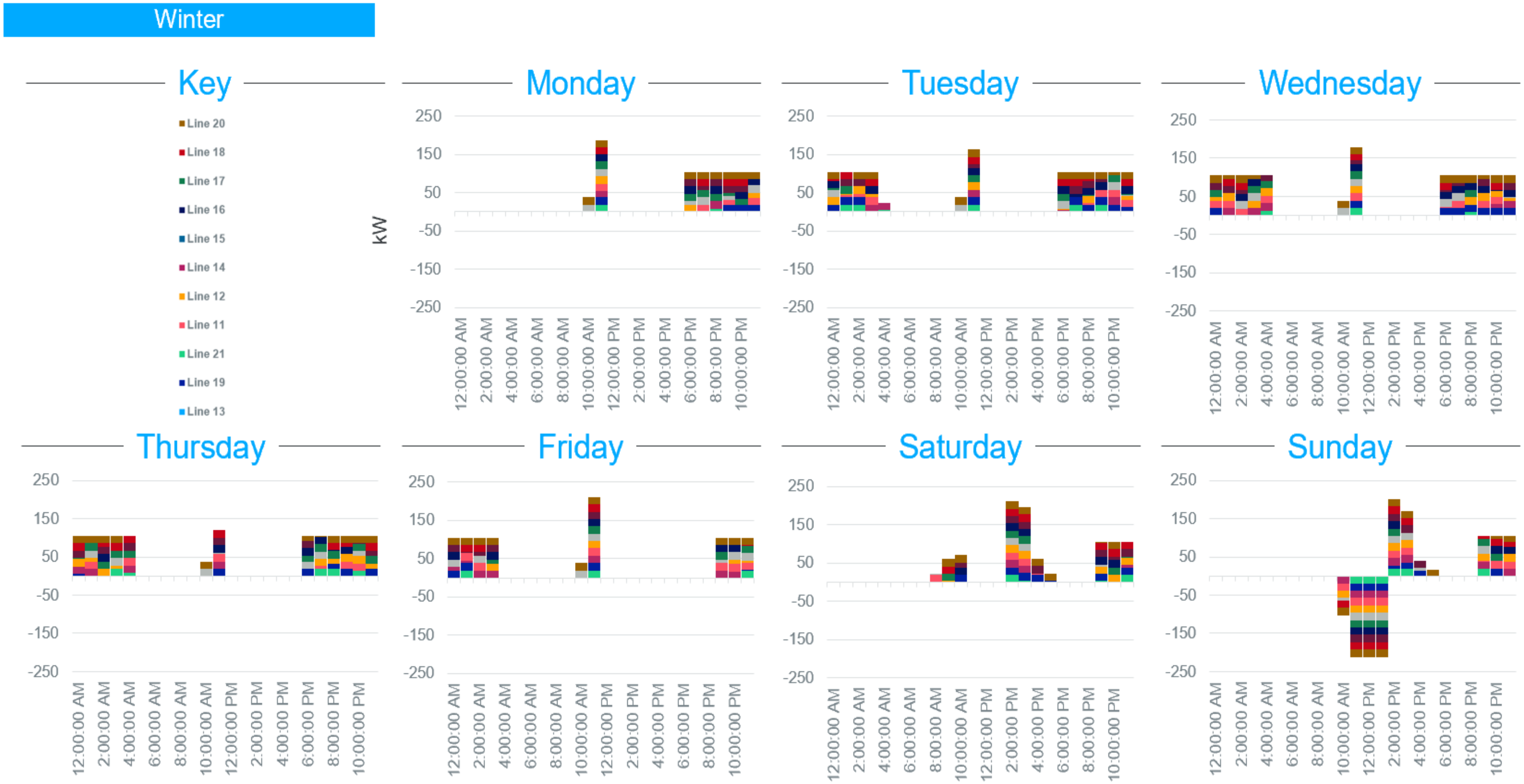


Figure 54: Sources of Energy for Bus Charging in Phase 3 Scenario 2 – Winter

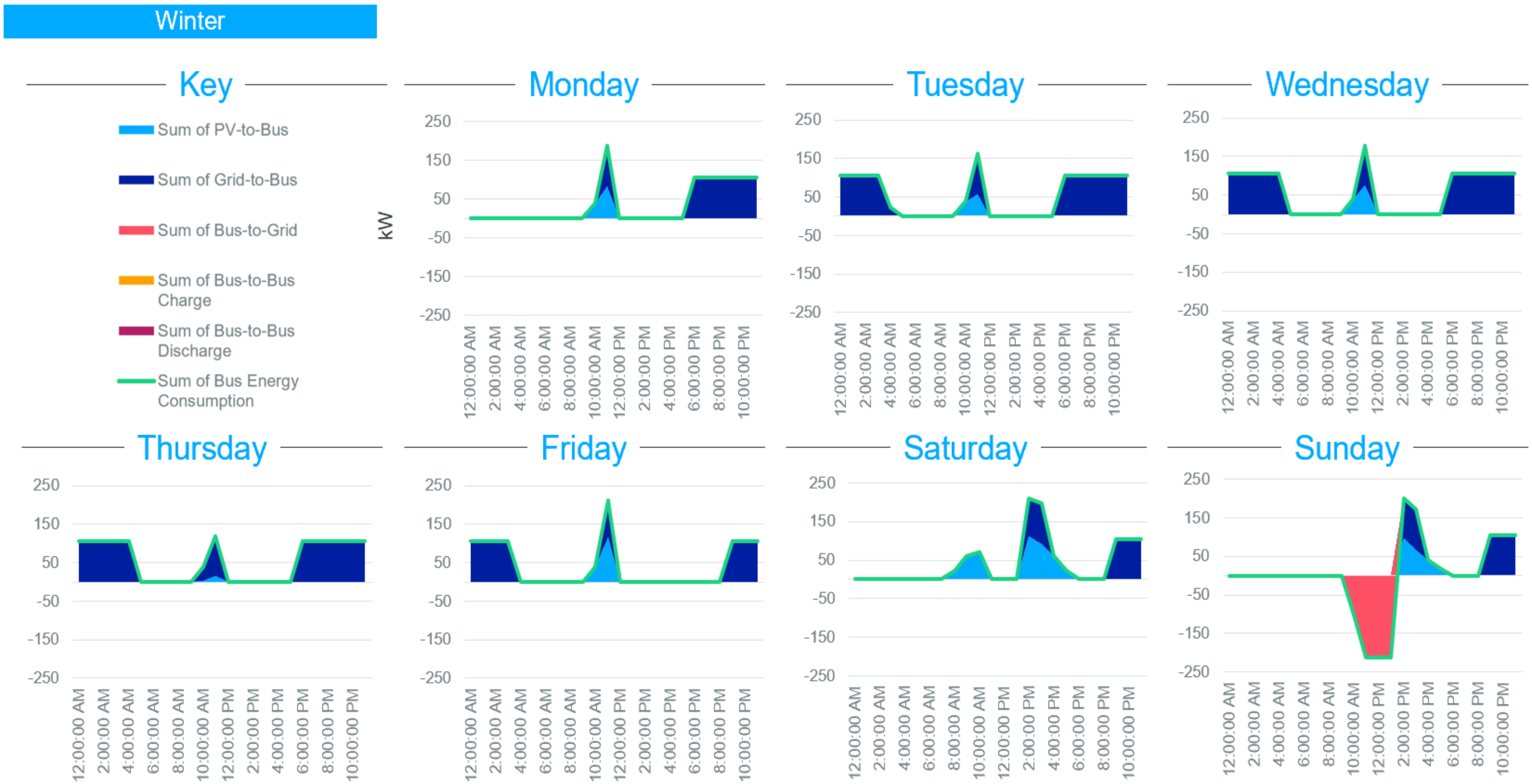


Figure 55: Energy Flows for Phase 3 Scenario 3 – Winter

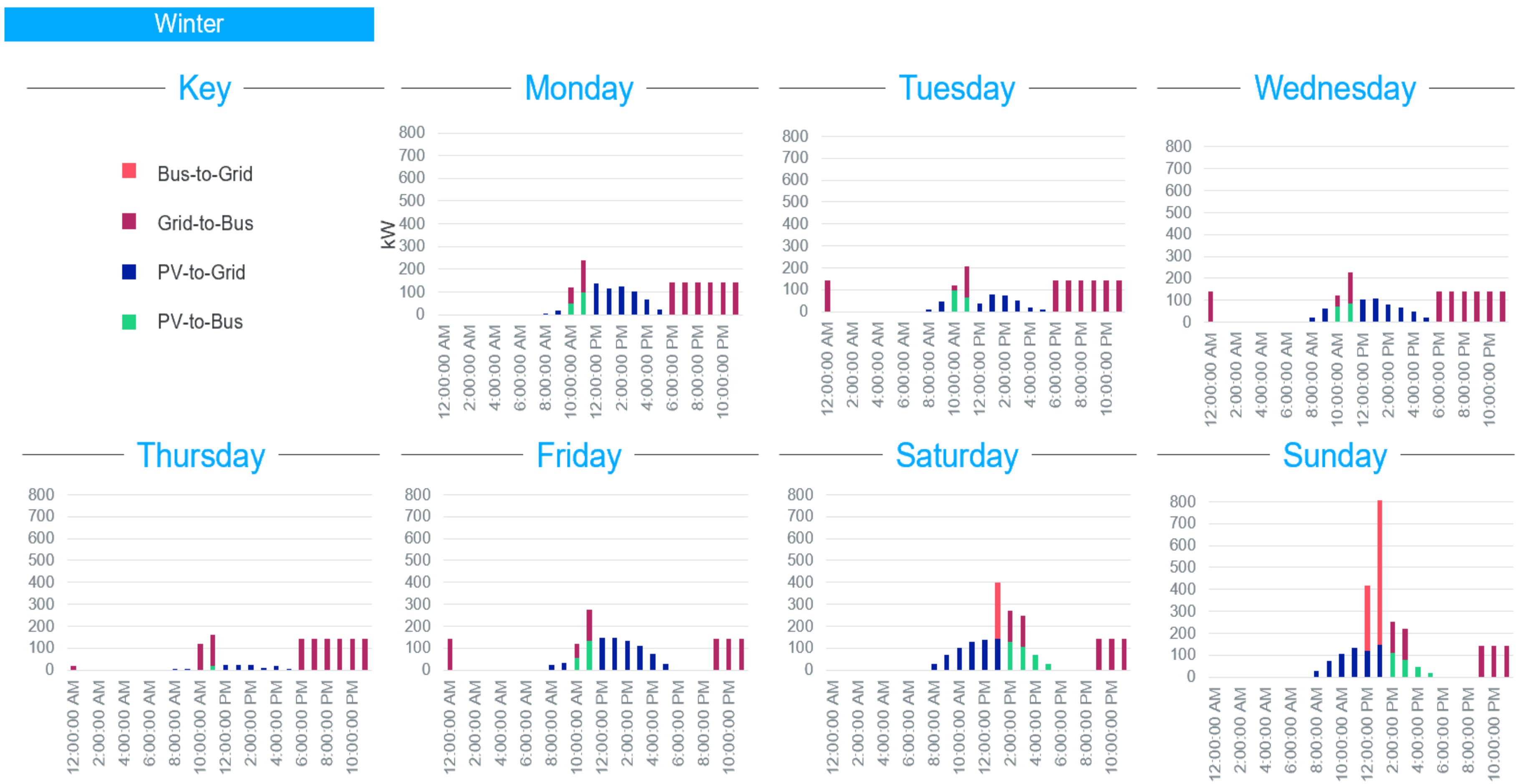


Figure 56: Charging Profiles for Phase 3 Scenario 3 – Winter

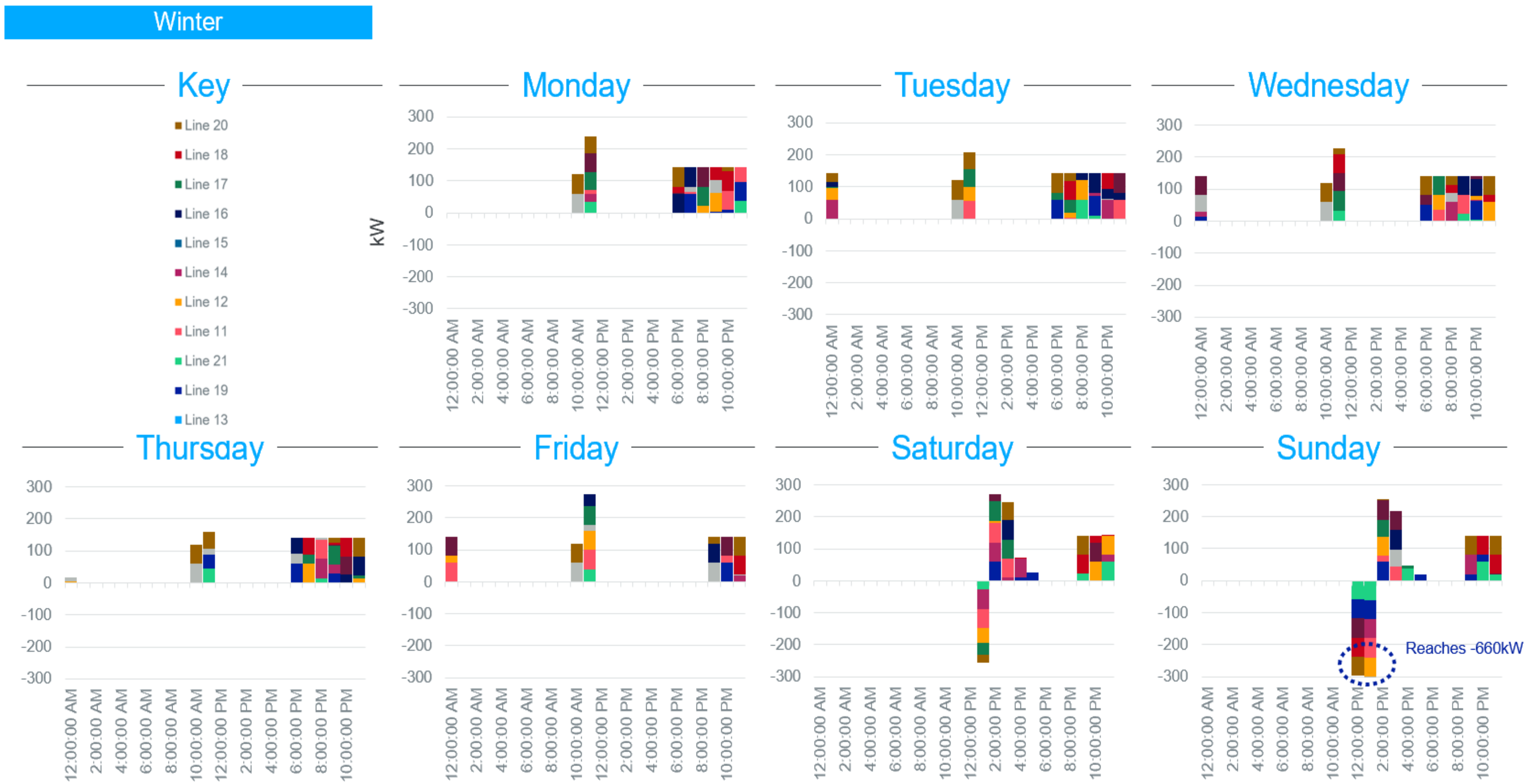


Figure 57: Sources of Energy for Bus Charging in Phase 3 Scenario 3 – Winter

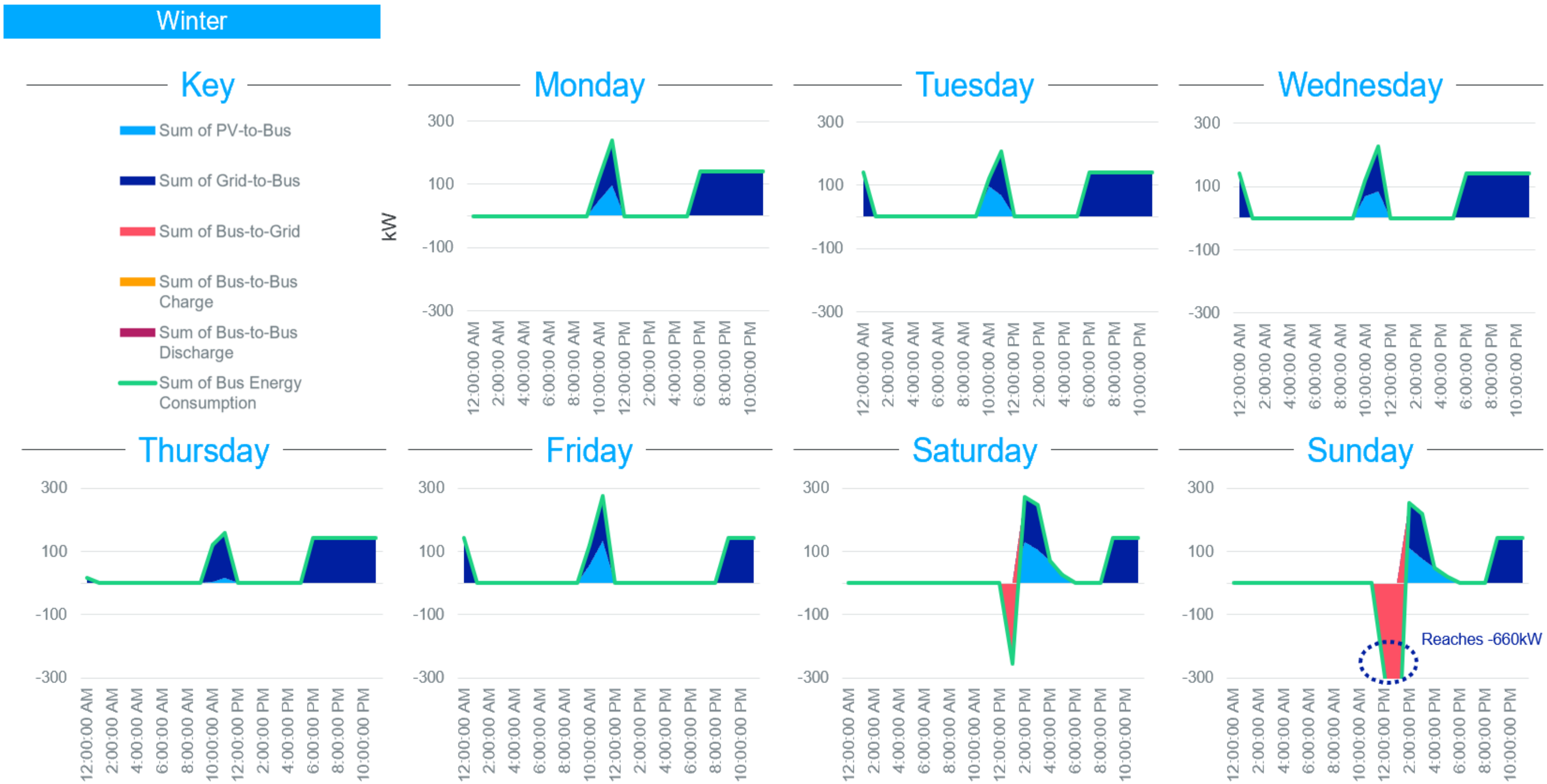


Figure 58: Energy Flows for Phase 4a Scenario 1 – Winter

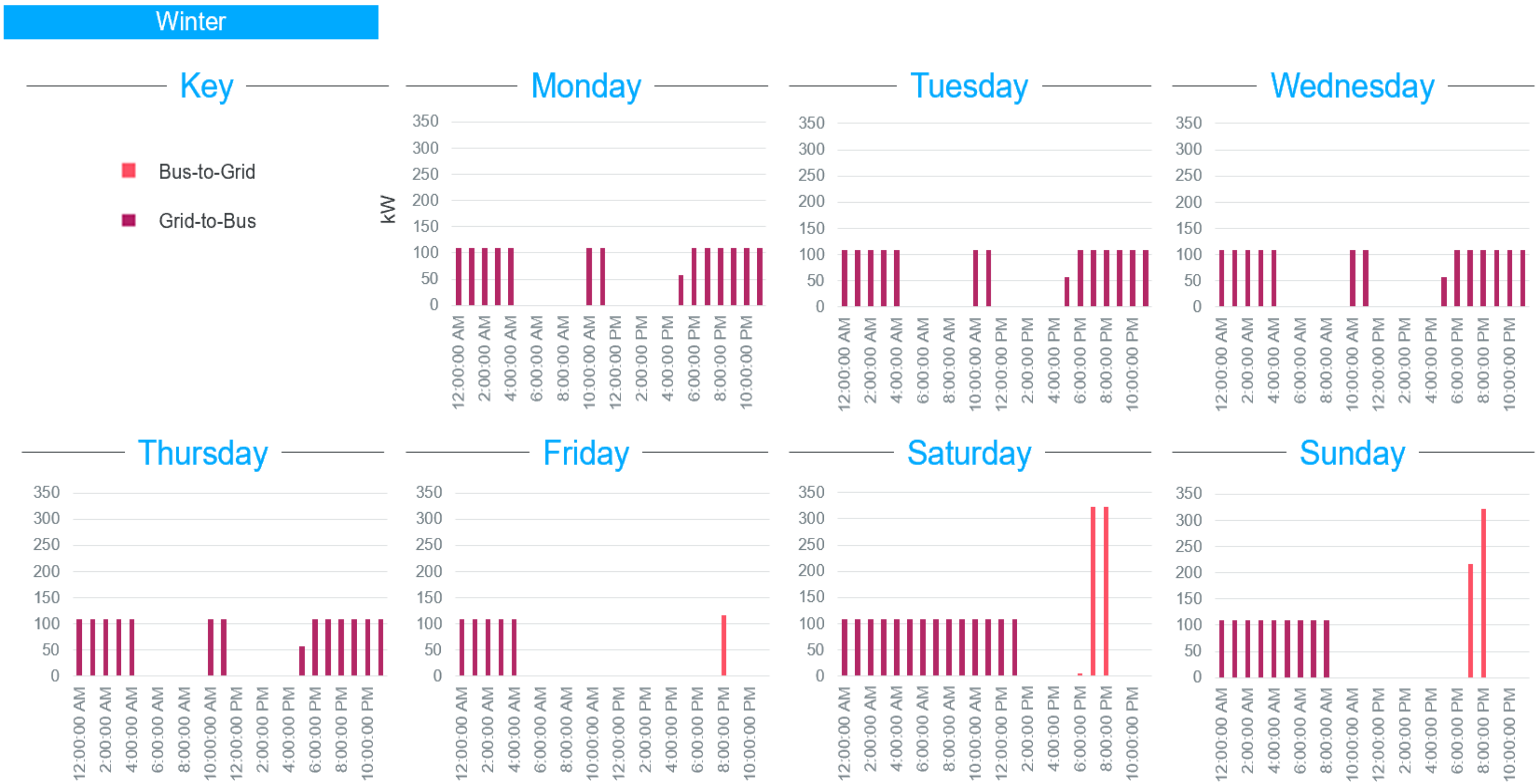


Figure 59: Charging Profiles for Phase 4a Scenario 1 – Winter

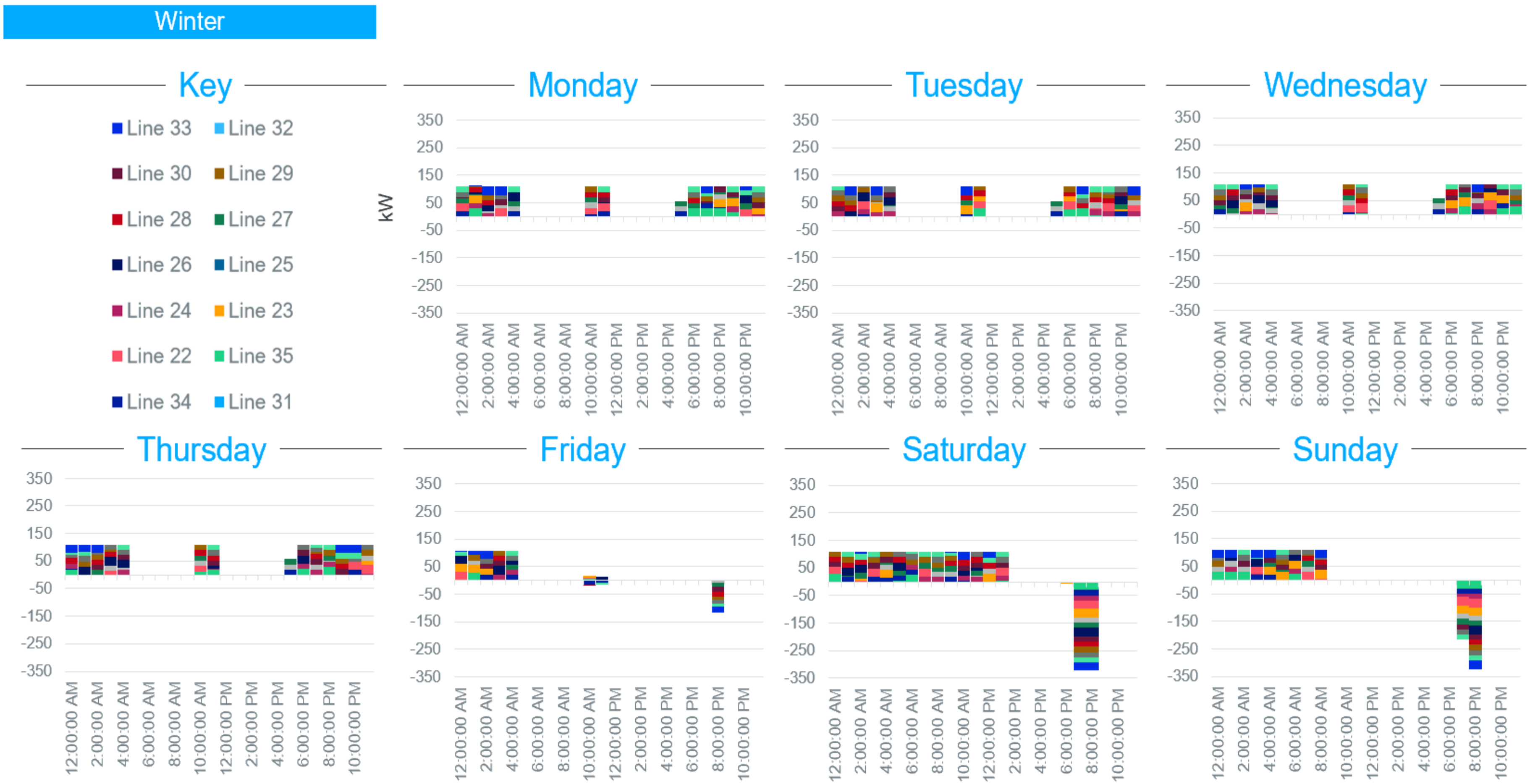


Figure 60: Sources of Energy for Bus Charging in Phase 4a Scenario 1 – Winter

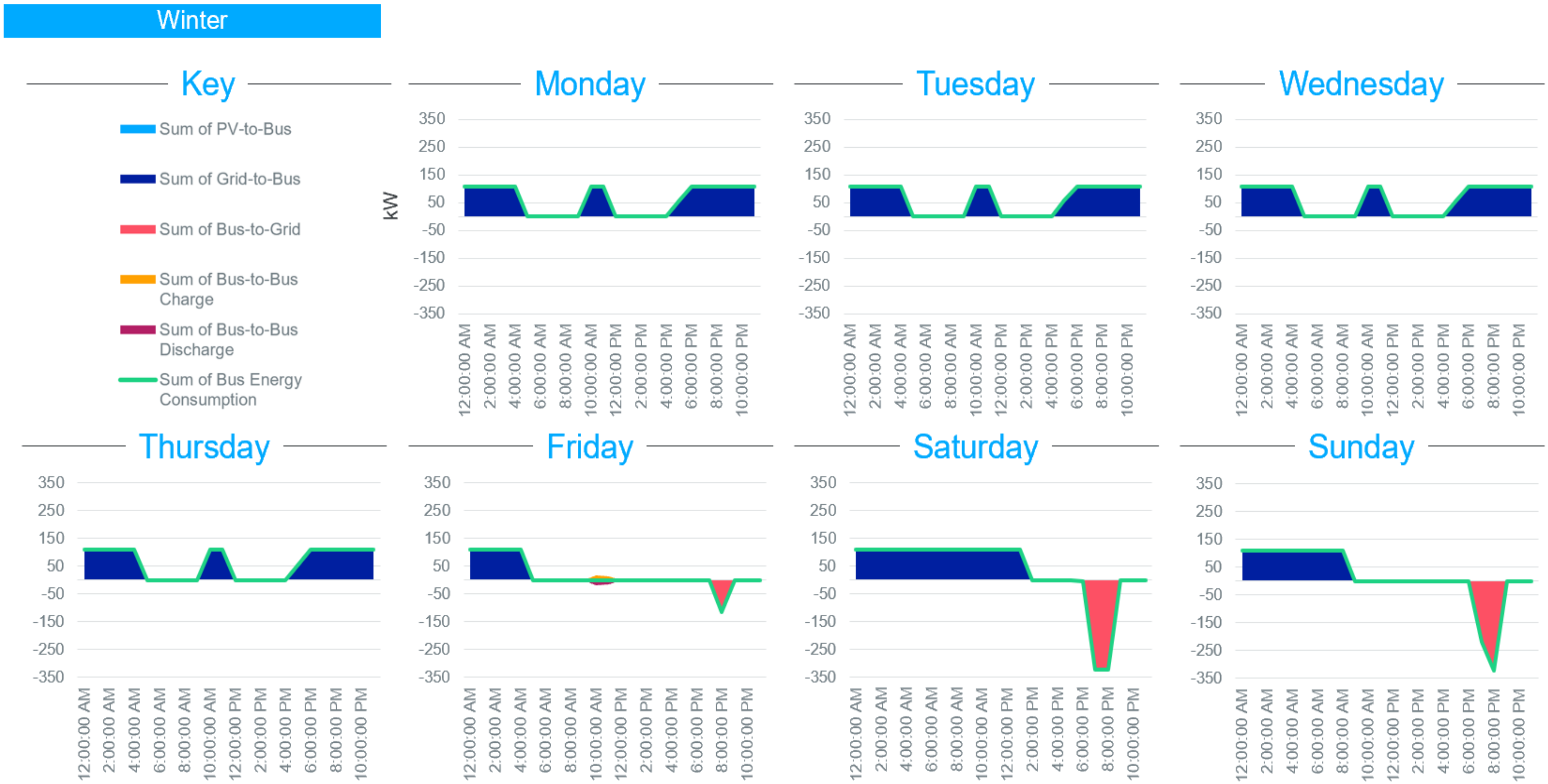


Figure 61: Energy Flows for Phase 4a Scenario 2 – Winter

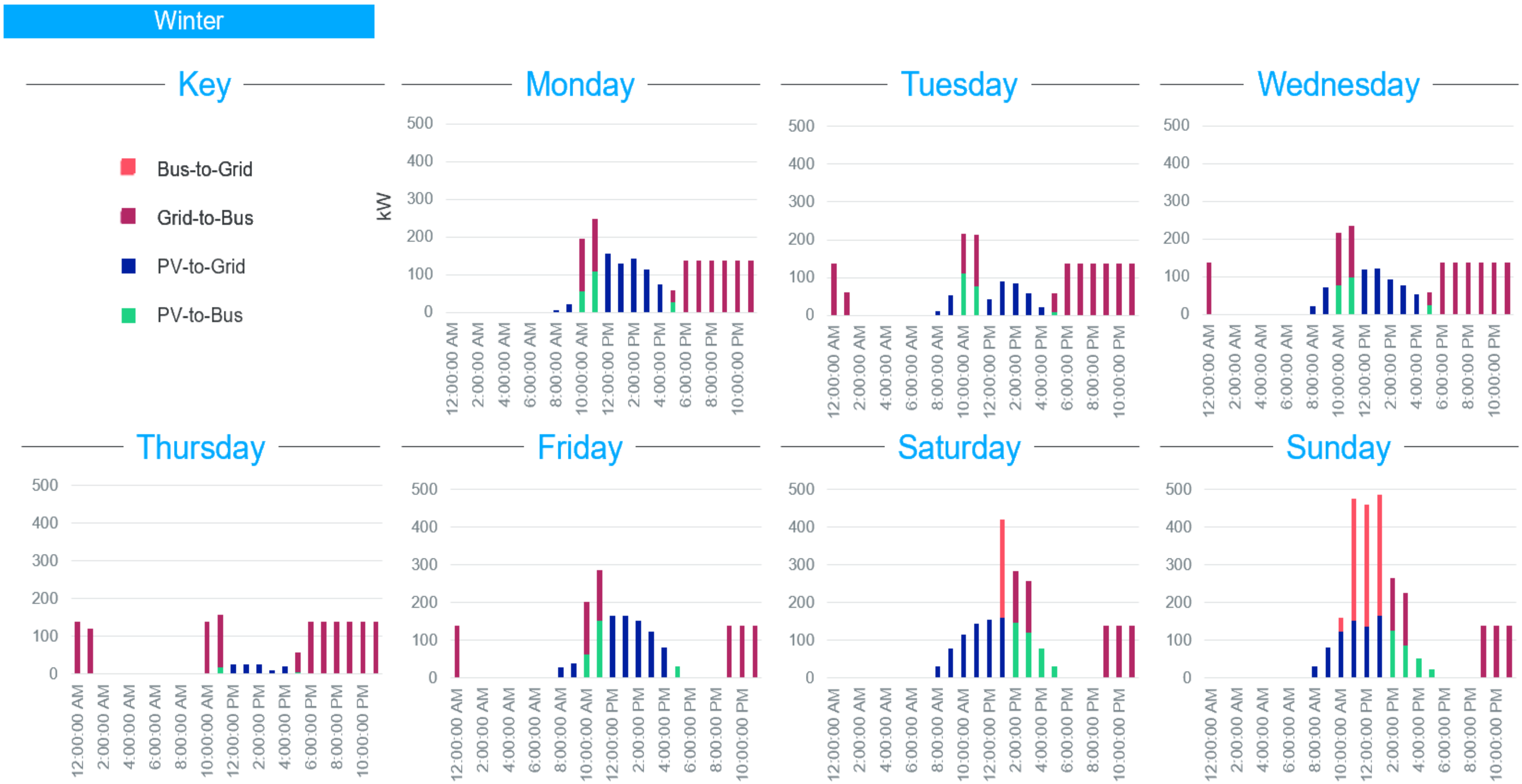


Figure 62: Charging Profiles for Phase 4a Scenario 2 – Winter

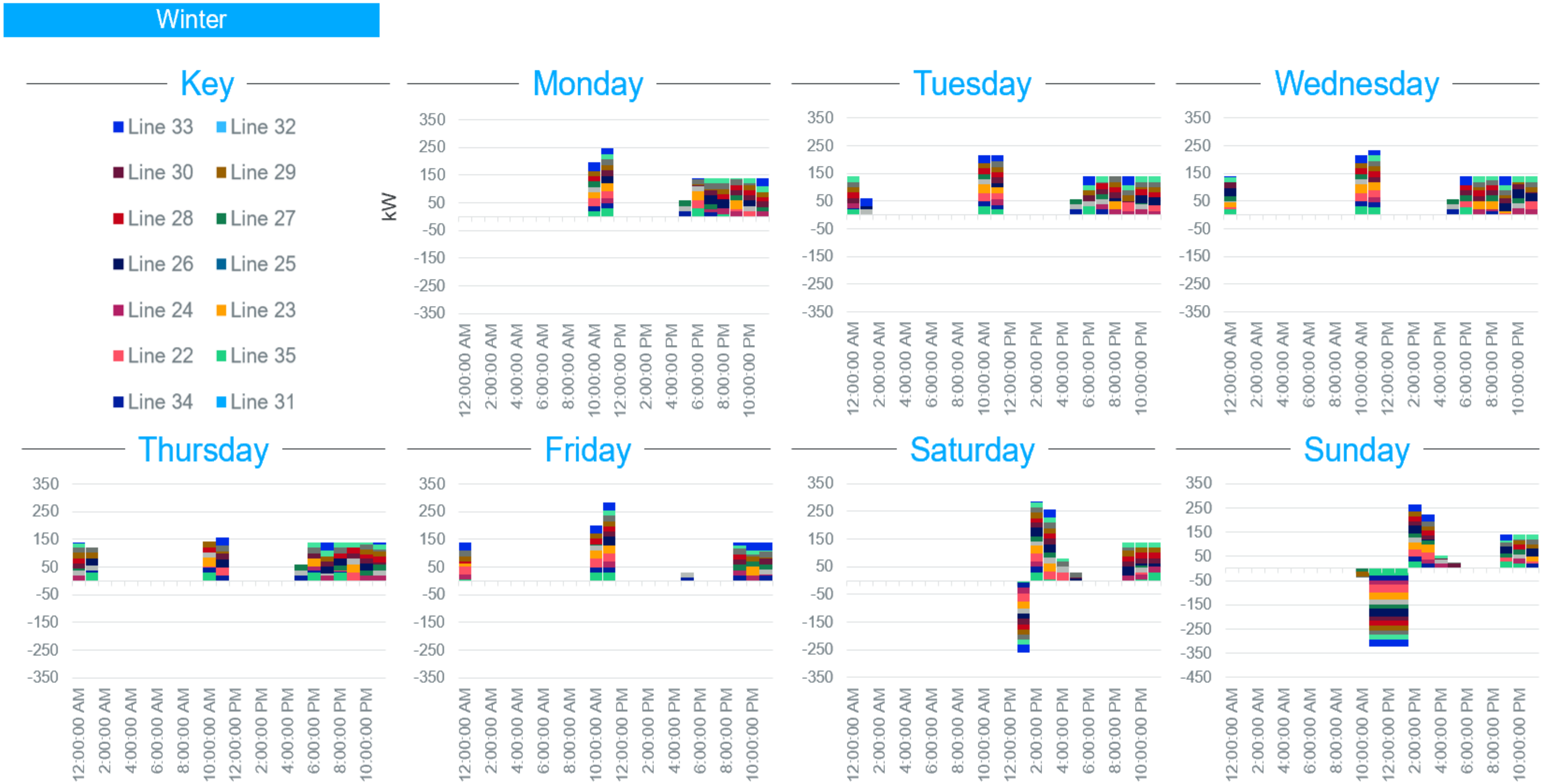


Figure 63: Sources of Energy for Bus Charging in Phase 4a Scenario 2 – Winter

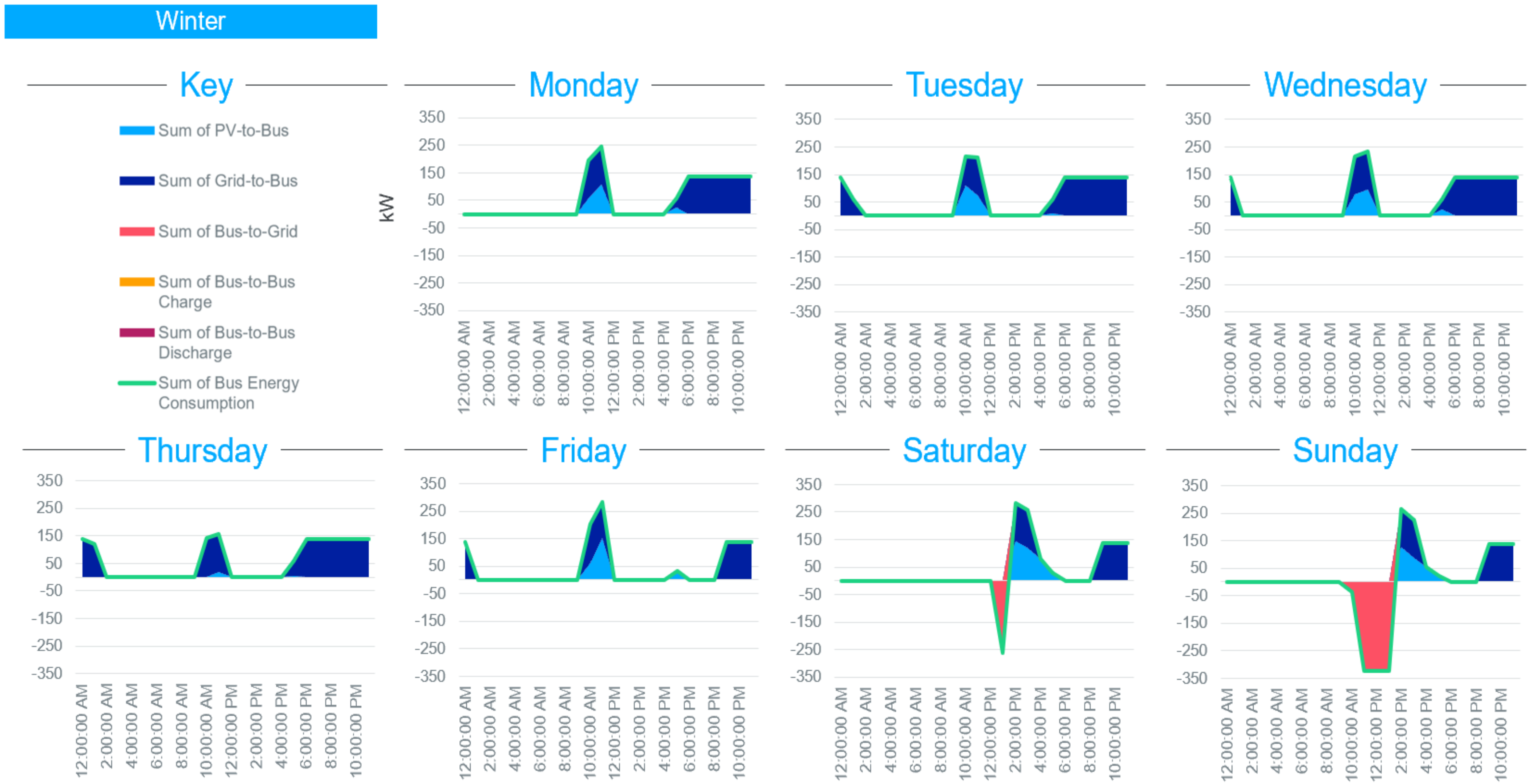


Figure 64: Energy Flows for Phase 4a Scenario 3 – Winter

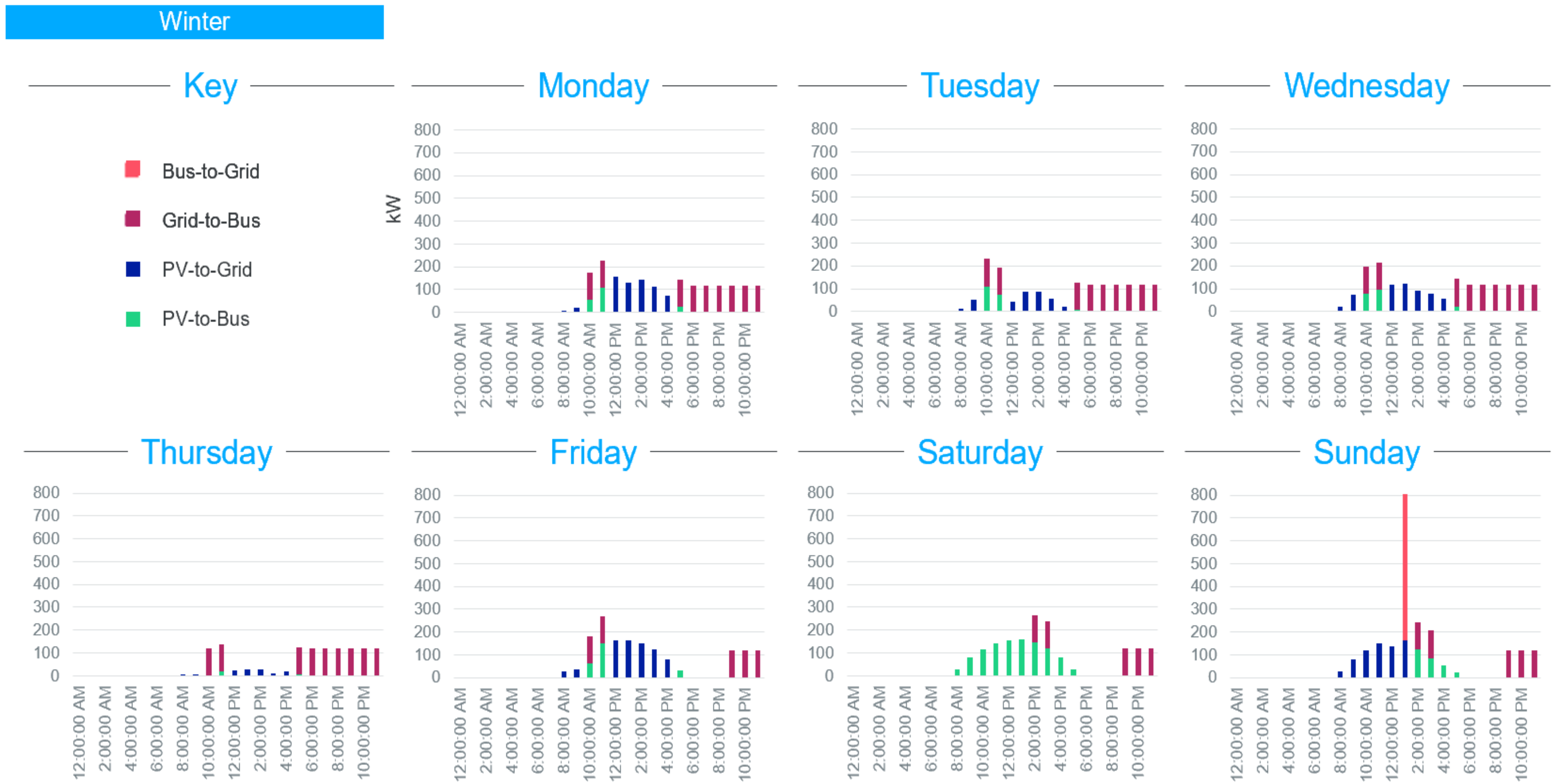


Figure 65: Charging Profiles for Phase 4a Scenario 3 – Winter

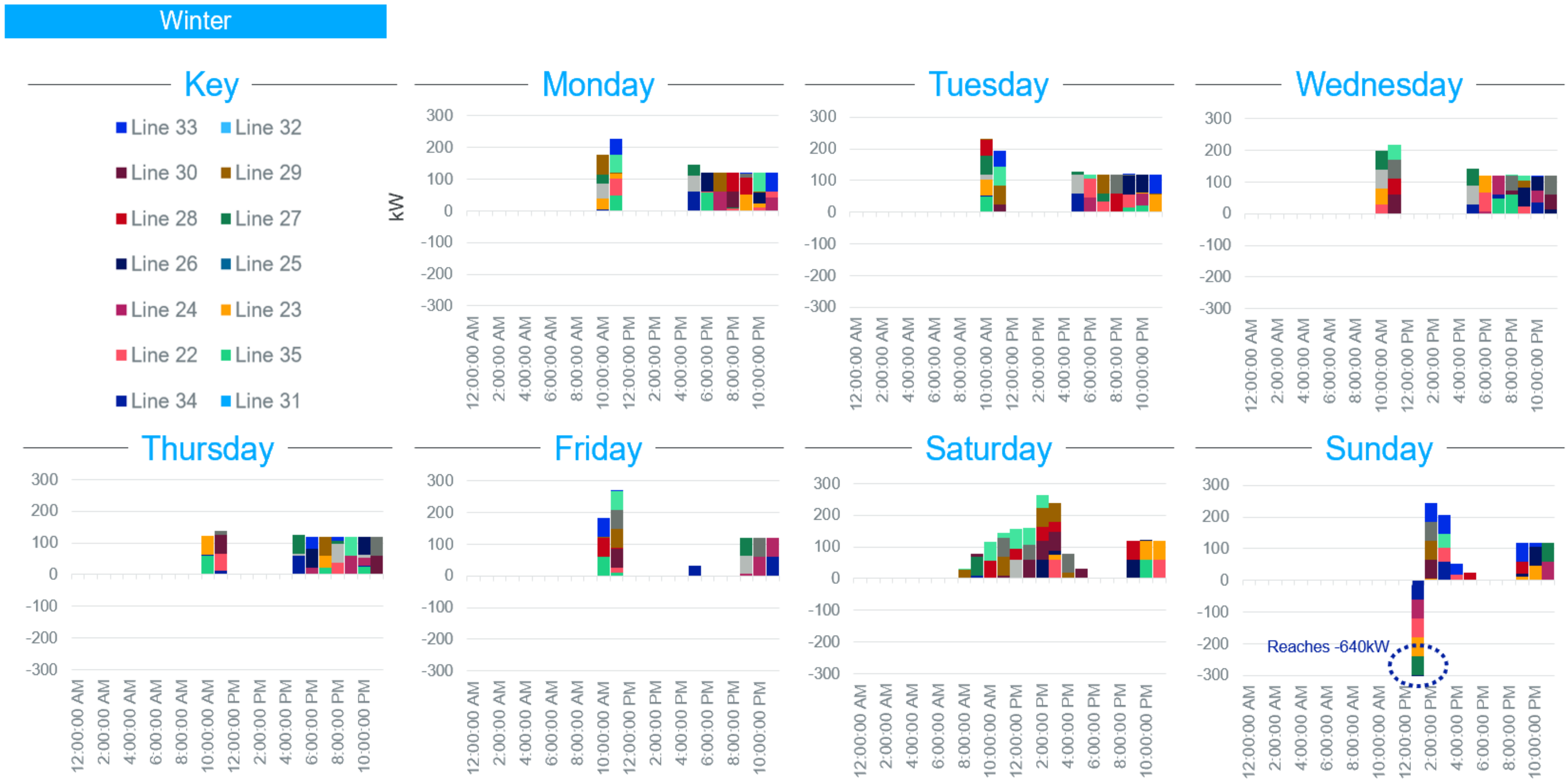


Figure 66: Sources of Energy for Bus Charging in Phase 4a Scenario 3 – Winter

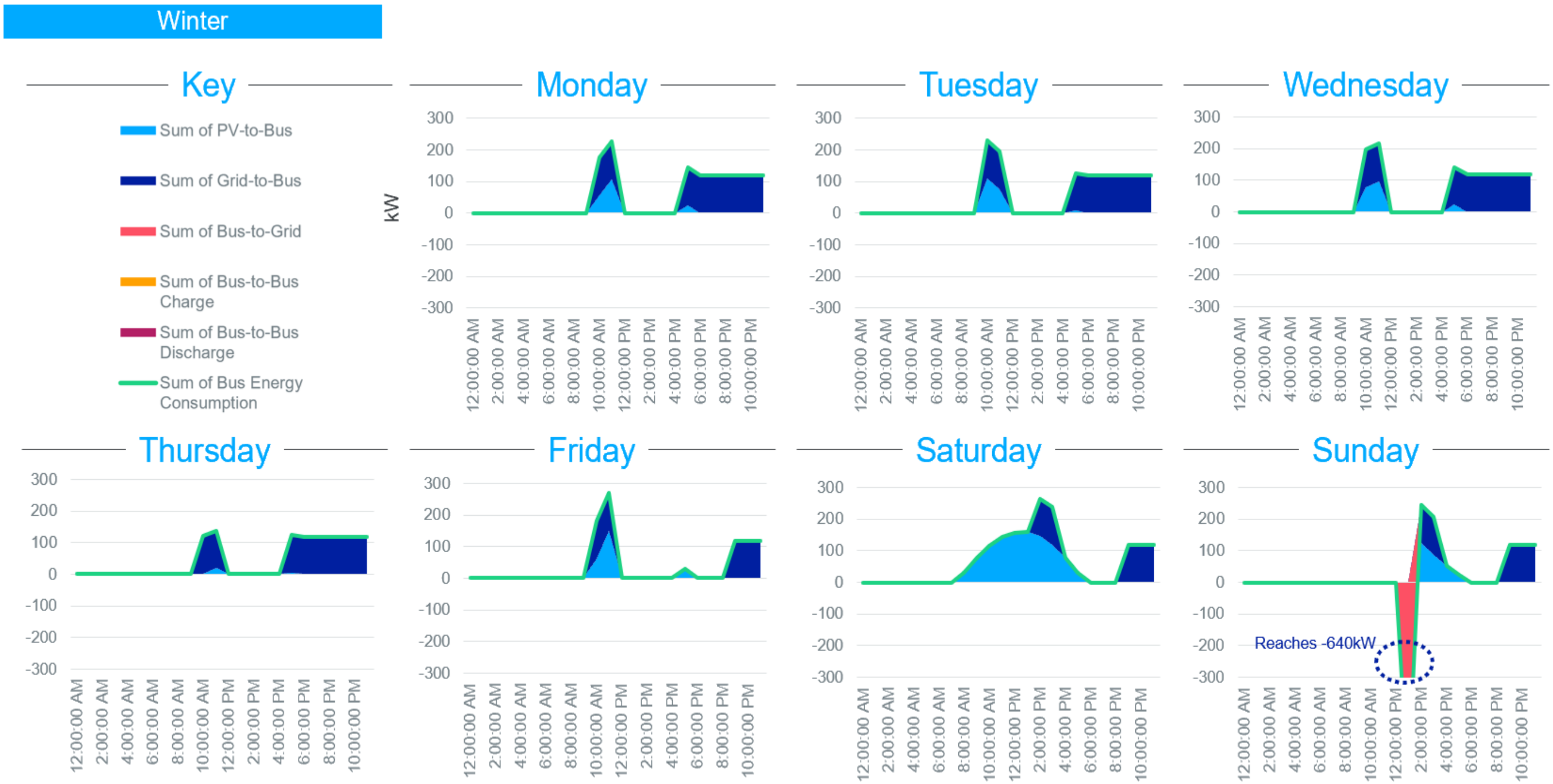


Figure 67: Energy Flows for Phase 4b Scenario 1 – Winter

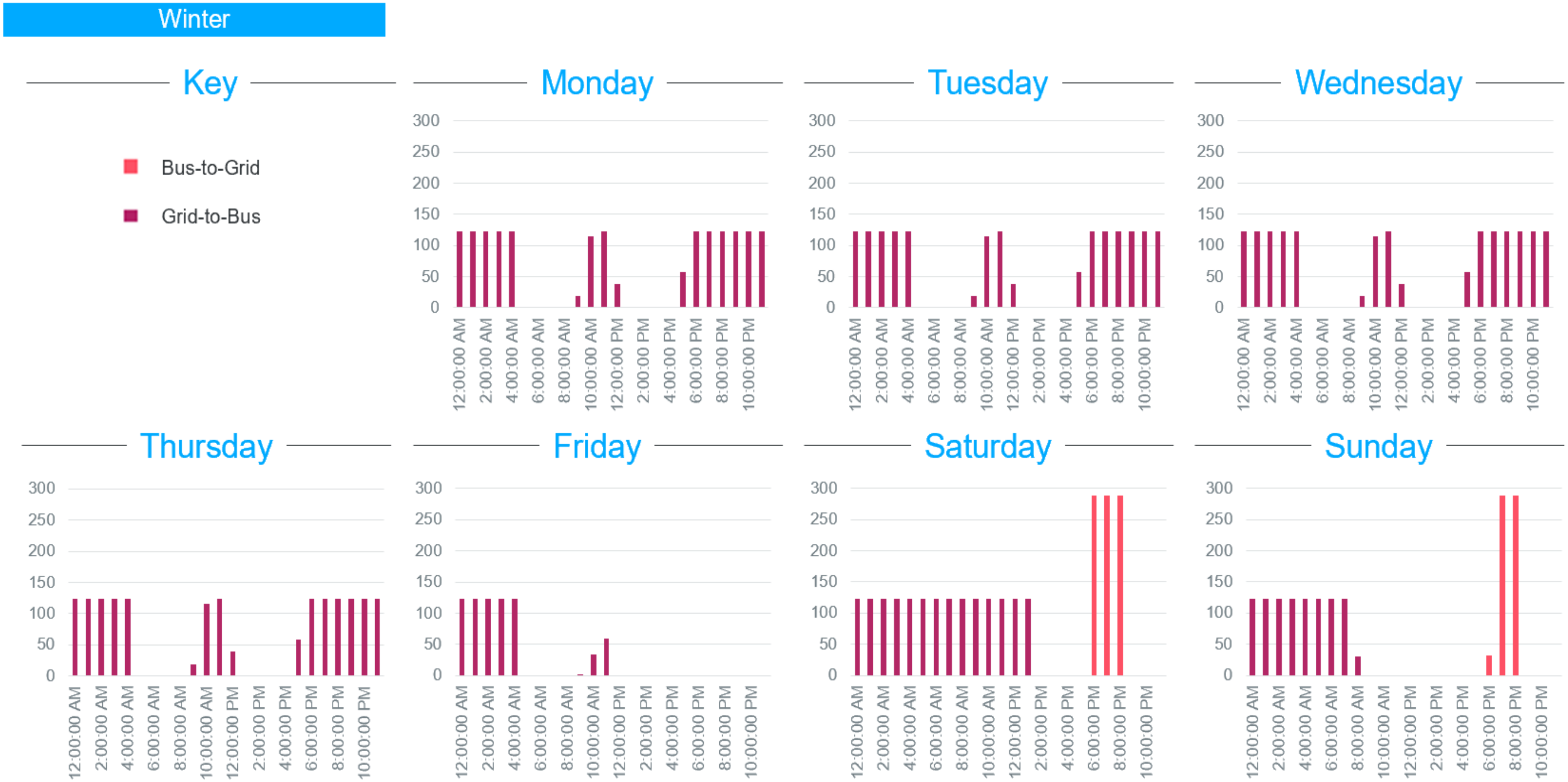


Figure 68: Charging Profiles for Phase 4b Scenario 1 – Winter

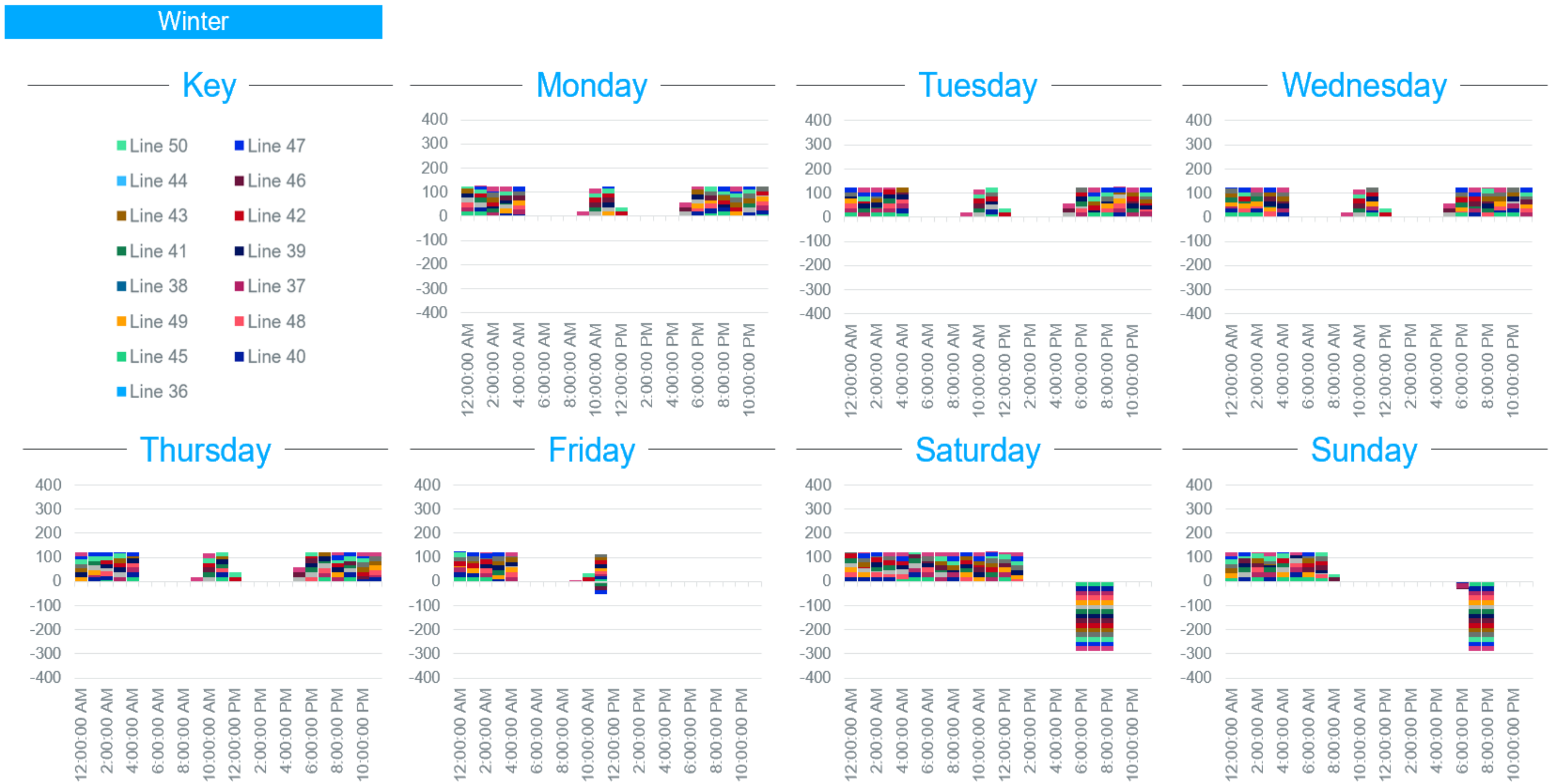


Figure 69: Sources of Energy for Bus Charging in Phase 4b Scenario 1 – Winter

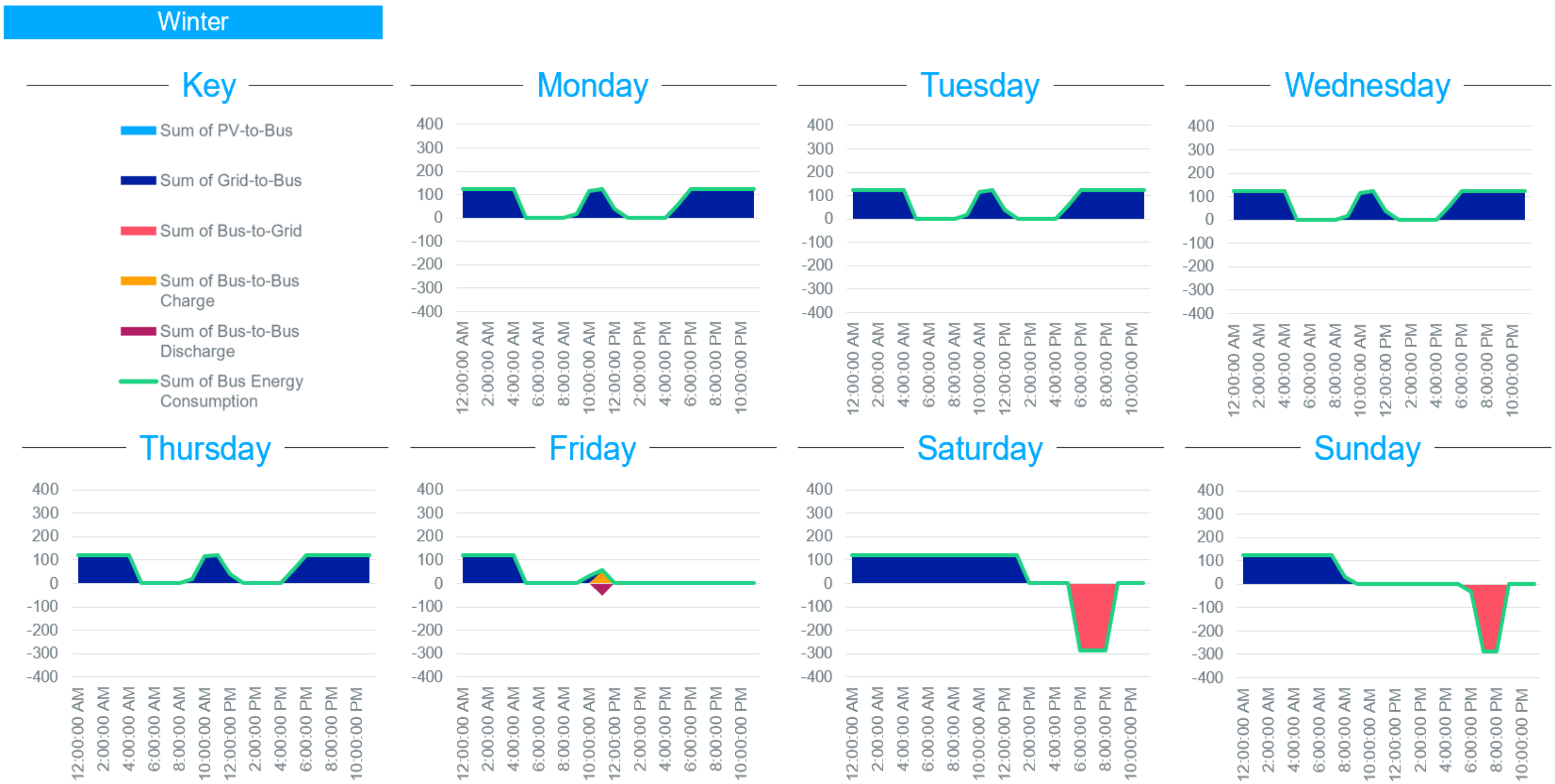


Figure 70: Energy Flows for Phase 4b Scenario 2 – Winter

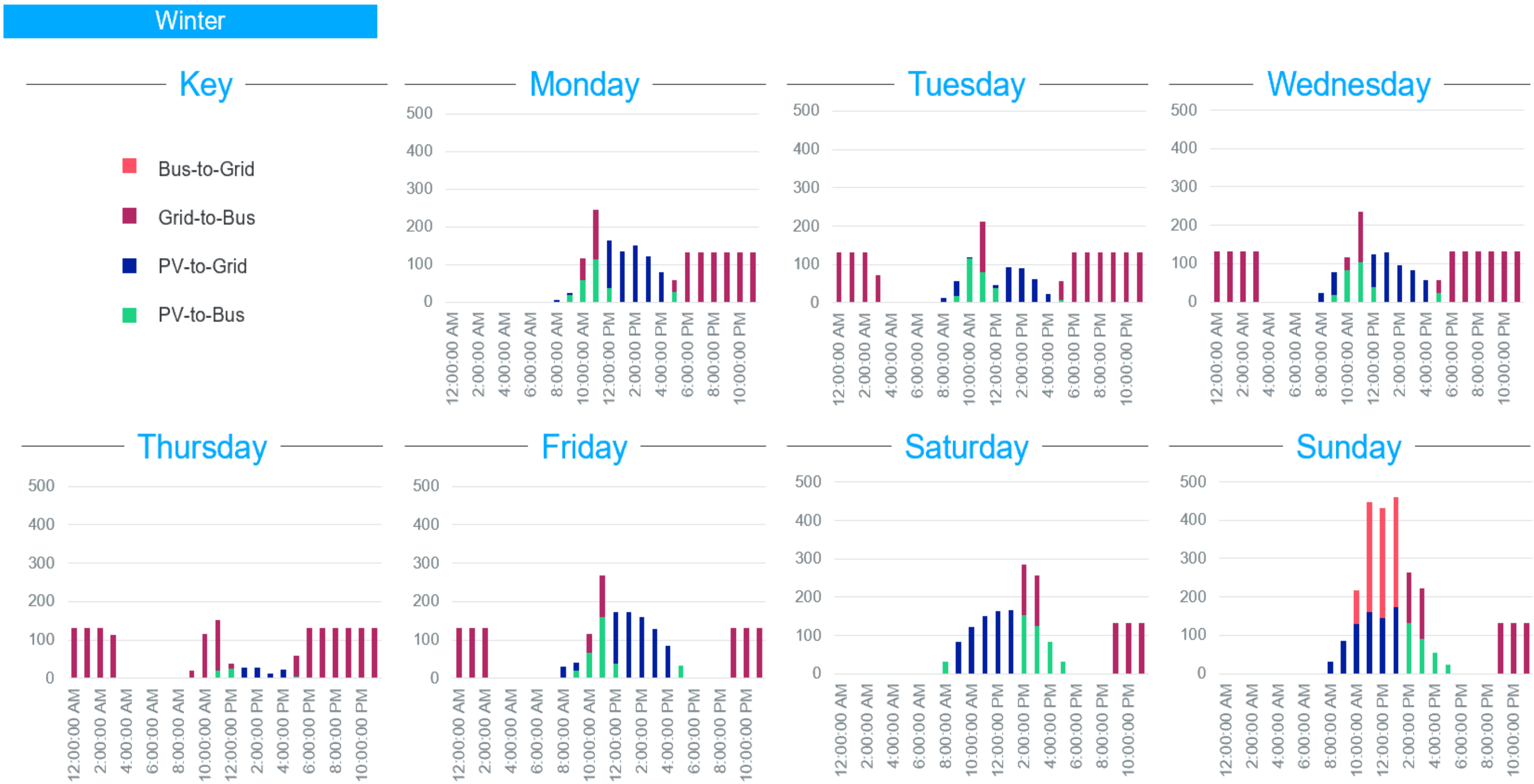


Figure 71: Charging Profiles for Phase 4b Scenario 2 – Winter

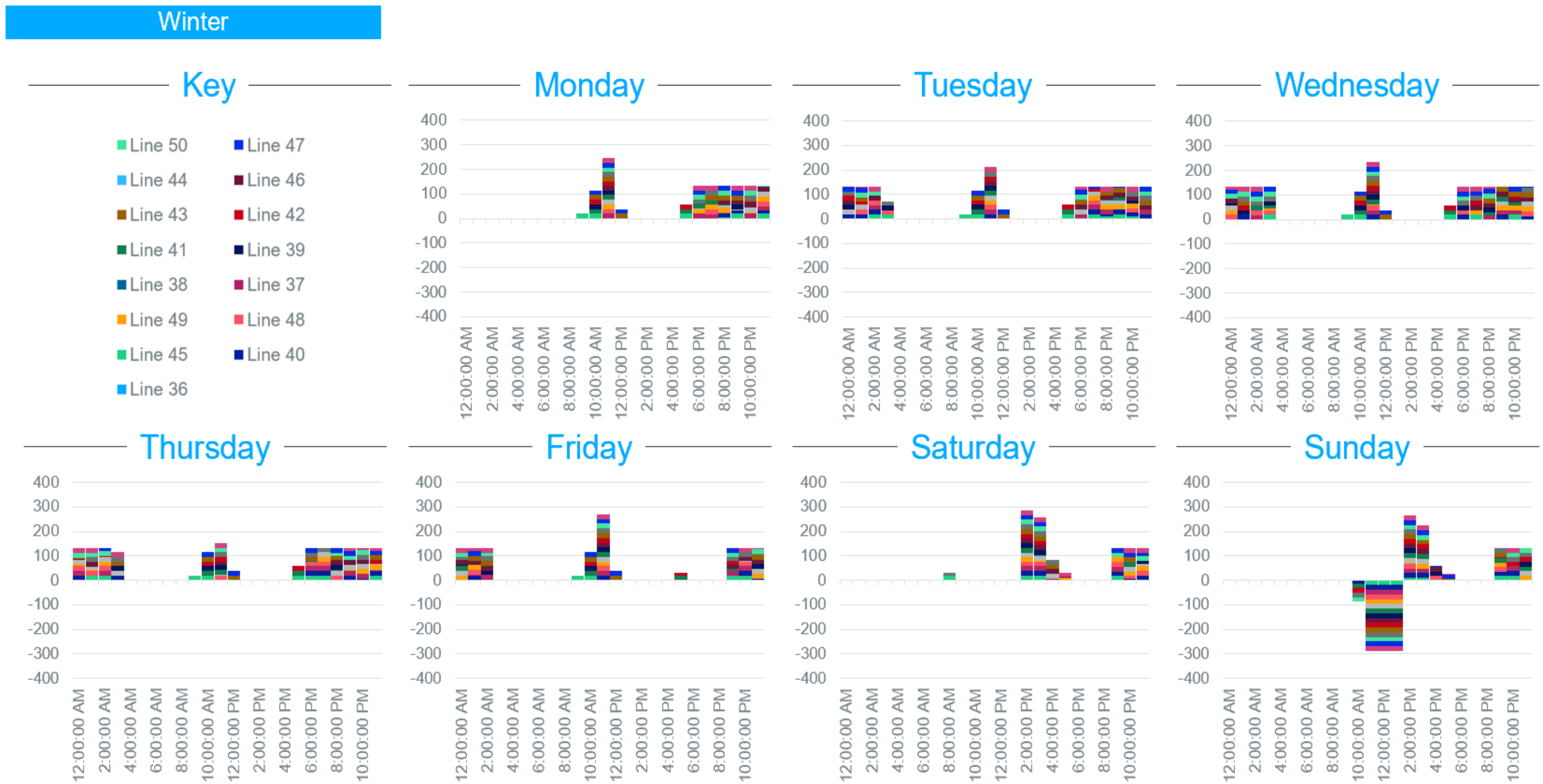


Figure 72: Sources of Energy for Bus Charging in Phase 4b Scenario 2 – Winter

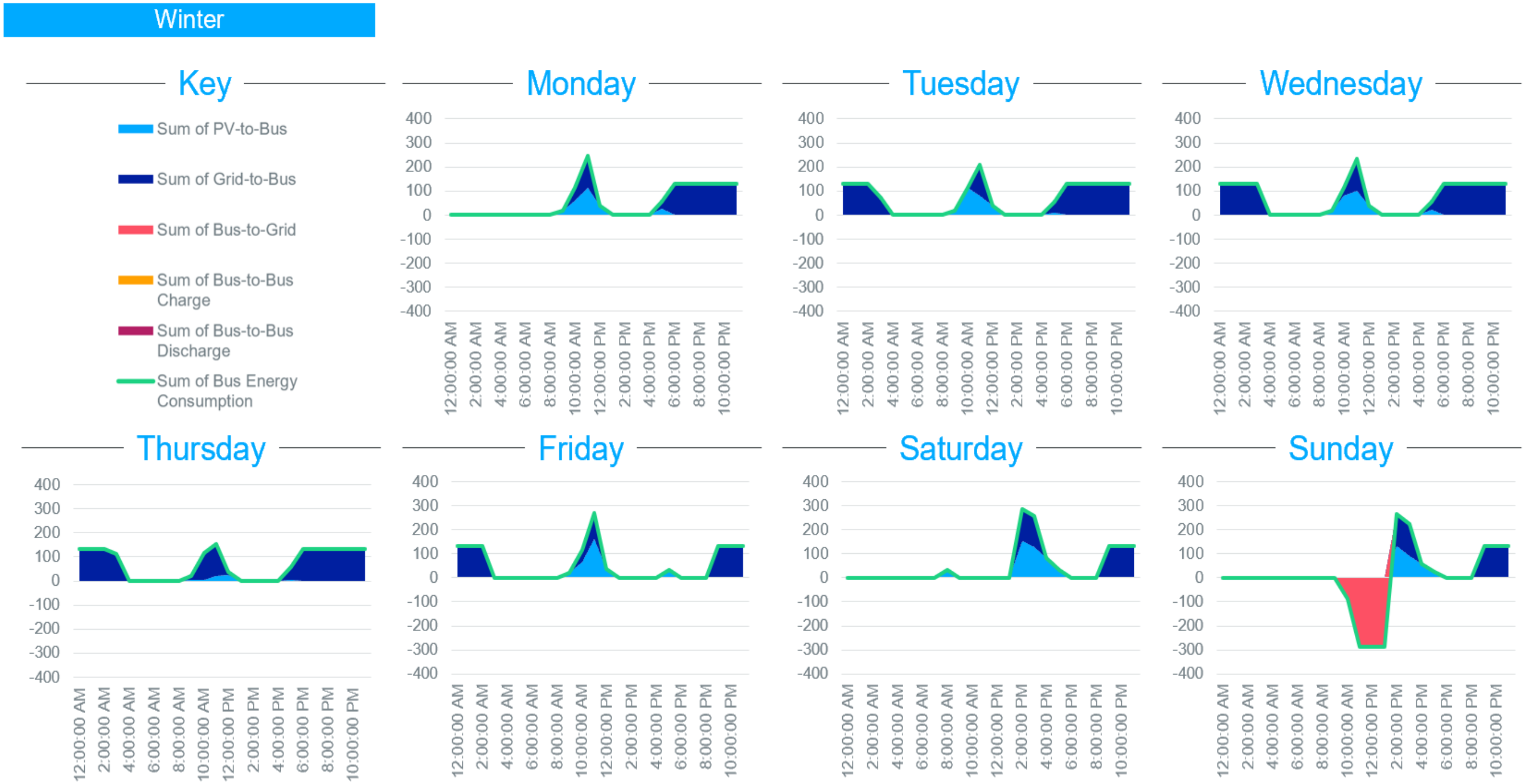


Figure 73: Energy Flows for Phase 4b Scenario 3 – Winter

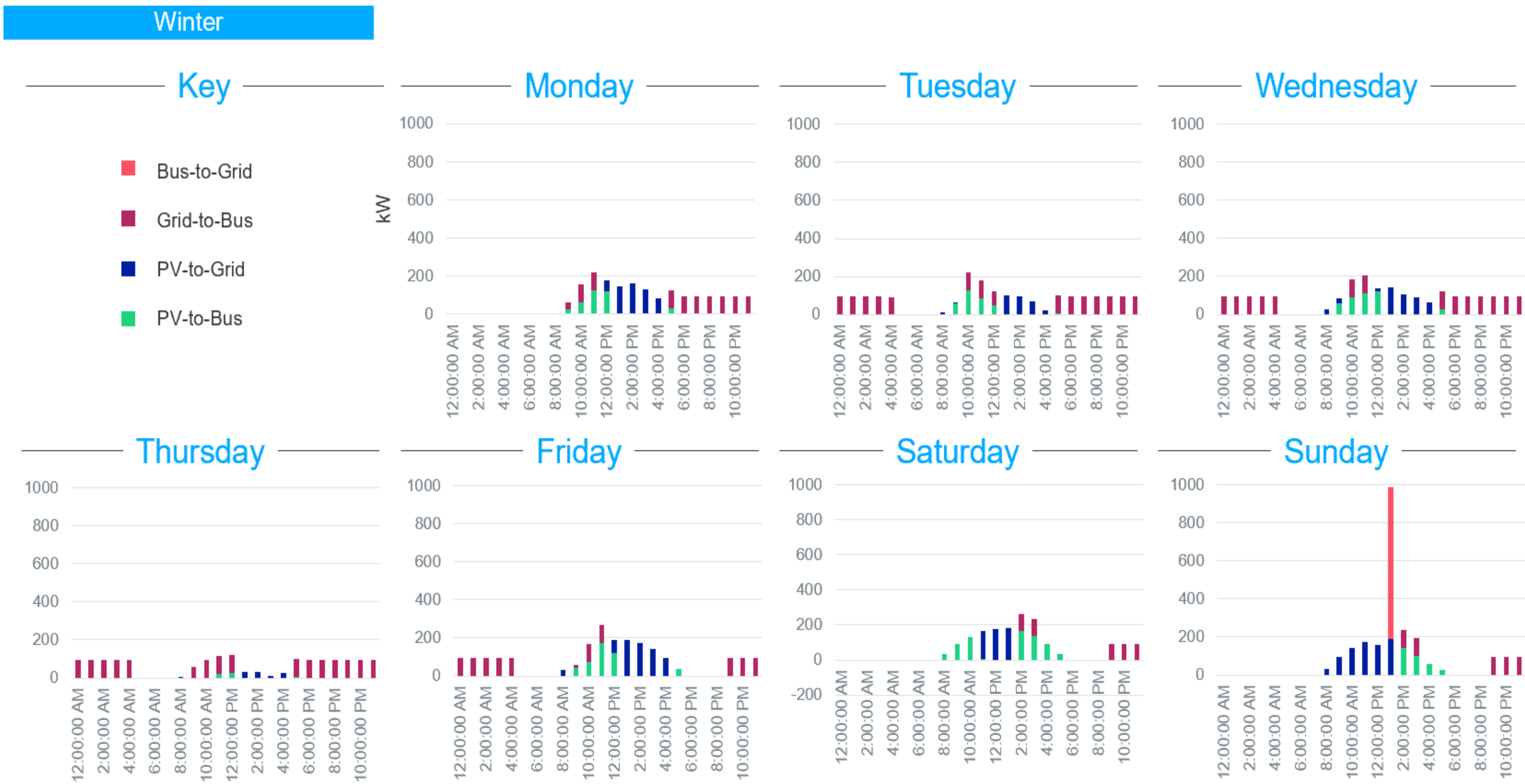


Figure 74: Charging Profiles for Phase 4b Scenario 3 – Winter

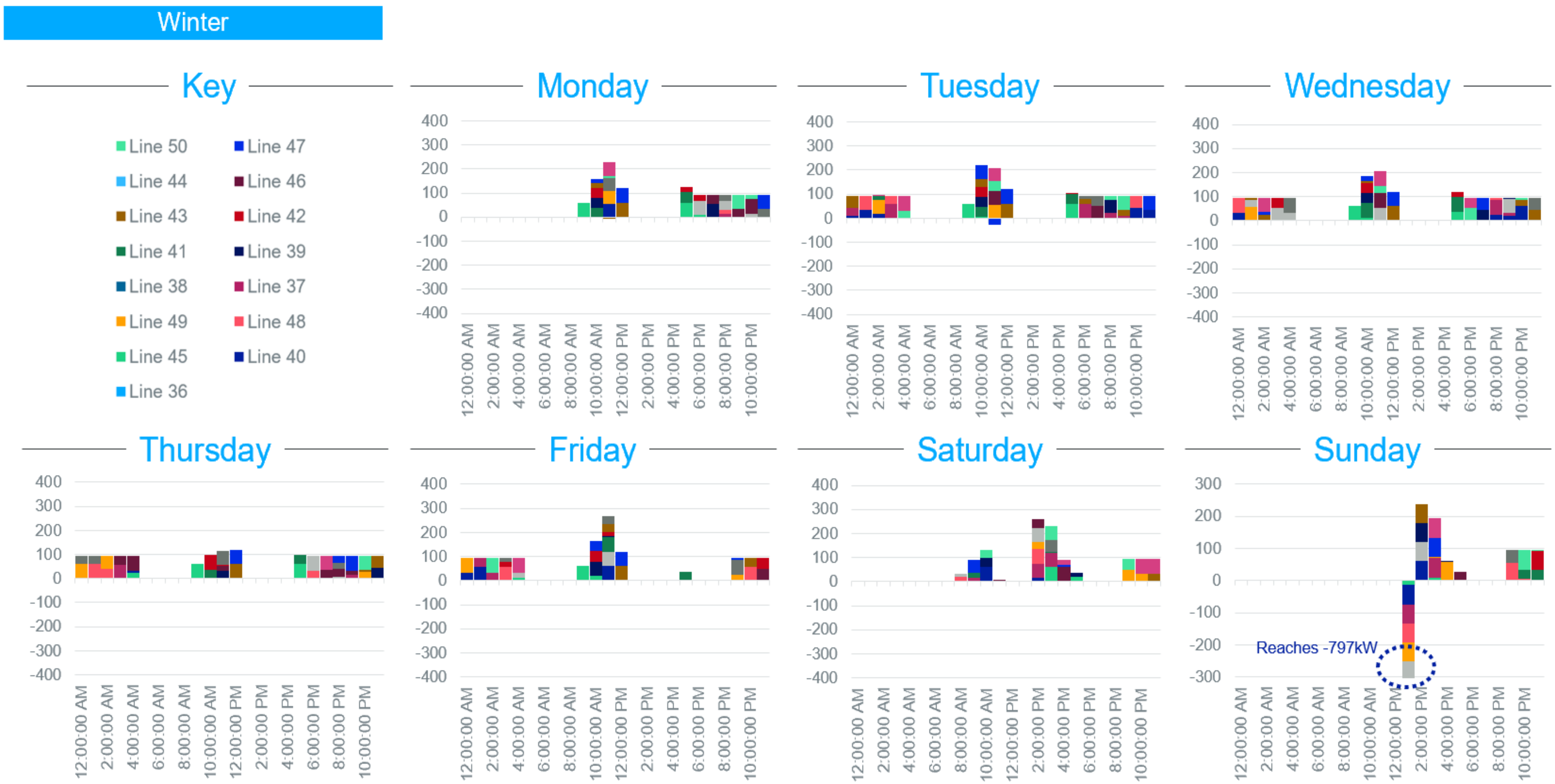


Figure 75: Sources of Energy for Bus Charging in Phase 4b Scenario 3 – Winter