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 2: Essential Electrification of Existing 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 school bus fleet at Grossmont Union High School District (GUHSD) 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 eliminating students' exposure to harmful pollutants. This blueprint will also inform the District'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 2 in the original application's Scope of Work.

Task 2. Essential Electrification of Existing School Bus Service: The goal of this task is to conduct a thorough technical, environmental, and economic analysis to transition the existing school bus fleet from diesel to electric. This includes optimal selection and sizing of electric school buses, charging infrastructure, needed grid capacity, and distributed energy resources (DERs); evaluation of total cost of ownership (TCO); and analysis of CO2 emissions reduction and other environmental benefits.

- Task 2.1. Identify, engage with, and secure the alignment of key decision-making and advisory stakeholders on objectives, responsibilities, processes, and timeline.
- Task 2.2. Collect all data inputs needed to run an energy-mobility optimization for fleet electrification, from various sources including from stakeholder engagement in Task 2.1.
- Task 2.3. Design and run the optimization process; describe how digital tools use technical, economic, and environmental data to select best electrification options.
- Task 2.4. Synthesize, document, and report on the methods, results, recommendations, and insights from the optimization analysis to electrify the existing fleet.

SECTION 2. METHODOLOGY

Stakeholder Engagement

Throughout the project, communication with stakeholders has been a priority. Engaged stakeholders fall under three categories:

- Decision-making stakeholders
    - Katy Wright: Executive Director of Facilities at GUHSD
    - 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. Stakeholders remain actively involved with the ENGIE Impact team to ensure coordination across all planning efforts and to support with relevant data and assumptions about GUHSD's fleet.
- Advisory stakeholders
    - Students and teachers from GUHSD:
        - 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 occurs on an almost monthly basis in virtual, hour-long town hall sessions. The objective of these sessions is 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.
- Dialogue with these stakeholders occurs via emails and phone calls as needed. The objective of these discussions is 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 are 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.

Digital Tools & Modeling Approach: Prosumer

The analysis is 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 leverages extensive up-to-date databases to select the optimal electric buses, charging stations, and distributed energy resources (DERs) from a variety of commercial 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 the whole fleet over a project lifetime of 20 years. This means having the optimal number and model of electric buses, as well as the number, location, and scheduling of mobility routes. From a charging infrastructure perspective, this means determining the optimal number of chargers, mix of charger types, and integration of charging with energy supply from the grid and/or distributed energy resources (DERs). To conduct the analysis, we split the routes into four distinct groups, reflecting the order in which they will be replaced, with each group containing between 10 and 20 vehicles.

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.

The implementation of vehicle electrification in Phase 1 is already underway, with vendor selection and procurement processes currently active and soon to be complete. Therefore, 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 earlier in the year.

This analysis focuses on modeling the future electrification of vehicles within Phases 2 through 4, for a total of 50 routes. The vehicle breakdown is as follows:

- Phase 2: 10 buses
- Phase 3: 11 buses
- Phase 4: 29 buses

The modeling for phase 4 is split into two groups: 4a with 14 buses, and 4b with 15 buses.

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 commercially available 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

Bus Routes & Schedules

- Each GUHSD bus route is assigned a dedicated bus. Each bus falls under one of three size categories: Large; Medium; Small. The assigned bus size is dependent on the typical number of students that this route has historically served.
- An hour-by-hour weekly schedule exists for each bus route (*Table 1*). Weekly schedules are repeated every week throughout the year, including during the summer. Since no specific data was available for summer schedules, weekly bus schedules are assumed to be the same during “winter” (Nov-May) and “summer” (June-Oct) seasons (definition of seasons is consistent with and based on SDG&E billing rates). This is a conservative assumption, yielding an overestimation of the energy and other operational expenses for the fleet.
- GUHSD is developing a new, state-of-the-art transportation hub to ensure reliable and clean fleet services for students across the district. When buses are not serving their route, they are available to charge at the bus depot. Each bus has a dedicated parking spot and charging spot.
- Conservative charging times have been adopted for each bus route. For example, a one-hour buffer after each trip as well as a one-hour buffer before the afternoon trip are assumed, in order to account for potential delays in trip start and end times. This conservative assumption reduces the time available for bus charging.
- Buses are required to be at least 90% charged by 5:00 am each day, Monday through Friday. Furthermore, buses should be at least 10% charged at any point in time. These constraints on state-of-charge (SOC) are imposed both to ensure robust operations and to adhere to manufacturers’ recommendations around the battery’s healthy state-of-charge (SOC).

Bus Technology

- For this analysis, ENGIE Impact leverages its extensive database of electric vehicles, including electric school buses, updating information where needed to track evolution in product offerings and specifications in the market (*Table 2*).
- Overall, this analysis considers 19 different electric bus models, which can be used over the next 20 years to replace existing diesel buses within GUHSD’s fleet.
- All bus models are assumed to be compatible with Alternating Current (AC) Level 2 and Direct Current Fast Charging (DCFC) , which is predominantly true today. Bus models are continuously and rapidly improving to accommodate both options. In line with US standards, the maximum

AC Level 2 charging rate is assumed 19.2kW, which is predominantly the case today.

- All buses have a lifetime shorter than 20 years and need to be replaced at some point during the project. The residual value of the last replacement bus at the end of the project is discounted from the total cost.
- A constant annual battery degradation is assumed for each bus.
- Current seat capacities for buses were considered to be a firm constraint. That is to say, buses with smaller seat capacities than those currently operating on a route were not considered to be sufficient to serve that route.
- Operational expenses (OPEX) – the annual costs associated with operating the electric school bus fleet – are not accounted for due to data limitations. Costs that fall under OPEX are, for example, maintenance and replacement parts like tires. Overall, OPEX is relatively low for electric vehicles. Furthermore, we assume that OPEX is relatively consistent and comparable across all bus models, so it does not impact the selection of optimal bus technology.

Table 1: Sample of Bus Route Schedule

Bus Route	**Line 1**	**Line 2**	**Line 3**	**Line 4**
Bus size	**Med/Large**	**Small**	**Small**	**Small**
12:00 am	Available to charge	Available to charge	Available to charge	Available to charge
1:00 am	Available to charge	Available to charge	Available to charge	Available to charge
2:00 am	Available to charge	Available to charge	Available to charge	Available to charge
3:00 am	Available to charge	Available to charge	Available to charge	Available to charge
4:00 am	Available to charge	Available to charge	Available to charge	Available to charge
5:00 am	Buffer	Buffer	Buffer	Buffer
6:00 am	Out	Out	Out	Out
7:00 am	Out	Out	Out	Out
8:00 am	Out	28	32	22
9:00 am	28	Buffer	Buffer	Buffer
10:00 am	Buffer	Available to charge	Available to charge	Available to charge
11:00 am	Available to charge	Available to charge	Available to charge	Available to charge
12:00 pm	Buffer	Buffer	Buffer	Buffer
1:00 pm	Out	Out	Out	Out
2:00 pm	Out	Out	Out	Out
3:00 pm	Out	38	Out	22
4:00 pm	32	Buffer	34	Buffer
5:00 pm	Buffer	Available to charge	Buffer	Available to charge
6:00 pm	Available to charge	Available to charge	Available to charge	Available to charge
7:00 pm	Available to charge	Available to charge	Available to charge	Available to charge
8:00 pm	Available to charge	Available to charge	Available to charge	Available to charge
9:00 pm	Available to charge	Available to charge	Available to charge	Available to charge
10:00 pm	Available to charge	Available to charge	Available to charge	Available to charge
11:00 pm	Available to charge	Available to charge	Available to charge	Available to charge

Table 2: Bus Technology Database

OEM	Model	Seat Capacity	Range (miles)	Battery Capacity (kWh)	Max L2 Charging (kW)	Max DCFC Charging (kW)	CAPEX ($)	Lifetime (Yr)
Blue Bird	All American	84	120	155	19.2	60	*	*
	Vision Electric	77	120	155	19.2	60	*	*
	Micro Bird	30	80	88	19.2	60	*	*
Motiv & Collins	Type A	24	105	127	19.2	60	*	*
Motiv and Starcraft Bus	Type C eQuest	20	105	127	19.2	60	*	*
Lion Electric Company	LionA1	24	75	84	19.2	50	*	*
	LionA2	24	150	168	19.2	50	*	*
	LionC1	77	100	126	19.2	50	*	*
	LionC2	77	125	168	19.2	50	*	*
	LionC3	77	155	210	19.2	50	*	*
	LionD1	61	100	132	19.2	50	*	*
	LionD2	83	125	168	19.2	50	*	*
	LionD3	83	155	210	19.2	50	*	*
GreenPower Motor Company	Beast	90	150	194	19.2	100	*	*
Proterra and Thomas Buses	C2 Jouley.1	54	138	226	19.2	60	*	*
	C2 Jouley.2	81	138	226	19.2	60	*	*
IC Buses	CE1 Electric	52	135	210	19.2	125	*	*
	CE2 Electric	72	135	210	19.2	125	*	*
	CE3 Electric	72	200	315	19.2	125	*	*

** Information redacted for confidentiality*

EVSE (EV Charging Stations) Technology

- For this analysis, ENGIE Impact leveraged its extensive database of electric vehicle charging infrastructure, updating information where needed to track evolution in product offerings and specifications in the market (*Table 3*).
- Overall, this analysis considers 22 different EV charging station models with a wide range of maximum charging rates, which can be used over the next 20 years for bus charging.
- It is assumed that all charging station models are compatible with all bus models. While most manufactures believe this is the case, this has not always been proven.
- All charging stations have a lifetime shorter than 20 years and need to be replaced at some point during the project. The residual value of the last replacement charging station at the end of project is discounted from the total cost.

Table 3: EVSE Technology Database

OEM	Model	Charging Level (L2 vs DCFC)	Charging Station (kW)	Number of Ports	CAPEX (Station Only) ($)	Total OPEX ($/Yr)	Lifetime (Yr)
EVBox	Business Line	L2	7.7	1	*	*	*
	Business Line	L2	7.7	2	*	*	*
	Troniq	DCFC	100	1	*	*	*
ClipperCreek	CS 60	L2	11.52	1	*	*	*
	CS 100	L2	19.2	1	*	*	*
ABB	Terra 54	DCFC	50.0	2	*	*	*
	Terra DC Wallbox	DCFC	22.5	1	*	*	*
	HVC-150	DCFC	150.0	1, 2 or 3	*	*	*
	Terra 94	DCFC	90.0	1	*	*	*
	Terra 175 HP	DCFC	175.0	2	*	*	*
	Terra 350 HP	DCFC	350.0	2	*	*	*
Proterra	60 kW System	DCFC	60	1	*	*	*
	90 kW System	DCFC	90	4	*	*	*
	120 kW System	DCFC	120	4	*	*	*
	150 kW System	DCFC	150	4	*	*	*
	180 kW System	DCFC	180	4	*	*	*
	240 kW System	DCFC	240	4	*	*	*
Nuvve	AC Powerport	L2	19.2	1	*	*	*
In-Charge	30 kW System	DCFC	30	1	*	*	*
Blink	IQ200	L2	19.2	1	*	*	*
	50 kW System	DCFC	50	1	*	*	*
	75 kW System	DCFC	75	1	*	*	*

** Information redacted for confidentiality*

- Capital expenditures (CAPEX) – defined as the cash paid to buy physical assets – for the charging stations does not account for EPC (engineering, procurement, and construction) costs and only includes the cost to purchase the charging stations. EPC costs vary widely and are hard to estimate without detailed site inspection. The team assumes that EPC costs are relatively consistent and comparable across EV charging stations of similar charging rates (AC L2 vs. DCFC), so it does not impact the selection of optimal EV charging station technology.

- The total OPEX includes charging station service and maintenance, as well as networking fees for smart/managed charging.

Solar and Battery Technology

- A solar irradiance profile[1,2] 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.
- Cost estimates related to both onsite solar PV systems and battery storage 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 DERs vs. utility rates from the grid (*Table 4*).
- We consider a total of 6 categories of onsite solar PV options and 2 categories of battery energy storage options; the categorization is based on the type and the scale of the system (*Table 4*).
- Consistent with reformed net-energy-metering and DER interconnection rules in California, an onsite battery storage system can be charged by solar and can discharge to the grid, but the battery storage system cannot be charged by the grid[3,4].

Table 4: Solar and Storage Technology Database

Technology	Model	Size (kW)	CAPEX ($/kWh)	CAPEX ($/kWp)	Total OPEX ($/kWp/Yr)	Lifetime (Yr)
Solar	Rooftop	< 500 kW	*	*	*	*
		500 kW - 1,000 kW	*	*	*	*
		> 1,000 kW	*	*	*	*
	Canopy	< 500 kW	*	*	*	*
		500 kW - 1,000 kW	*	*	*	*
		> 1,000 kW	*	*	*	*
Battery Storage	--	< 2,000 kWh	*	*	*	*
	--	> 2,000 kWh	*	*	*	*

** Information redacted for confidentiality*

Time-of-Use Utility Rates

- Electricity cost for EV charging is calculated based on SDG&E EV-HP billing rate (*Table 5*). 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). SDG&E has released two estimated billing rates: the first starts in January 2022 and will last for the following three years;

[1] 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)
[2] PVWatts Calculator by NREL: https://pvwatts.nrel.gov/pvwatts.php
[3] Credit Cap | San Diego Gas & Electric (sdge.com)
[4] https://www.solarpowerworldonline.com/2020/04/energy-storage-net-metering-an-illustration-of-why-its-so-valuable/

a second rate will likely take effect 11 years after that.

- 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 1-3), and Rate 2 (beyond year 11) (*Table 6*). Although energy prices and utility billing rates for EV charging will likely continue to evolve over time, it is hard to estimate price variation. SDG&E has been actively involved in planning discussions with both GUHSD and ENGIE Impact.
- Only EV charging load is accounted for in this analysis, assuming it will be on a separate dedicated meter. Building or facility load is not included.
- The cost of grid upgrades is assumed to be zero, to be covered for free by SDG&E as part of the Power Your Drive for Fleets program and other similar future programs.

Table 5: SDG&E EV-HP Time-of-Use Rate – Year 1-3 and Year 11+

	Utility Billing Rate 1: Year 1-3				Utility Billing Rate 2: Year 11+			
	Summer		Winter		Summer		Winter	
Hour	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
12:00 am	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.16	$ 0.16	$ 0.14	$ 0.14
1:00 am	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.14	$ 0.14	$ 0.14	$ 0.14
2:00 am	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.14	$ 0.14	$ 0.14	$ 0.14
3:00 am	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.14	$ 0.14	$ 0.14	$ 0.14
4:00 am	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.14	$ 0.14	$ 0.14	$ 0.14
5:00 am	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.14	$ 0.14	$ 0.14	$ 0.14
6:00 am	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
7:00 am	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
8:00 am	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
9:00 am	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
10:00 am	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
11:00 am	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
12:00 pm	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
1:00 pm	$ 0.12	$ 0.10	$ 0.11	$ 0.10	$ 0.16	$ 0.14	$ 0.15	$ 0.14
2:00 pm	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.16	$ 0.16	$ 0.15	$ 0.15
3:00 pm	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.16	$ 0.16	$ 0.15	$ 0.15
4:00 pm	$ 0.19	$ 0.19	$ 0.18	$ 0.18	$ 0.37	$ 0.37	$ 0.35	$ 0.35
5:00 pm	$ 0.19	$ 0.19	$ 0.18	$ 0.18	$ 0.37	$ 0.37	$ 0.35	$ 0.35
6:00 pm	$ 0.19	$ 0.19	$ 0.18	$ 0.18	$ 0.37	$ 0.37	$ 0.35	$ 0.35
7:00 pm	$ 0.19	$ 0.19	$ 0.18	$ 0.18	$ 0.37	$ 0.37	$ 0.35	$ 0.35
8:00 pm	$ 0.19	$ 0.19	$ 0.18	$ 0.18	$ 0.37	$ 0.37	$ 0.35	$ 0.35
9:00 pm	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.16	$ 0.16	$ 0.15	$ 0.15
10:00 pm	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.16	$ 0.16	$ 0.15	$ 0.15
11:00 pm	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.16	$ 0.16	$ 0.15	$ 0.15

Tiered Net Energy Metering (Tiered NEM) [5]

- Net-energy-metering (NEM) is a utility-billing accounting mechanism that allows utility customers with on-site solar to offset the electricity they draw from the grid throughout a specific billing cycle. GUHSD pays for the net energy consumed from the utility grid.
- Throughout the year, GUHSD can use the electricity produced by the onsite solar and storage system in two ways: either directly to charge the electric buses, or indirectly by feeding it to the grid and receiving credit. If GUHSD uses more electricity for bus charging than their solar system produces, they import electricity from the grid, and pay the full retail rate for that electricity. If the amount of solar electricity generation exceeds the amount of electricity needed for EV charging, the excess amount is exported to the grid in exchange for credit valued at the

[5] https://www.nrel.gov/state-local-tribal/basics-net-metering.html

retail rate as well (*Table 5*).

- GUHSD is compensated for excess electricity exports to the grid on a per kilowatt-hour (kWh) basis. At the end of the monthly billing cycle, GUHSD's charges for energy imported are netted against credits for energy exported. This netting occurs in three distinct tiers, consistent with the TOU billing rate structure. Specifically, charges from super-off-peak periods can be offset by credits generated only during super-off-peak periods; the same applies to off-peak and on-peak tiers.
- Within each NEM tier, GUHSD can carry the net-positive credits balance forward into future billing cycles (i.e., a rollover credit) for a total duration of one calendar year. At the end of each year, the remaining credit balance will be zeroed out and the process will start over.
- For modeling purposes, the reseller rate is assumed to be the price to purchase one kWh of energy from the grid during a given season and tier, less $0.01. This prevents excessive investment in solar to exploit arbitrage opportunities.

Table 6: Average SDG&E EV-HP Time-of-Use Rate and NEM Retail Reseller Rate

	Average Utility Billing Rate				NEM Resell Rate			
	Summer		Winter		Summer		Winter	
Hour	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
12:00 am	$ 0.12	$ 0.12	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.11	$ 0.11
1:00 am	$ 0.12	$ 0.12	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.11	$ 0.11
2:00 am	$ 0.12	$ 0.12	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.11	$ 0.11
3:00 am	$ 0.12	$ 0.12	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.11	$ 0.11
4:00 am	$ 0.12	$ 0.12	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.11	$ 0.11
5:00 am	$ 0.12	$ 0.12	$ 0.12	$ 0.12	$ 0.11	$ 0.11	$ 0.11	$ 0.11
6:00 am	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
7:00 am	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
8:00 am	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
9:00 am	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
10:00 am	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
11:00 am	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
12:00 pm	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
1:00 pm	$ 0.14	$ 0.12	$ 0.13	$ 0.12	$ 0.13	$ 0.11	$ 0.12	$ 0.11
2:00 pm	$ 0.14	$ 0.14	$ 0.13	$ 0.13	$ 0.13	$ 0.13	$ 0.12	$ 0.12
3:00 pm	$ 0.14	$ 0.14	$ 0.13	$ 0.13	$ 0.13	$ 0.13	$ 0.12	$ 0.12
4:00 pm	$ 0.28	$ 0.28	$ 0.27	$ 0.27	$ 0.27	$ 0.27	$ 0.26	$ 0.26
5:00 pm	$ 0.28	$ 0.28	$ 0.27	$ 0.27	$ 0.27	$ 0.27	$ 0.26	$ 0.26
6:00 pm	$ 0.28	$ 0.28	$ 0.27	$ 0.27	$ 0.27	$ 0.27	$ 0.26	$ 0.26
7:00 pm	$ 0.28	$ 0.28	$ 0.27	$ 0.27	$ 0.27	$ 0.27	$ 0.26	$ 0.26
8:00 pm	$ 0.28	$ 0.28	$ 0.27	$ 0.27	$ 0.27	$ 0.27	$ 0.26	$ 0.26
9:00 pm	$ 0.14	$ 0.14	$ 0.13	$ 0.13	$ 0.13	$ 0.13	$ 0.12	$ 0.12
10:00 pm	$ 0.14	$ 0.14	$ 0.13	$ 0.13	$ 0.13	$ 0.13	$ 0.12	$ 0.12
11:00 pm	$ 0.14	$ 0.14	$ 0.13	$ 0.13	$ 0.13	$ 0.13	$ 0.12	$ 0.12

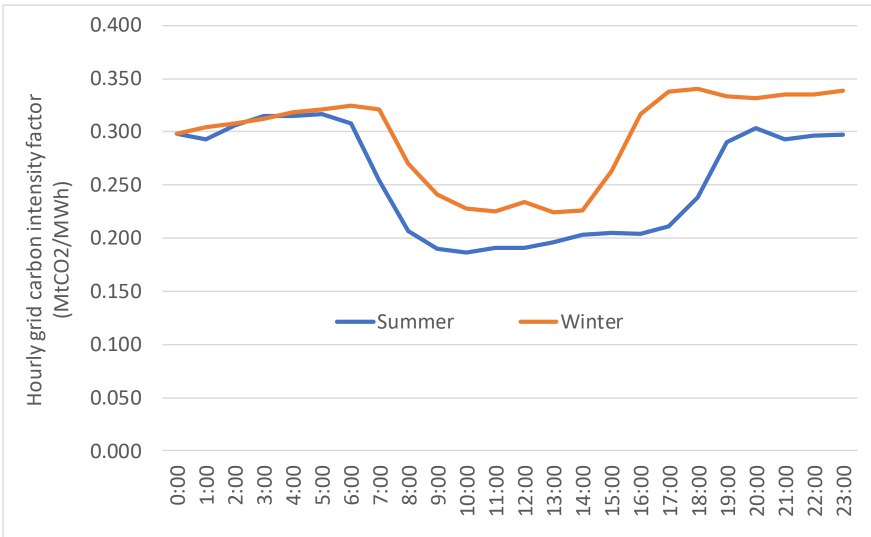
Greenhouse Gas (GHG) Emissions

One of the primary drivers for transitioning to electric bus fleet is reducing greenhouse gas (GHG) emissions and their associated environmental and health impacts. 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 renewable energy.

- The GHG emissions from the diesel fleet is computed based on a constant GHG emissions factor for diesel powered buses, assumed to be 2,680 grams of CO2 equivalent per mile (gCO2e/mile).[6]

- The GHG emissions from the electric fleet is computed based on an hourly average carbon intensity factor for the electricity mix fueling the buses. The average carbon intensity factor for the electricity mix takes into account the fraction of electricity coming from the grid as well as the fraction of electricity coming from onsite solar PV.
- The hourly carbon intensity of grid electricity is based on granular data documented by CAISO. We use the data for 07/15/2020 as representative of the carbon intensity for grid electricity during “summer” period and the data for 01/15/2020 as representative of the carbon intensity for grid electricity during “winter” season (*Figure 1*). Our analysis does not take into account the progressive increase in renewables penetration on the California grid, year after year. In addition, given that most of California’s fossil-fuel electricity generation comes from natural gas with low NOx, Sox, and PM emissions, CO2 is the only greenhouse gas accounted for in electricity fueling.
- The carbon intensity of onsite solar PV electricity is assumed to be zero.

Figure 1: Average Daily Grid Carbon Intensity



[6] https://www.ucsusa.org/sites/default/files/attach/2019/04/Electric-Utility-Investment-Truck-Bus-Charging.pdf

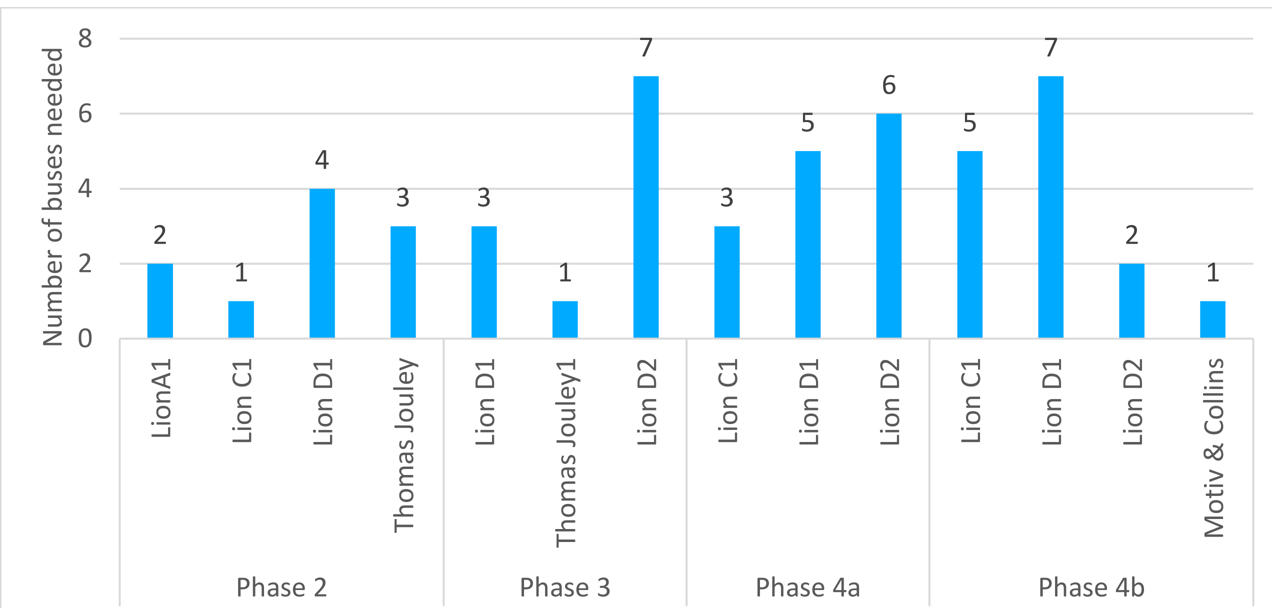
SECTION 3. RESULTS

The analysis identifies the optimal number and sizing of the electric buses, charging stations, onsite solar PV, and battery storage systems to fulfil all mobility needs under the lowest total cost of ownership. After modeling Phases 2, 3, 4a, and 4b, a consistent pattern emerged that identified a small specific subset of buses and charging assets as optimal for GUHSD across all phases.

For buses, Prosumer selects 6 models of electric buses, four of which come from the same automaker, to meet the district's transportation needs (*Figure 2*). Specifically:

- 2 Lion A1 buses (24 seats, 84 kWh battery, 75 mile range)
- 9 Lion C1 buses (77 seats, 126 kWh battery, 100 mile range)
- 19 Lion D1 buses (61 seats, 132 kWh battery, 100 mile range)
- 15 Lion D2 buses (83 seats, 168 kWh battery, 125 mile range)
- 4 Thomas Jouley1 buses (54 seats, 226 kWh battery, 138 mile range)
- 1 Motiv & Collins bus (24 seats, 127 kWh battery, 105 mile range)

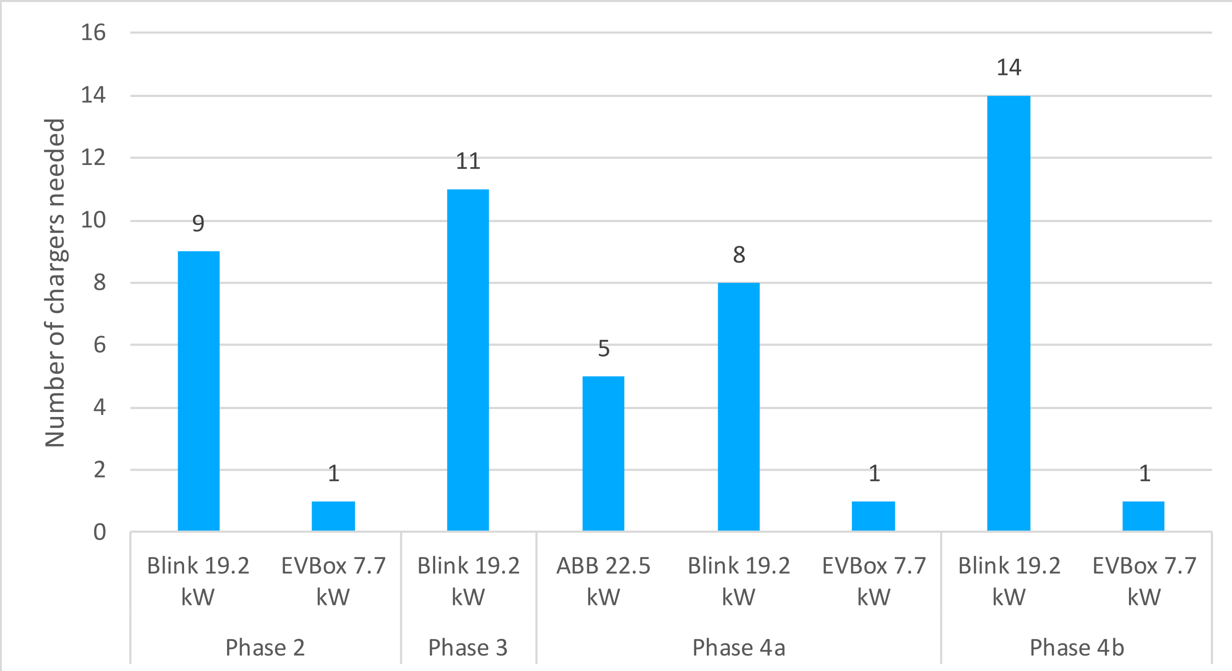
Figure 2: Recommended Number of Buses Based Off Seating Capacity



To power these buses, Prosumer selected two types of AC L2 chargers with specific maximum charging rate (*Figure 3*). As explained later, routes that were assigned 19.2 kW or 22.5 chargers are the ones where the charging schedule allows maximizing solar intake in the middle of the day.

- 42 Blink IQ200 AC L2 chargers (maximum charging rate at 19.2 kW)
- 3 EVBox BusinessLine AC L2 chargers (maximum charging rate at 7.7 kW)
- 5 ABB Terra DC Wallbox chargers (maximum charging rate of 22.5 kW)

Figure 3: Recommended Number of EVSEs Based Off Charging Capacity



In terms of energy supply, the analysis shows that charging the buses is mostly done during the day and late at night, using both the grid and onsite DERs. Roughly 24% of the total energy used to charge buses comes directly from onsite solar PV, while 76% comes from the grid – though even when charging from the grid, the vast majority of energy is from solar credits. To that end, it's optimal to install a total of 973 kW capacity of onsite rooftop solar PV to power the charging of the whole fleet in Phases 2, 3, 4a, and 4b. So long as the accounting for onsite solar generation follows Tiered NEM rules, the investment in onsite battery storage is not favorable. In essence, Tiered NEM allows using the grid as a limited virtual storage system: within each of the three tier (on-peak, off-peak, super-off-peak), credit surplus accumulated during weekends and in the summer is used to cover energy deficits and charge the buses on weekdays and in the winter.

Adding the nameplate capacity of all required charging stations show that the theoretical grid capacity needed to charge the buses is about 942 kW. However, the maximum peak load from the grid for Phases 2 through 4b does not exceed 511 kW at any point in time. This is because Prosumer models the optimal charging behavior of the whole fleet to minimize TCO, including demand charges, so not all buses will be charging at maximum rate at the same time.

The total cost of ownership for the fleet transition is about $34.5 million, which consists of $32.9 million for CAPEX and $1.6 million for OPEX. The CAPEX expenses consist of 91% electric bus, 3% charging stations, 6% onsite solar PV. The OPEX expenses consists of 71% energy supply from the grid, 13% maintenance and networking fees for the charging stations, and 16% maintenance for solar PV. As a reminder, the OPEX for buses is not accounted for due to lack of sufficient data.

Most notably, transitioning the GUHSD fleet to electric buses reduces its total GHG emissions by 86%, from 46,480 metric ton of CO2-equivalent (MtCO2e) to 6,586 MtCO2e.

Tiered NEM shifts some of the optimal charging behavior, to ensure maximum utilization of solar credits and minimum total cost of ownership. The unique impact of Tiered NEM on charging profiles is demonstrated in two primary areas. First, the fleet uses the surplus in on-peak NEM credits on weekends to allow occasional charging from the grid during on-peak periods on weekdays (later afternoon and early evening). Second, the fleet uses the surplus in off-peak NEM credits to charge from the grid on weekends, even though all charging needs on weekends can be met using onsite solar.

Optimal charging requires maximum utilization of on-peak and off-peak credits whenever possible; otherwise, they will go to waste at the end of the year.

In the following sections, we provide a more granular description of the results for each Phase of the 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 are available in the Appendix.

Phase 2

The results for optimal technology selection are as follows:

Buses: To serve the 10 routes in Phase 2, the analysis shows that the optimal bus options are

- 2 Lion A1 buses (24 seats, 84 kWh battery, 75 mile range)
- 1 Lion C1 bus (77 seats, 126 kWh battery, 100 mile range)
- 4 Lion D1 buses (61 seats, 132 kWh battery, 100 mile range)
- 3 Thomas Jouley1 buses (54 seats, 226 kWh battery, 138 mile range)

Bus selection options: Buses are by far the most significant cost item in fleet electrification, so their optimal selection is key. For each route, the electric bus is selected based on three sequential criteria. First, the bus should have sufficient mileage range. Second, among all the bus models with suitable mileage range, the buses seating capacity should be equal or closely matching (always greater than) current bus seat capacity. Finally, among all bus models with suitable range and seat capacity, select the bus that results in lowest TCO.

Table 7: Alternative Bus Options for Phase 2

Route	Best option	2nd best option	TCO increase ($)
line_1	Lion C1	Thomas Jouley2	*
line_2	Lion A1	Collins & Motive	*
line_3	Lion A1	Collins & Motive	*
line_4	Lion D1	Thomas Jouley1	*
line_5	Lion D1	Thomas Jouley1	*
line_6	Thomas Jouley1	IC Bus CE1	*
line_7	Lion D1	Thomas Jouley1	*
line_8	Thomas Jouley1	IC Bus CE1	*
line_9	Lion D1	Thomas Jouley1	*
line_10	Thomas Jouley1	IC Bus CE1	*

** Information redacted for confidentiality*

- By following this process, many of the GUHSD buses have to be upgraded to larger buses with more seat capacity. For example, 28-seat and 42-seat diesel buses are replaced with 61-seat electric buses.
- The Table below (*Table 7*) provides further alternatives for GUHSD for bus selection, presenting second-best options from other vendors/automakers that meet range and seat capacity but

result in higher TCO.

Chargers: To charge the buses in Phase 2, the optimal options are

- 9 Blink IQ200 with maximum charging rate of 19.2 kW
- 1 EVBox BusinessLine with maximum charging rate of 7.7 kW

Onsite DERs: In Phase 2, we see the investment in 181 kW rooftop PV system. The solar system produces about 246 MWh every year. About 28% of the solar energy is directly used for bus charging, while the remaining 72% 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 181 kW. However, the maximum peak load on the grid does not exceed 93 kW at any point in time. This is because the optimal charging behavior relies on high level of charging from solar PV in the middle of the day, while spreading charging throughout the remainder of the day to minimize energy costs and demand charges; not all buses charge at maximum rate at the same time.

Economics: The total cost of ownership for the electric fleet in Phase 2 over 20 years is detailed in *Table 8* below.

Table 8: Total Cost of Ownership for Phase 2

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	90.9%
Charging Stations – CAPEX	*	2.6%
Charging Stations – OPEX	*	0.6%
Solar PV – CAPEX	*	2.7%
Solar PV – OPEX	*	0.3%
Battery storage – CAPEX	*	0.0%
Battery Storage – OPEX	*	0.0%
Grid energy supply – OPEX	*	2.9%

** Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 2 from diesel to electric reduces 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 1,196 MtCO2, compared to an estimate of 8,230 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. Furthermore, the nearly 1,196 MtCO2 factors in only 28% 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.

Optimal Charging

Energy flows: *Figure 4* shows all seven energy flows in and out of the system, on daily basis over the 28^{th} week of the summer season. The results show how 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. Grid electricity is used to fulfill remaining charging needs after midnight, and in the evening when needed.

Charging profiles: *Figure 5* and *Figure 6* focus on the bus charging profiles. *Figure 5* shows the stack of charging profiles for every bus in Phase 2, and *Figure 6* shows the sources of electricity used to charge these buses. Some key takeaways:

- Charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. To optimize charging profiles, buses charge during multiple periods on weekdays and weekends.
- During weekdays, bus charging occurs during three time periods: after midnight and through the early morning hours, in the middle of the day after the morning trips, and occasionally also in the evening after the afternoon trips. Throughout the year, maximum charging rate reaches 181 kW, with peak load from the grid at 93 kW.
    - Between 9:00 pm and 5:00 am, the buses charge consistently from the grid, benefiting from off-peak and super-off-peak rates.
    - In the middle of the day, between 10:00 am and 12:00 pm, significant amount of charging occurs. The majority of charging is enabled directly by solar PV, with additional supply from the grid at off-peak rates.
    - Occasionally, buses charge during on-peak hours between 5:00 pm and 9:00 pm, primarily due to the unique construct of Tiered NEM. To explain this in more depth: solar generation results in NEM credit surplus for the on-peak tier in two occasions: between 4:00 pm and 5:00 pm on weekdays when buses are still “out” completing their trips, as well as on Saturdays and Sundays when buses do not need to charge in the afternoon. That credit surplus is then depleted during weekdays between 5:00 pm and 8:00 pm when buses are back to depot and ready to charge. 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 solar generation and the Tiered NEM construct.
- On weekends (Satuday and Sunday), the buses continue to charge in the afternoon from both solar and the grid. While all charging can be fulfilled by daytime solar, optimal charging requires that the buses also use grid electricity, during off-peak period. The reason for that is also uniquely attributed to the Tiered NEM construct. The supply of energy from the grid on weekends allows consuming the surplus in NEM credits during the off-peak period.

Buses’ State of Charge: The state of charge (SoC) for all the buses in the fleet follow a similar pattern, regardless of the size of bettery (*Figure 7*).

- As previoulsy noted, charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. Similarly, at no point in time will buses fall between a 10% SoC, providing a energy buffer in case of emergency.
- During the middle of the day, in between the morning and afternoon trips, all buses charge for at least one hour.

NEM Credit Balance:

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of solar credits and minimum total cost of ownership. Of the total 246 MWh of electricity generated by the PV system each year, about 68 MWh are used to directly charge the buses and 178 MWh are fed into the grid to generate NEM credits.
- As shown in *Figure 8*, those credits fall under the three tiers: 18 MWh on-peak, 112 MWh off-peak, and 48 MWh super-off-peak. Optimal charging requires energy credits to balance energy expense in each tier as closely as possible.
- For Phase 2, all three tiers of credits seem to be effectively balanced, ensuring maximum

utilization of credits throughout the year. Overall, there is less than 9% imbalance (surplus) in credits across all tiers for fleet charging in Phase 2. In other word, only 9% of the credits are not utilized and lost at the end of each year. The 9% lost credit is equivalent to only 6% of the total solar energy in that year.

- *Figure 9* further emphasizes the optimization of solar energy supply and consumption. Within the on-peak and off-peak tiers, only a small fraction of solar energy is not utilized. Within the super off-peak tier all solar energy is utilized (in addition to substantial amount of grid electricity).

Figure 4: Energy Flows for Phase 2 – Summer

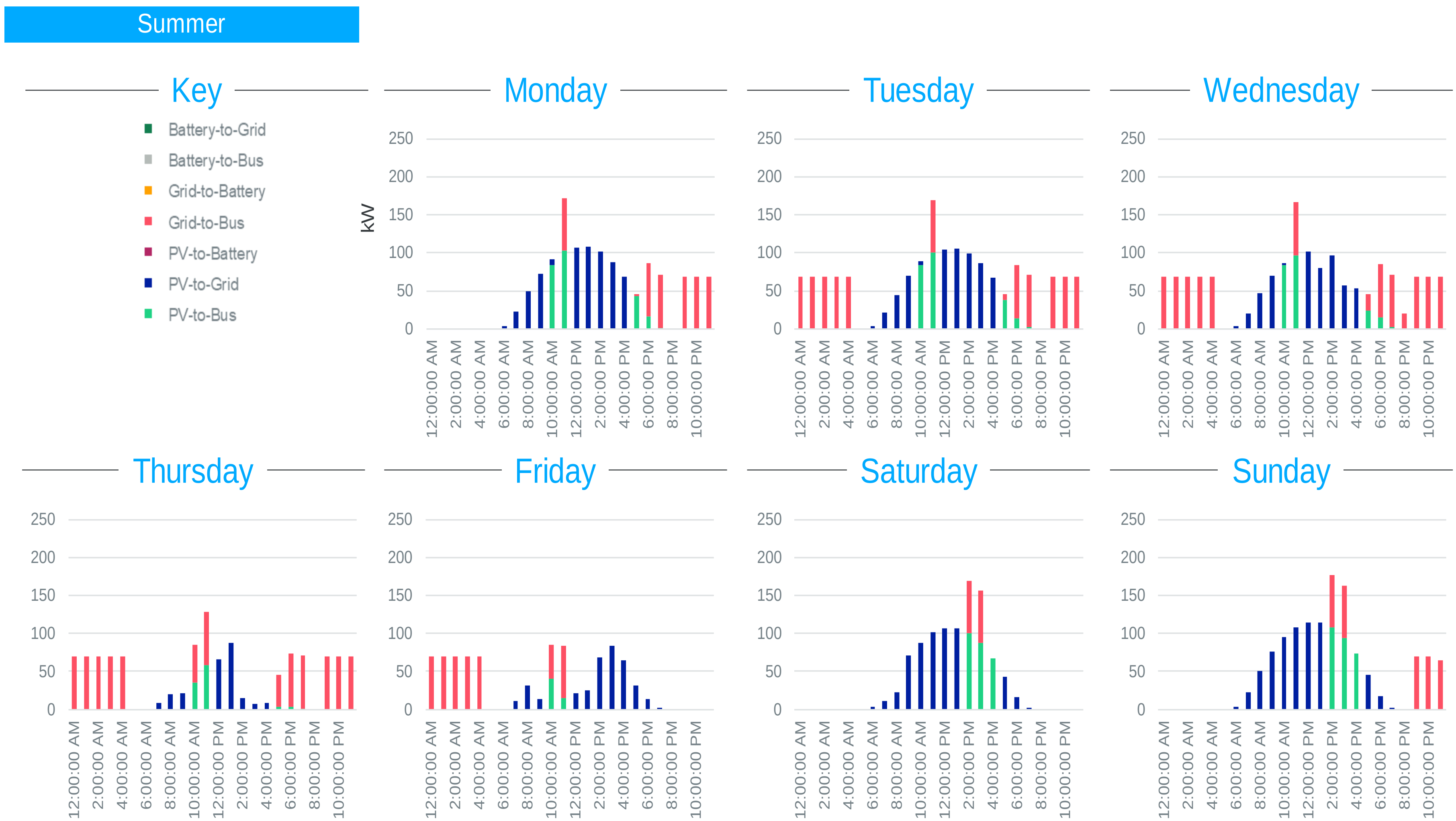


Figure 5: Charging Profiles for Phase 2 – Summer

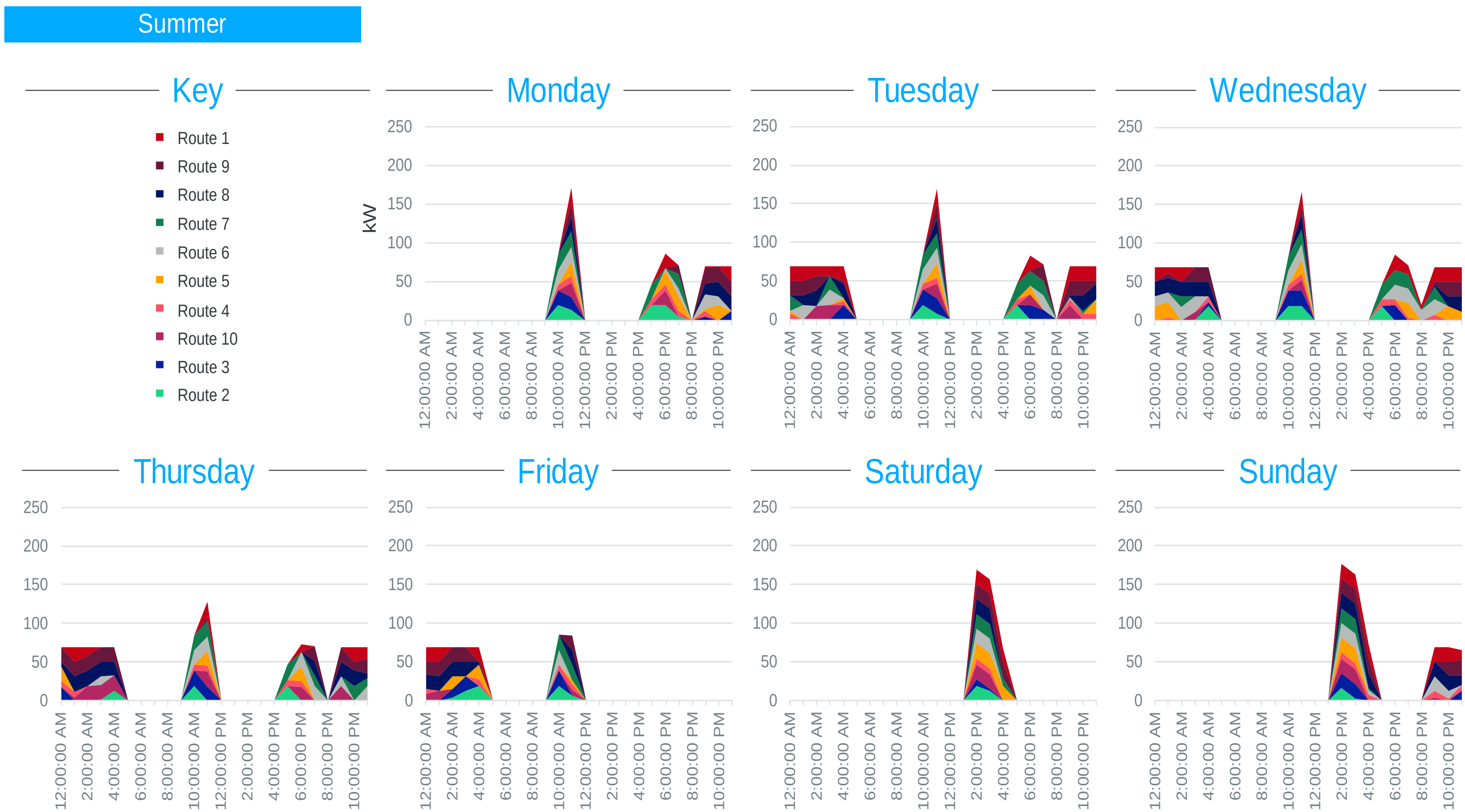


Figure 6: Sources of Energy for Bus Charging in Phase 2 – Summer

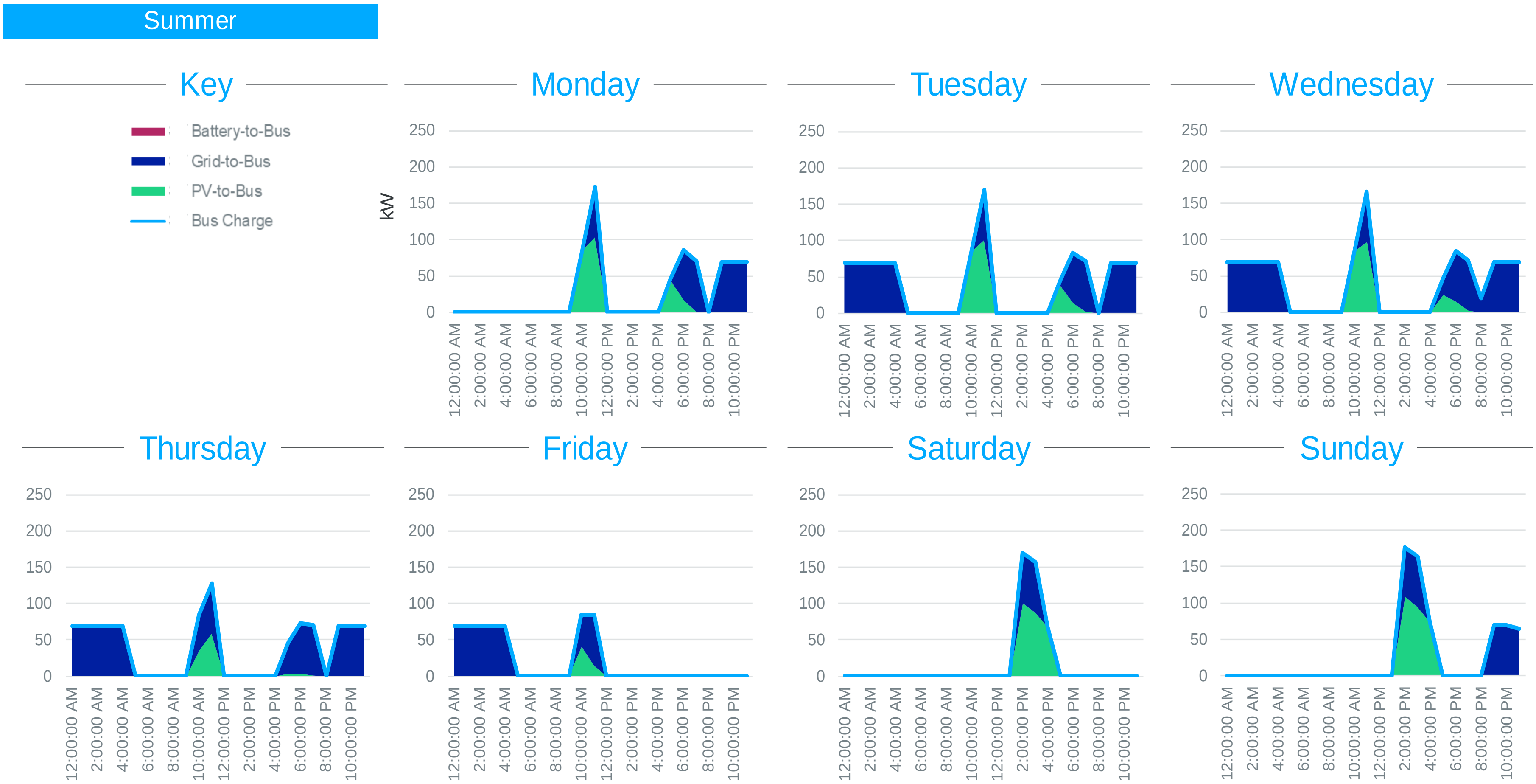


Figure 7: Weekly State of Charge for Phase 2 - Summer

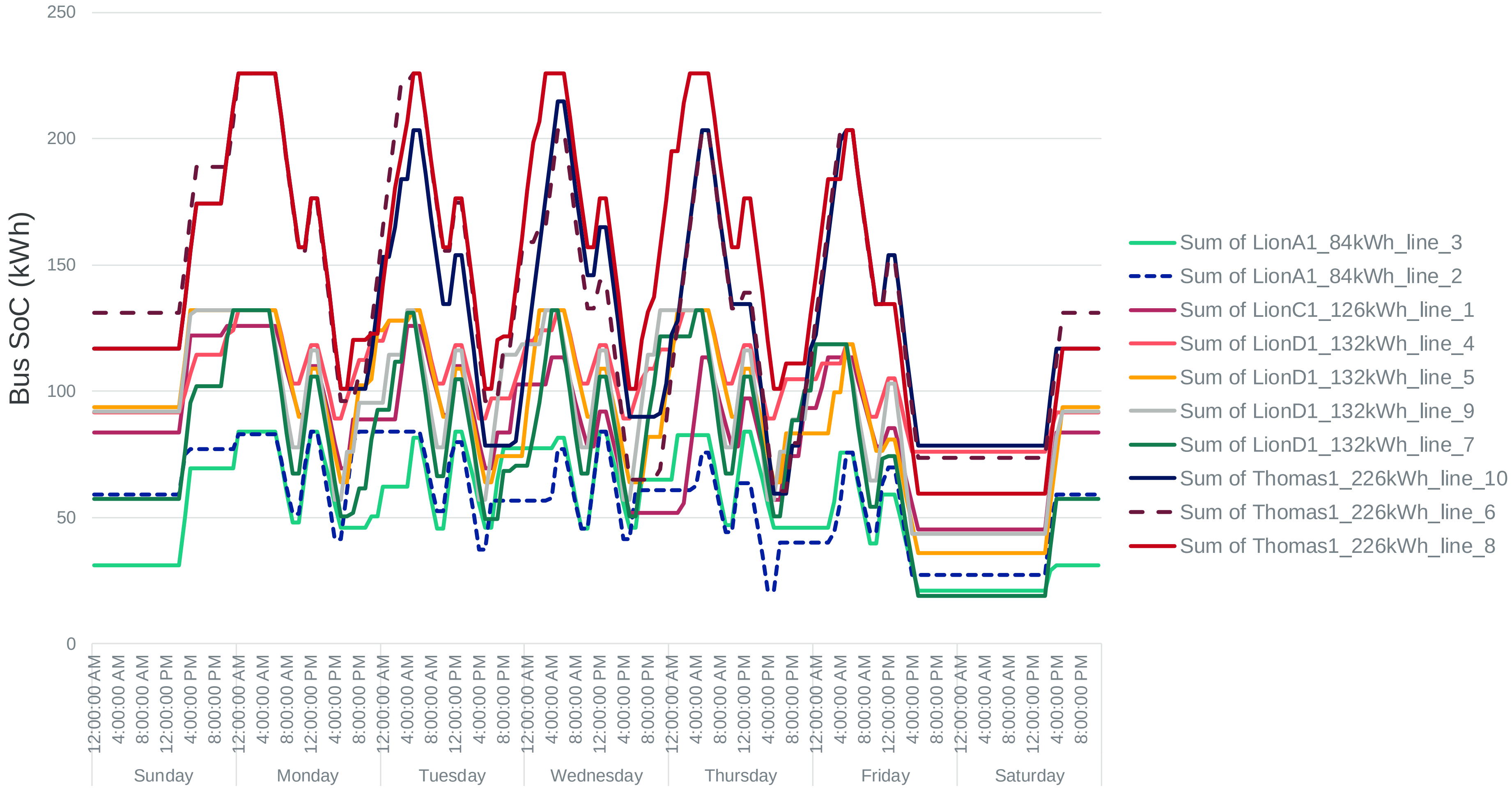


Figure 8: Tiered NEM Credit Balance for Phase 2

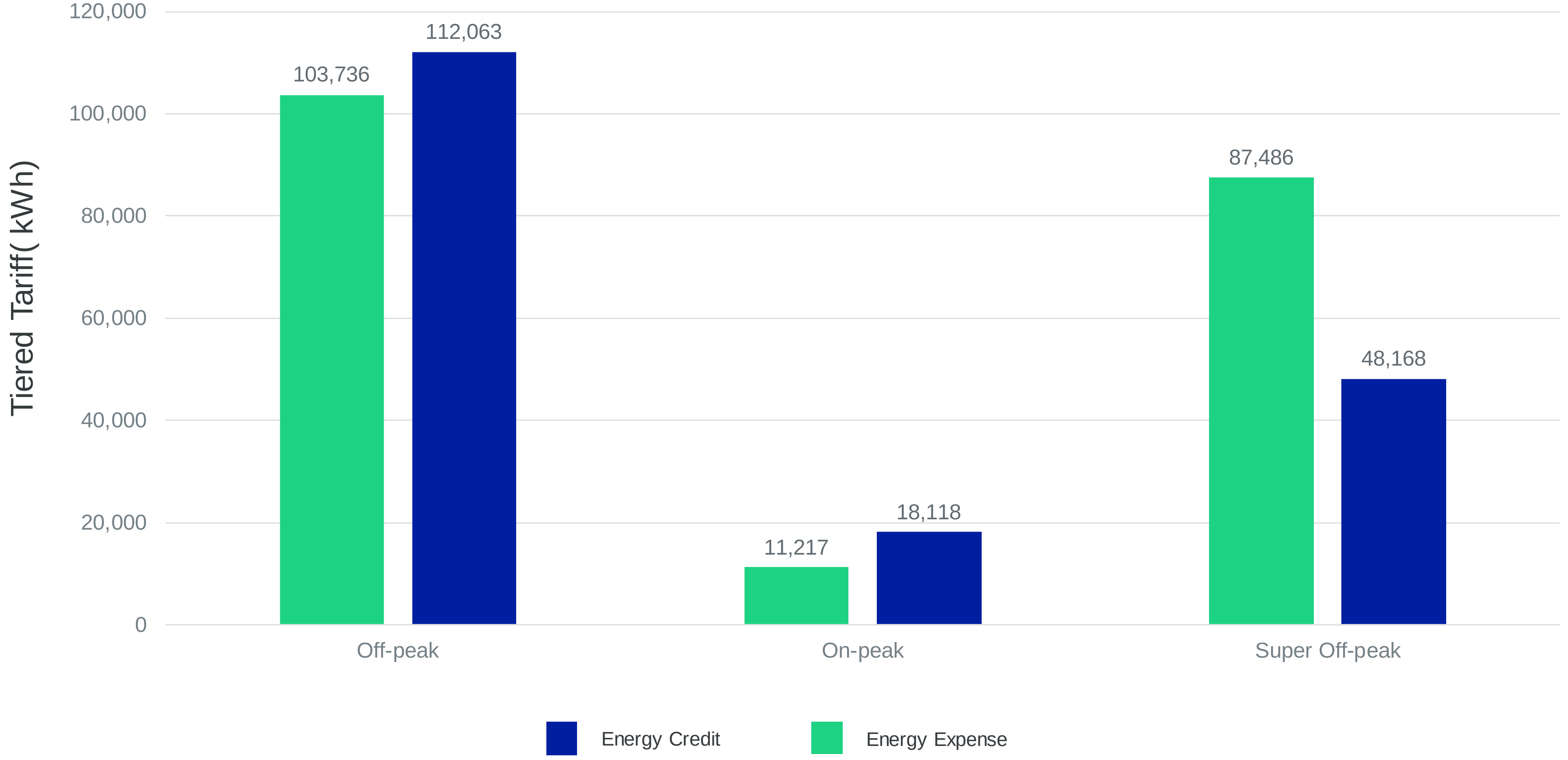
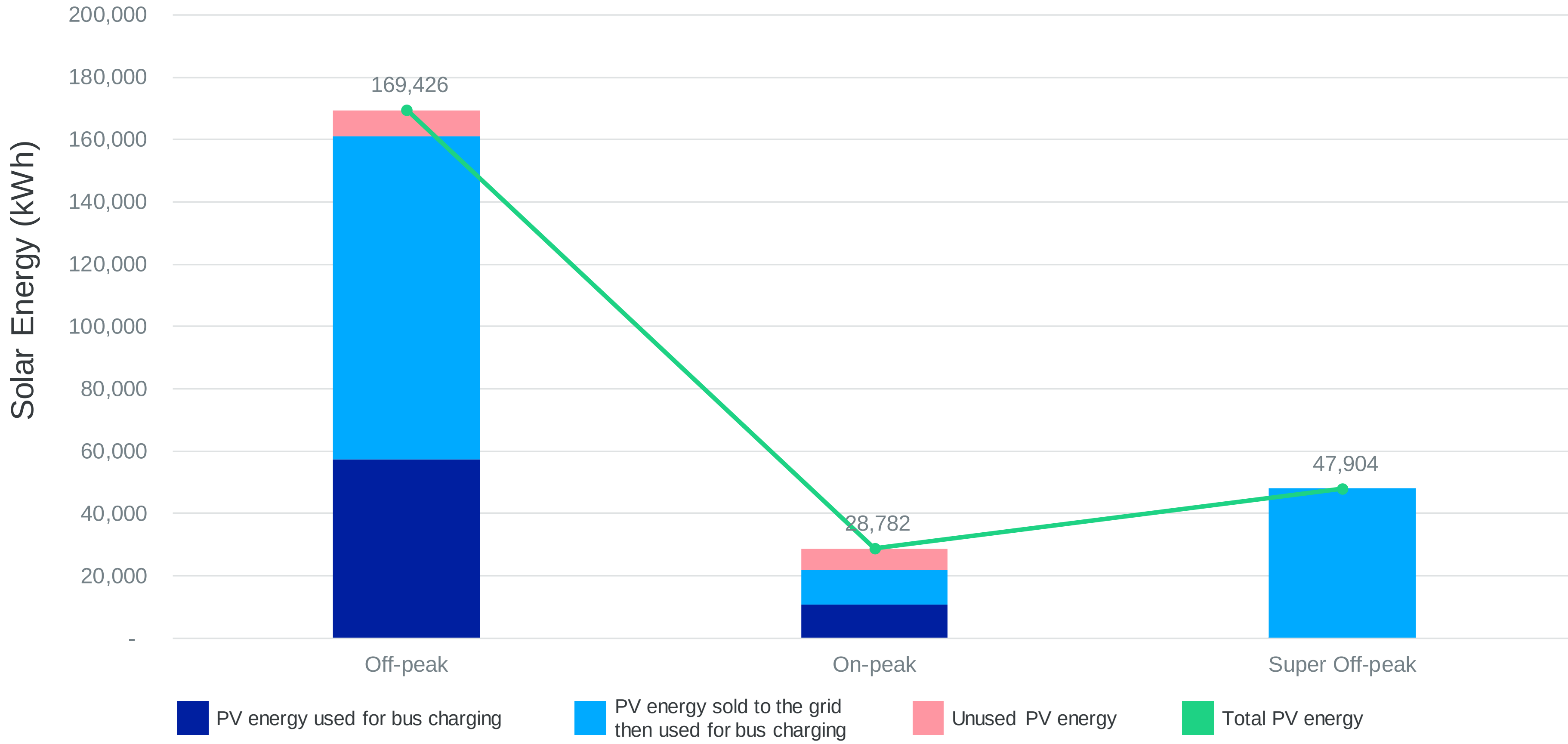


Figure 9: Solar Energy Generation and Consumption for Phase 2



Phase 3

The results for optimal technology selection are as follows:

Buses: To serve the 11 routes in Phase 3, the analysis shows that the optimal bus options are

- 3 Lion D1 buses (61 seats, 132 kWh battery, 100 mile range)
- 1 Thomas Jouley1 bus (54 seats, 226 kWh battery, 138 mile range)
- 7 Lion D2 buses (83 seats, 168 kWh battery, 125 mile range)

Bus selection options: Buses are by far the most significant cost item in fleet electrification, so their optimal selection is key. For each route, the electric bus is selected based on three sequential criteria. First, the bus should have sufficient mileage range. Second, among all the bus models with suitable mileage range, the buses seating capacity should be equal or closely matching (always greater than) current bus seat capacity. Finally, among all bus models with suitable range and seat capacity, select the bus that results in lowest TCO.

- By following this process, many of the GUHSD buses have to be upgraded to larger buses with more seat capacity. For example, 48-seat and 50-seat diesel buses are replaced with 61-seat electric buses. The only exception is for 84-seat diesel buses, where the best option is to actually replace them with 83-seat buses – losing 1 seating space.
- The Table below (*Table 9*) provides further alternatives for GUHSD for bus selection, presenting second-best options from other vendors/automakers that meet range and seat capacity but result in higher TCO.

Table 9: Alternative Bus Options for Phase 3

Route	Best option	2nd best option	TCO increase ($)
line_11	Lion D2	Green Power Beast	*
line_12	Lion D2	Green Power Beast	*
line_13	Lion D1	Thomas Jouley1	*
line_14	Lion D2	Green Power Beast	*
line_15	Lion D2	Green Power Beast	*
line_16	Lion D2	Green Power Beast	*
line_17	Lion D2	Green Power Beast	*
line_18	Lion D2	Green Power Beast	*
line_19	Lion D1	Thomas Jouley1	*
line_20	Thomas1	IC Bus CE1	*
Line_21	Lion D1	Thomas Jouley1	*

** Information redacted for confidentiality*

Chargers: To charge the buses in Phase 3, the optimal options are

- 11 Blink IQ200 with maximum charging rate of 19.2 kW

Onsite DERs: In Phase 3, we see the investment in a 223 kW solar rooftop PV system. The solar system produces about 302 MWh every year. About 22% of the solar energy is directly used for bus charging, while the remaining 78% 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 211 kW. However, the maximum peak load on the grid does not exceed 128 kW at any point in time. This is because the optimal charging behavior relies on high level of charging from solar PV in the middle of the day, while spreading charging throughout the remainder of the day to minimize energy costs and demand charges; not all buses charge at maximum rate at the same time.

Economics: The total cost of ownership for the electric fleet in Phase 3 over 20 years is detailed in *Table 10* below.

Table 10: Total Cost of Ownership for Phase 3

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	86.1%
Charging Stations – CAPEX	*	2.5%
Charging Stations – OPEX	*	0.6%
Solar PV – CAPEX	*	6.2%
Solar PV – OPEX	*	0.8%
Battery storage – CAPEX	*	0.0%
Battery Storage – OPEX	*	0.0%
Grid energy supply – OPEX	*	3.8%

** Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 3 from diesel to electric reduces the GHG emissions from the buses by about 84%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,679 $MtCO_2$, compared to an estimate of 10,702 $MtCO_2e$ 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. Furthermore, the 1679 $MtCO_2$ factors in only 22% of the onsite solar PV generation used to directly charge the buses; it does not account for the clean energy that was generated by the system and fed into grid.

Optimal Charging

Energy flows: *Figure 10* shows all seven energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how the majority of daytime solar generation is fed back into the grid both in the morning and in the afternoon, since the buses are away completing their trip. 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. Grid electricity is used to fulfill remaining charging needs after midnight, and in the evening when needed.

Charging profiles: *Figure 11* and *Figure 12* focus on the bus charging profiles. *Figure 11* shows the stack of charging profiles for every bus in Phase 3, and *Figure 12* shows the sources of electricity used to charge these buses. Some key takeaways:

- Charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. To optimize charging profiles, buses charge during multiple periods on weekdays and weekends.
- During weekdays, bus charging occurs during three time periods: after midnight and through the early morning hours, in the middle of the day after the morning trips, and occasionally also in the evening after the afternoon trips. The maximum charging rate reaches 211 kW, with peak load from the grid at 128 kW.
    - Between 9:00 pm and 5:00 am, the buses charge consistently from the grid, benefiting from off-peak and super-off-peak rates.

  - In the middle of the day, between 10:00 am and 12:00 pm, significant amount of charging occurs. The majority of charging is enabled by solar PV, with additional supply from the grid at off-peak rates.
  - Occasionally, buses charge during on-peak hours between 5:00 pm and 9:00 pm, primarily due to the unique construct of Tiered NEM. To explain this in more depth: solar generation results in NEM credit surplus for the on-peak tier in two occasions: between 4:00 pm and 5:00 pm on weekdays when buses are still “out” completing their trips, as well as on Saturdays and Sundays when buses do not need to charge in the afternoon. That credit surplus is then depleted during weekdays between 5:00 pm and 8:00 pm when buses are back to depot and ready to charge. 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 solar generation and the Tiered NEM construct.
- On weekends (Satuday and Sunday), the buses continue to charge directly from solar. While all charging can be fulfilled by daytime solar, optimal charging requires that the buses also use grid electricity, during off-peak period. The reason for that is also uniquely attributed to the Tiered NEM construct. The supply of energy from the grid on weekends allows consuming the surplus in NEM credits during the off-peak period.

<u>Buses’ State of Charge:</u> The state of charge (SoC) for all the buses in the fleet follow a similar pattern, regardless of the size of battery (*Figure 13*).

- As previoulsy noted, charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. Similarly, at no point in time will buses fall below a 10% SoC, providing a energy buffer in case of emergency.
- During the middle of the day, in between the morning and afternoon trips, all buses charge for at least one hour.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of solar credits and minimum total cost of ownership. Of the total 302 MWh of electricity generated by the PV system each year, about 66 MWh are used to directly charge the buses and 236 MWh are fed into the grid to generate NEM credits.
- As shown in *Figure 14*, those credits fall under the three tiers: 27 MWh on-peak, 150 MWh off-peak, and 59 MWh super-off-peak. Optimal charging requires energy credits to balance energy expense in each tier as closely as possible.
- For Phase 3, all three tiers of credits seem to be effectively balanced, ensuring maximum utilization of credits throughout the year. Overall, there is about 8% imbalance (surplus) in credits across all tiers for fleet charging in Phase 2. In other word, only 8% of the credits are not utilized and lost at the end of each year. The 8% lost credit is equivalent to about 7% of the total solar energy in that year.
- *Figure 15* further emphasizes the optimization of solar energy supply and consumption. Within the on-peak and off-peak tiers, only a small fraction of solar energy is not utilized. Within the super off-peak tier all solar energy is utilized (in addition to substantial amount of grid electricity).

Figure 10: Energy Flows for Phase 3 – Summer

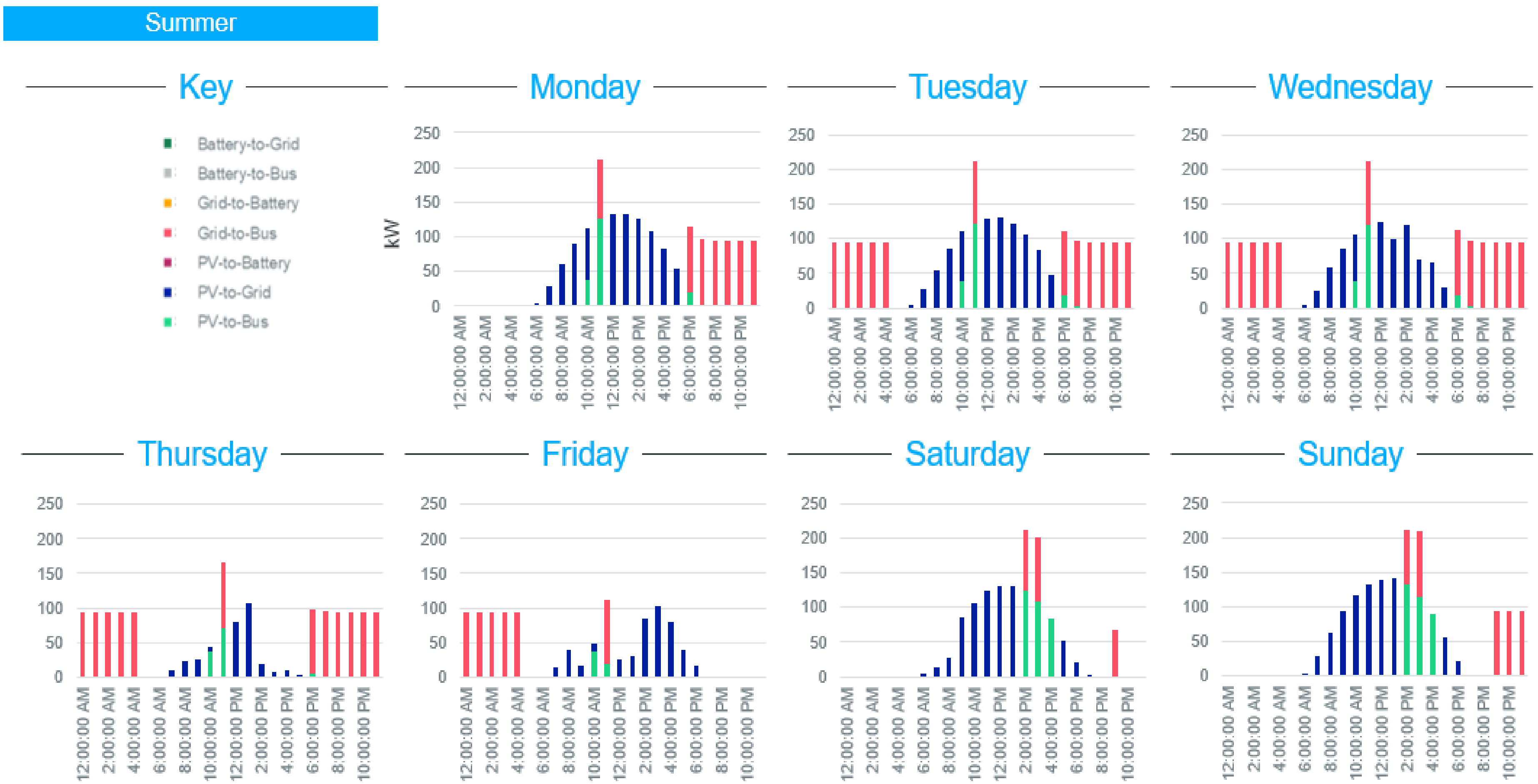


Figure 11: Charging Profiles for Phase 3 – Summer

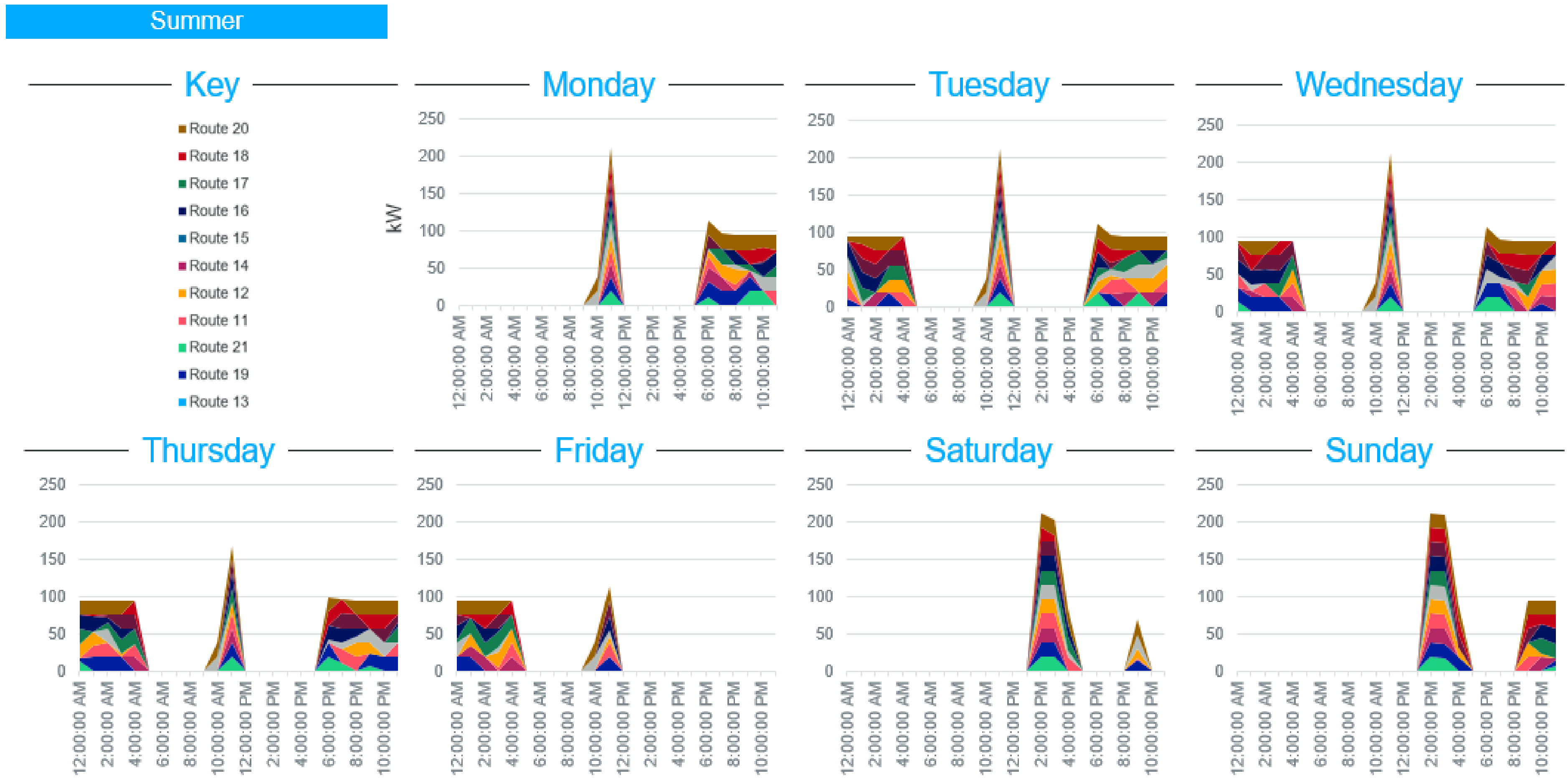


Figure 12: Sources of Energy for Bus Charging in Phase 3 - Summer

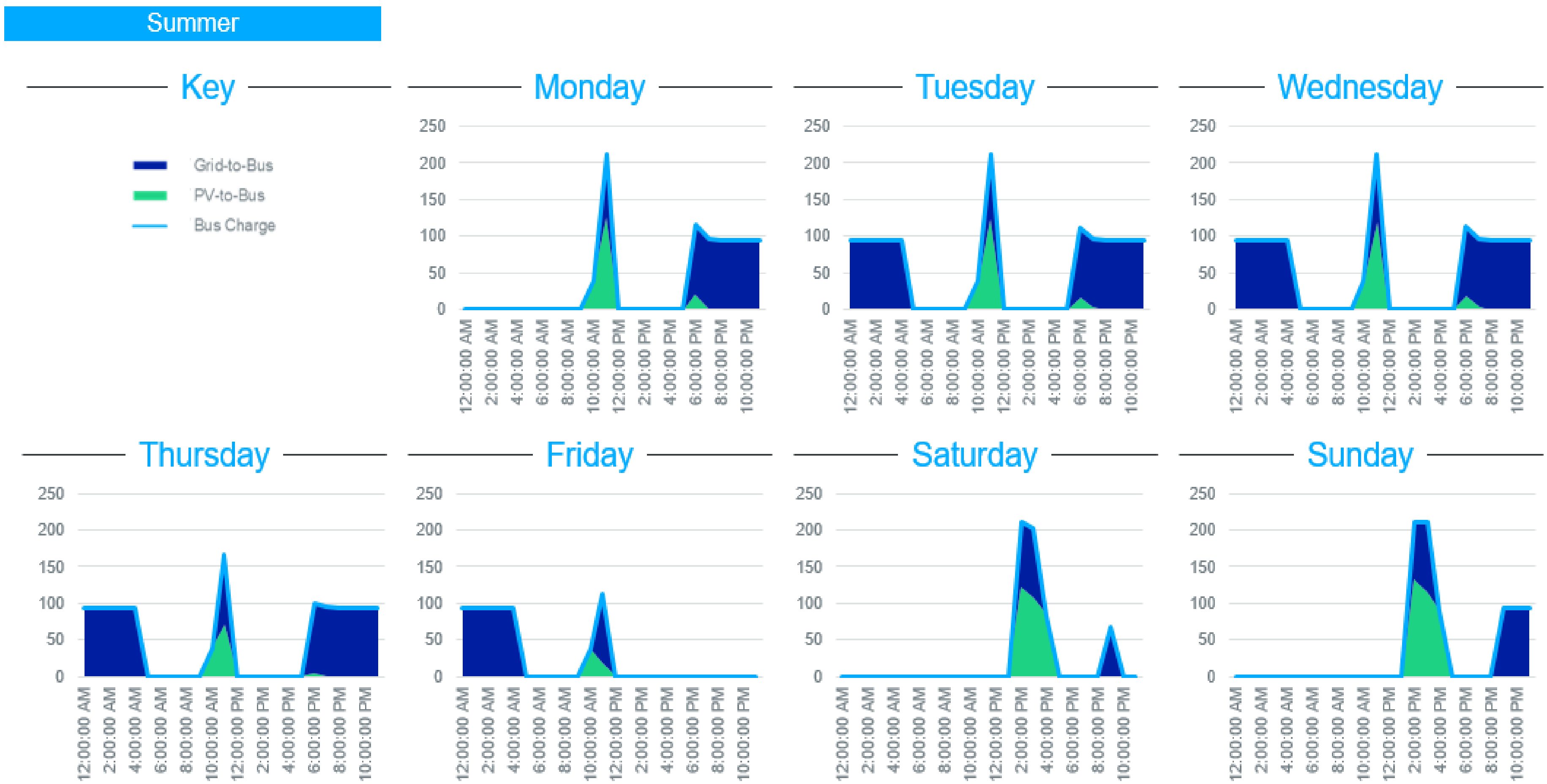


Figure 13: Weekly State of Charge for Phase 3 - Summer

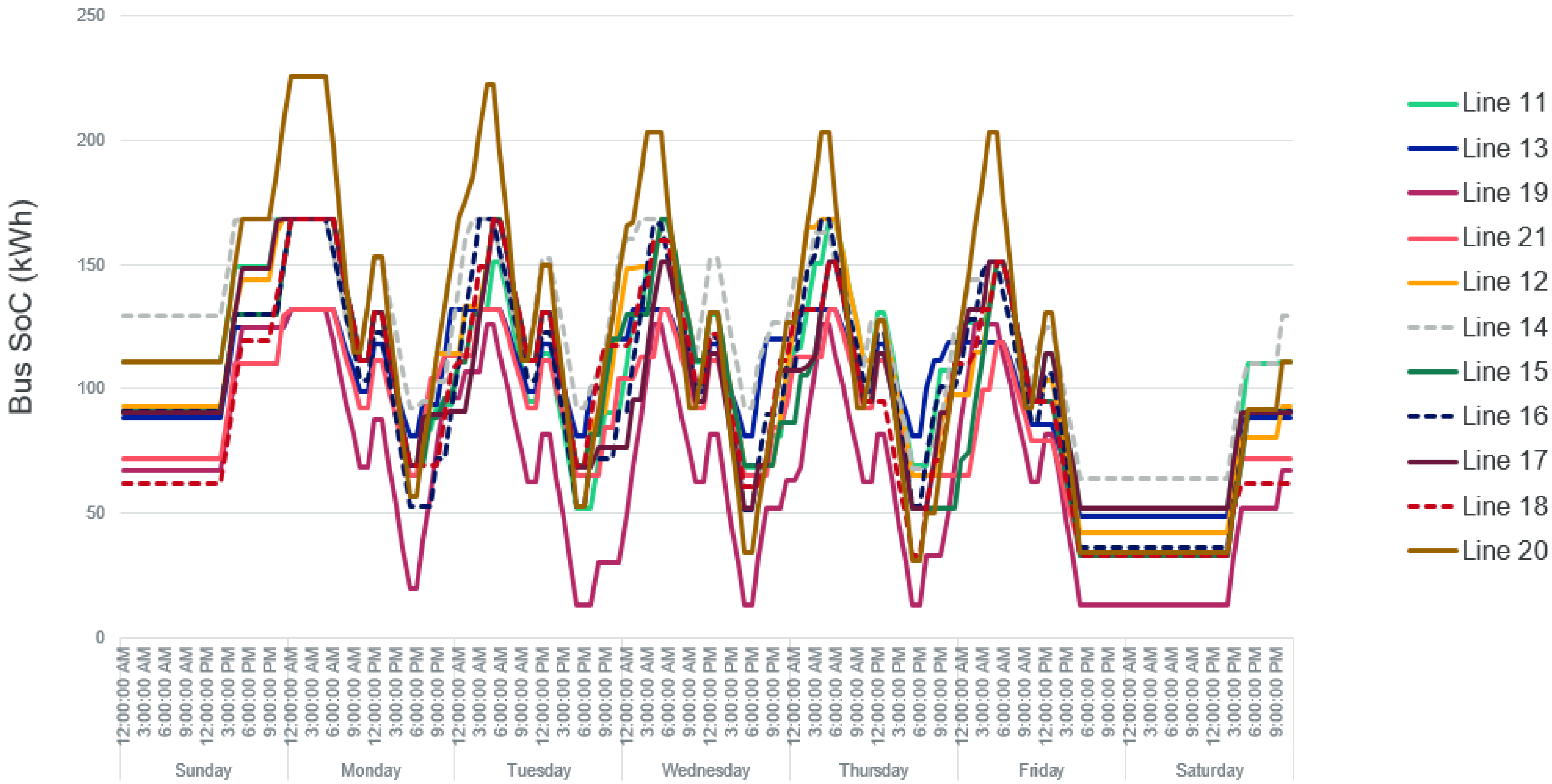


Figure 14: Tiered NEM Credit Balance for Phase 3

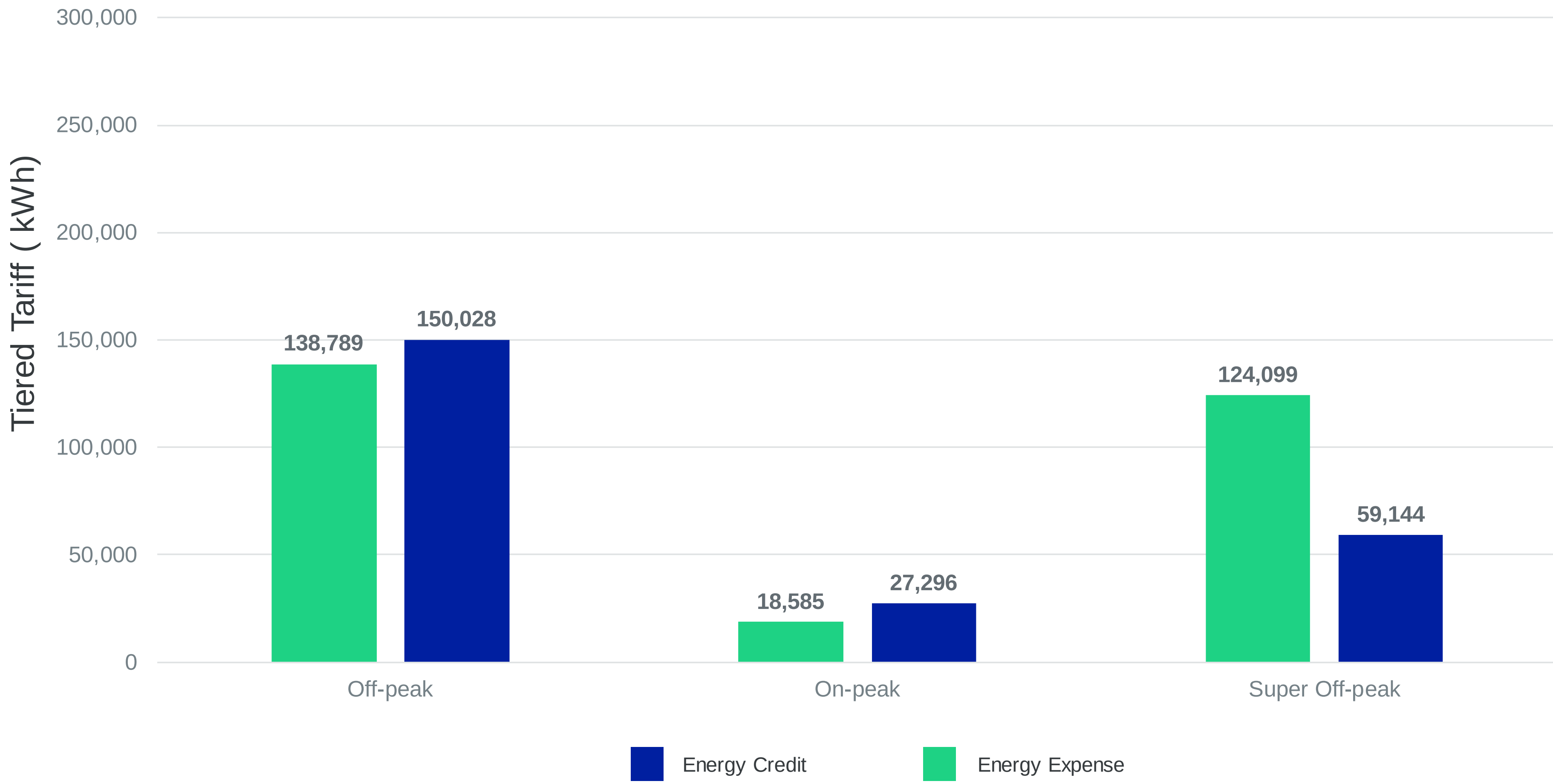
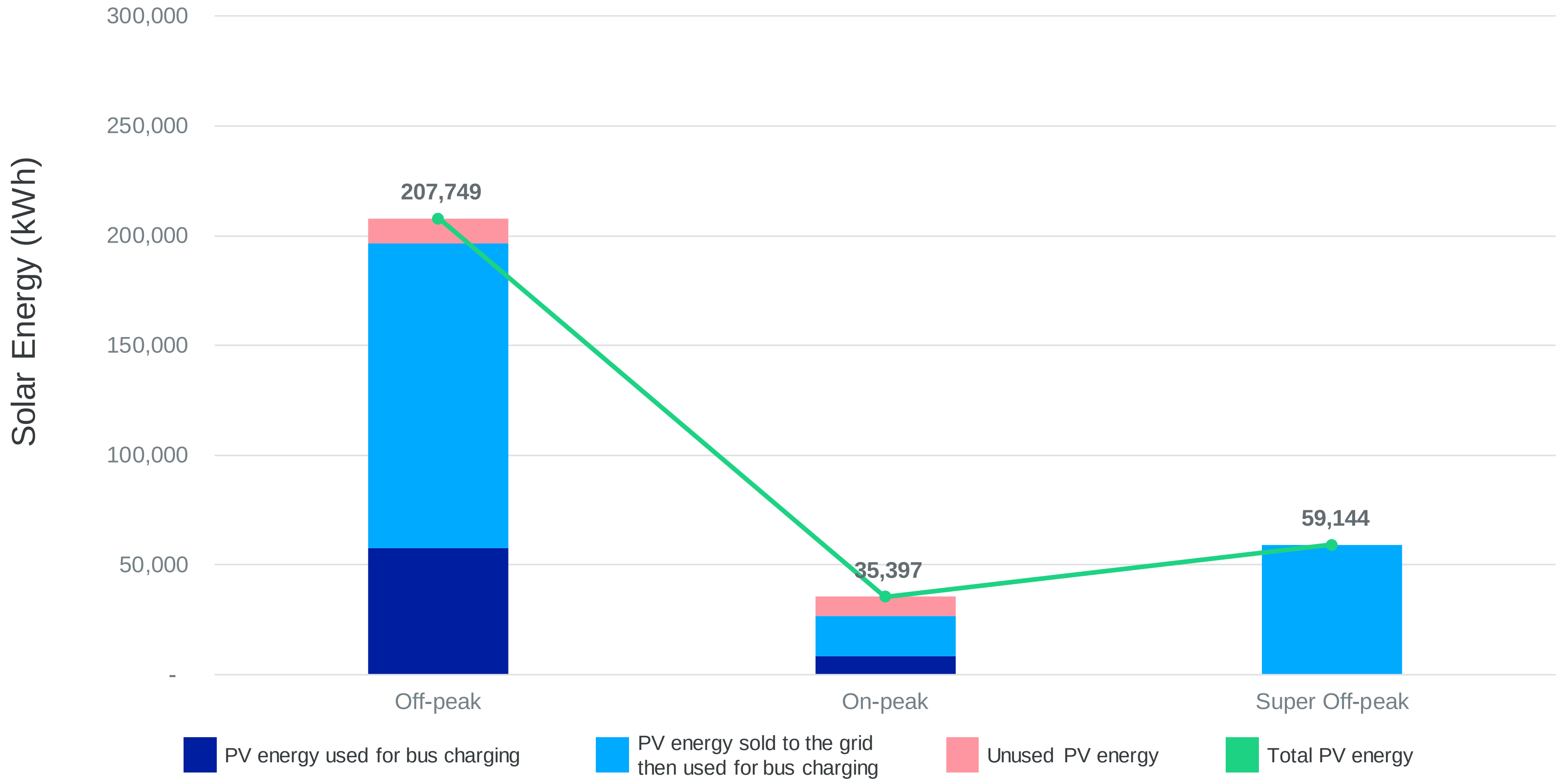


Figure 15: Solar Energy Generation and Consumption for Phase 3



Phase 4a

The results for optimal technology selection are as follows:

Buses: To serve the 14 routes in Phase 4a, the analysis shows that the optimal bus options are

- 3 Lion C1 buses (77 seats, 126 kWh battery, 100 mile range)
- 5 Lion D1 buses (61 seats, 132 kWh battery, 100 mile range)
- 6 Lion D2 buses (83 seats, 168 kWh battery, 125 mile range)

Bus selection options: Buses are by far the most significant cost item in fleet electrification, so their optimal selection is key. For each route, the electric bus is selected based on three sequential criteria. First, the bus should have sufficient mileage range. Second, among all the bus models with suitable mileage range, the buses seating capacity should be equal or closely matching (always greater than) current bus seat capacity. Finally, among all bus models with suitable range and seat capacity, select the bus that results in lowest TCO.

- By following this process, many of the GUHSD buses have to be upgraded to larger buses with more seat capacity. For example, 28-seat, 40-seat, and 47-seat diesel buses are replaced with 61-seat electric buses. The only exception is for 84-seat diesel buses, where the best option is to actually replace them with 83-seat buses – losing 1 seating space.
- The Table below (*Table 11*) provides further alternatives for GUHSD for bus selection, presenting second-best options from other vendors/automakers that meet range and seat capacity but result in higher TCO.

Table 11: Alternative Bus Options for Phase 4a

Route	Best option	2nd best option	TCO increase ($)
line_22	LionD1	Thomas Jouley1	*
line_23	LionD1	Thomas Jouley1	*
line_24	LionD1	Thomas Jouley1	*
line_25	LionD1	Thomas Jouley1	*
line_26	LionD1	Thomas Jouley1	*
line_27	LionD2	Green Power Beast	*
line_28	LionD2	Green Power Beast	*
line_29	LionD2	Green Power Beast	*
line_30	LionD2	Green Power Beast	*
line_31	LionC1	Thomas Jouley2	*
line_32	LionD2	Green Power Beast	*
line_33	LionD2	Green Power Beast	*
line_34	LionC1	Thomas Jouley2	*
line_35	LionC1	Thomas Jouley2	*

** Information redacted for confidentiality*

Chargers: To charge the buses in 4a, the optimal options are

- 5 ABB Terra DC Wallbox with a maximum charging rate of 22.5 kW
- 8 Blink IQ200 with maximum charging rate of 19.2 kW
- 1 EVBox Business Line with maximum charging rate of 7.7 kW

- The ABB Terra DC chargers (22.5 kW) can be replaced with the Blink IQ200 chargers (19.2 kW) and still be sufficient for the buses to fulfill their trips on these routes. However, in this case, the buses may not get to 90% SoC before 5:00 am each day.

Onsite DERs: In Phase 4a, we see the investment in a 268 kW solar rooftop PV system. The solar system produces about 363 MWh every year. About 28% of the solar energy is directly used for bus charging, while the remaining 72% 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 274 kW. However, the maximum peak load on the grid does not exceed 132 kW at any point in time. This is because the optimal charging behavior relies on high level of charging from solar PV in the middle of the day, while spreading charging throughout the remainder of the day to minimize energy costs and demand charges; not all buses charge at maximum rate at the same time.

Economics: The total cost of ownership for the electric fleet in Phase 4a over 20 years is detailed in *Table 12* below.

Table 12: Total Cost of Ownership for Phase 4a

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	86.1%
Charging Stations – CAPEX	*	3.5%
Charging Stations – OPEX	*	0.5%
Solar PV – CAPEX	*	6.2%
Solar PV – OPEX	*	0.8%
Battery storage – CAPEX	*	0.0%
Battery Storage – OPEX	*	0.0%
Grid energy supply – OPEX	*	2.8%

** Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 4a from diesel to electric reduces the GHG emissions from the buses by about 87%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 1,711 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 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. Furthermore, the 1,711 MtCO2 factors in only 28% of the onsite solar PV generation used to directly charge the buses; it does not account for the clean energy that was generated by the system and fed into grid.

Optimal Charging

Energy flows: *Figure 16* shows all seven energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how the majority of daytime solar generation is fed back into the grid both in the morning and in the afternoon, since 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. Grid electricity is used to fulfill remaining charging needs after midnight, and in the evening when needed.

Charging profiles: *Figure 17* and *Figure 18* focus on the bus charging profiles. *Figure 17* shows the stack of charging profiles for every bus in Phase 4a, and *Figure 18* shows the sources of electricity used to charge these buses. Some key takeaways:

- Charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. To optimize charging profiles, buses charge during multiple periods on weekdays and weekends.
- During weekdays, bus charging occurs during three time periods: after midnight and through the early morning hours, in the middle of the day after the morning trips, and occasionally also in the evening after the afternoon trips. The maximum charging rate reaches 274 kW, with peak load from the grid at 132 kW.
    - Between 9:00 pm and 5:00 am, the buses charge consistently from the grid, benefiting from off-peak and super-off-peak rates.
    - In the middle of the day, between 10:00 am and 12:00 pm, significant amount of charging occurs. The majority of charging is enabled by solar PV, with additional supply from the grid at off-peak rates.
    - Occasionally, buses charge during on-peak hours between 5:00 pm and 9:00 pm, primarily due to the unique construct of Tiered NEM. To explain this in more depth: solar generation results in NEM credit surplus for the on-peak tier in two occasions: between 4:00 pm and 5:00 pm on weekdays when buses are still "out" completing their trips, as well as on Saturdays and Sundays when buses do not need to charge in the afternoon. That credit surplus is then depleted during weekdays between 5:00 pm and 8:00 pm when buses are back to depot and ready to charge. 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 solar generation and the Tiered NEM construct.
- On weekends (Satuday and Sunday), the buses continue to charge directly from solar. While all charging can be fulfilled by daytime solar, optimal charging requires that the buses also use grid electricity, during off-peak period. The reason for that is also uniquely attributed to the Tiered NEM construct. The supply of energy from the grid on weekends allows consuming the surplus in NEM credits during the off-peak period.

Buses' State of Charge: The state of charge (SoC) for all the buses in the fleet follow a similar pattern, regardless of the size of bettery (*Figure 19*).

- As previoulsy noted, charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. Similarly, at no point in time will buses fall between a 10% SoC, providing a energy buffer in case of emergency.
- During the middle of the day, in between the morning and afternoon trips, all buses charge for at least one hour.

NEM Credit Balance:

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of solar credits and minimum total cost of ownership. Of the total 363 MWh of electricity generated by the PV system each year, about 100 MWh are used to directly charge the buses and 263 MWh are fed into the grid to generate NEM credits.
- As shown in *Figure 20*, those credits fall under the three tiers: 28 MWh on-peak, 164 MWh off-peak, and 71 MWh super-off-peak. Optimal charging requires energy credits to balance energy expense as closely as possible.
- For Phase 4a, the portfolio of credits is effectively balanced, ensuring maximum utilization of credits throughout the year. Overall, there is less than 9% imbalance (surplus) in credits across all tiers for fleet charging in Phase 2. In other word, only 9% of the credits are not utilized and lost at the end of each year, primarily on-peak and off-peak credits. The 9% lost credit is equivalent to only 6% of the total solar energy in that year.

- *Figure 21* further emphasizes the optimization of solar energy supply and consumption. Within the on-peak and off-peak tiers, only a small fraction of solar energy is not utilized. Within the super off-peak tier all solar energy is utilized (in addition to substantial amount of grid electricity).

Figure 16: Energy Flows for Phase 4a – Summer

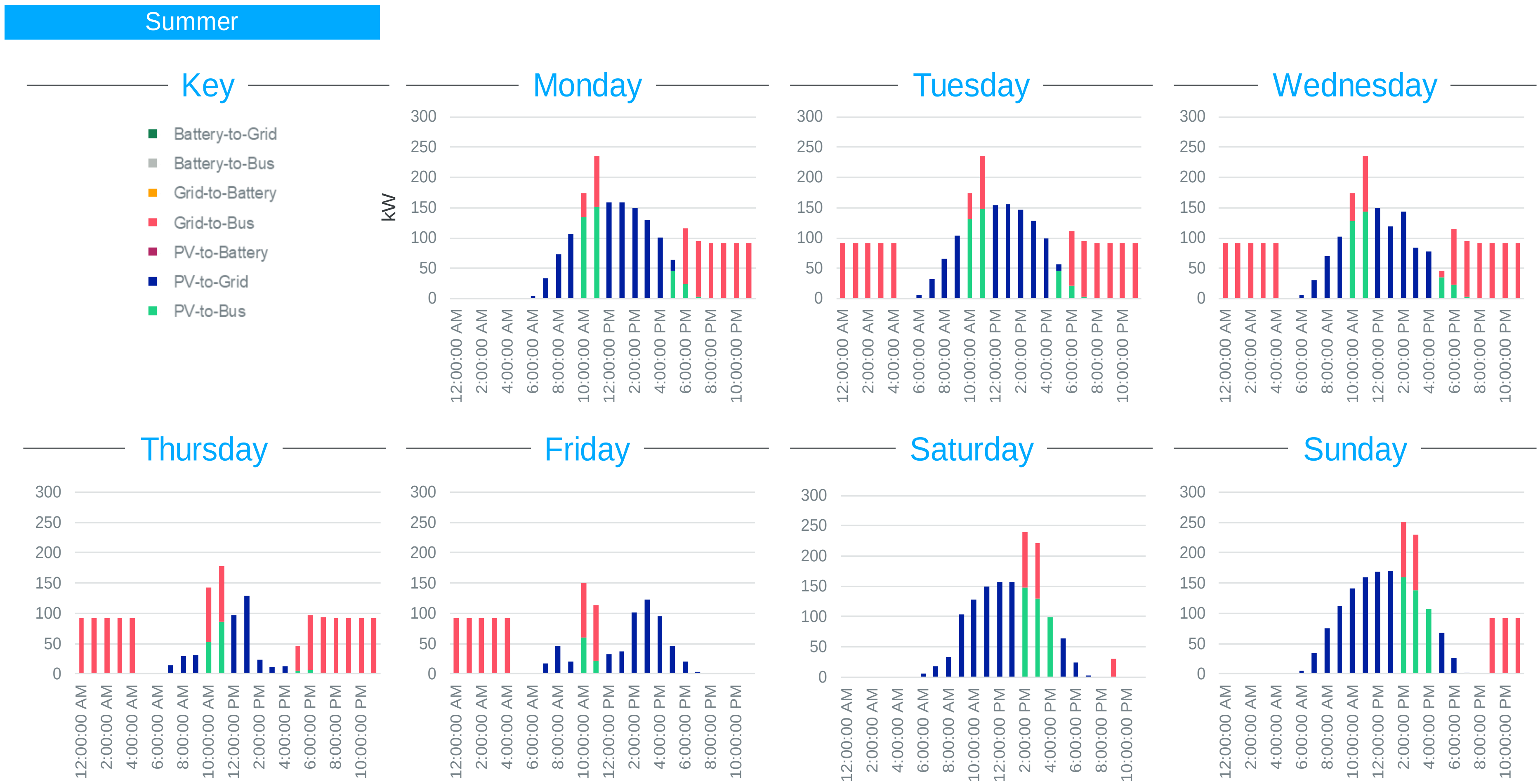


Figure 17: Charging Profiles for Phase 4a – Summer

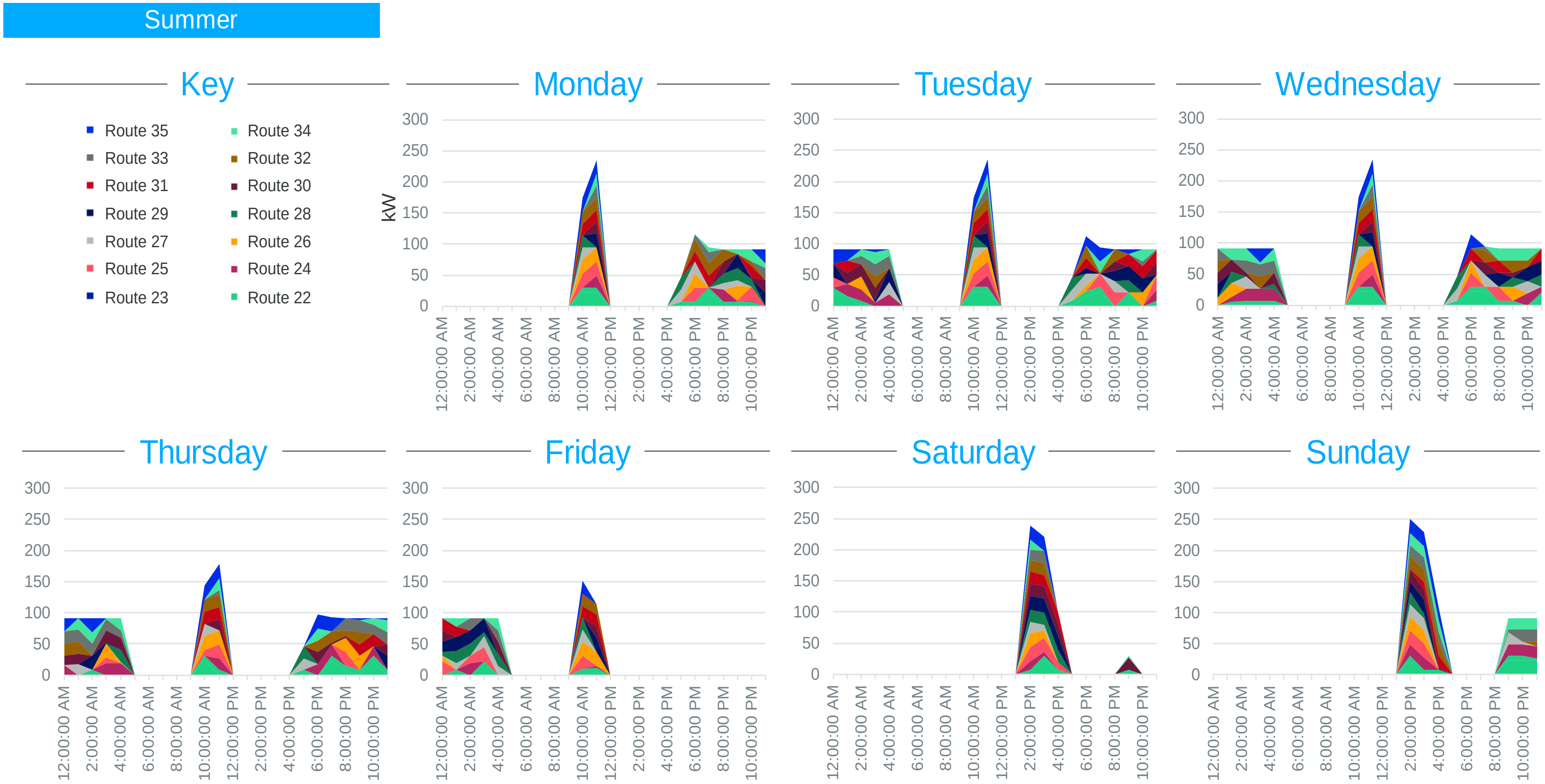


Figure 18: Sources of Energy for Bus Charging in Phase 4a – Summer

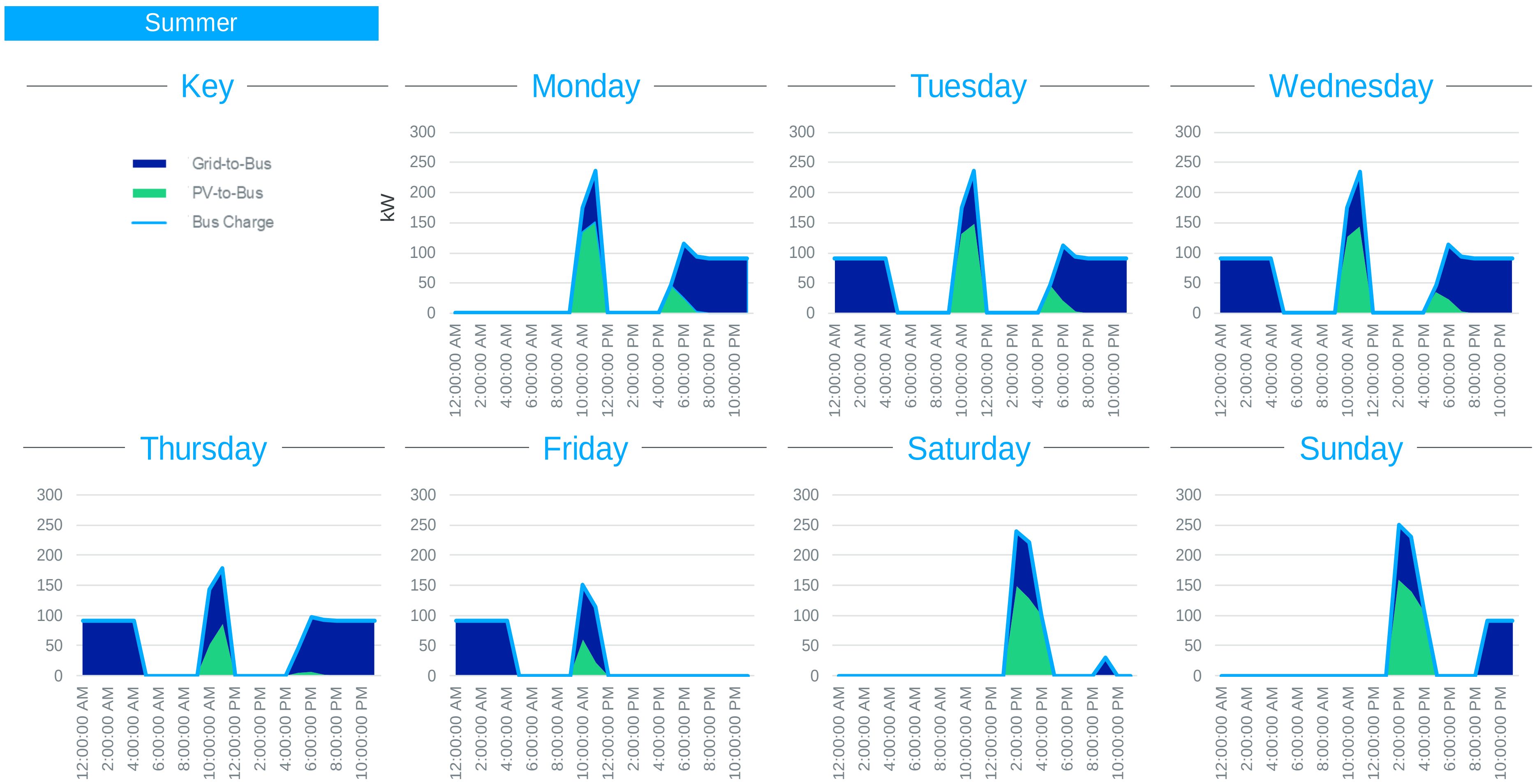


Figure 19: Weekly State of Charge for Phase 4a - Summer

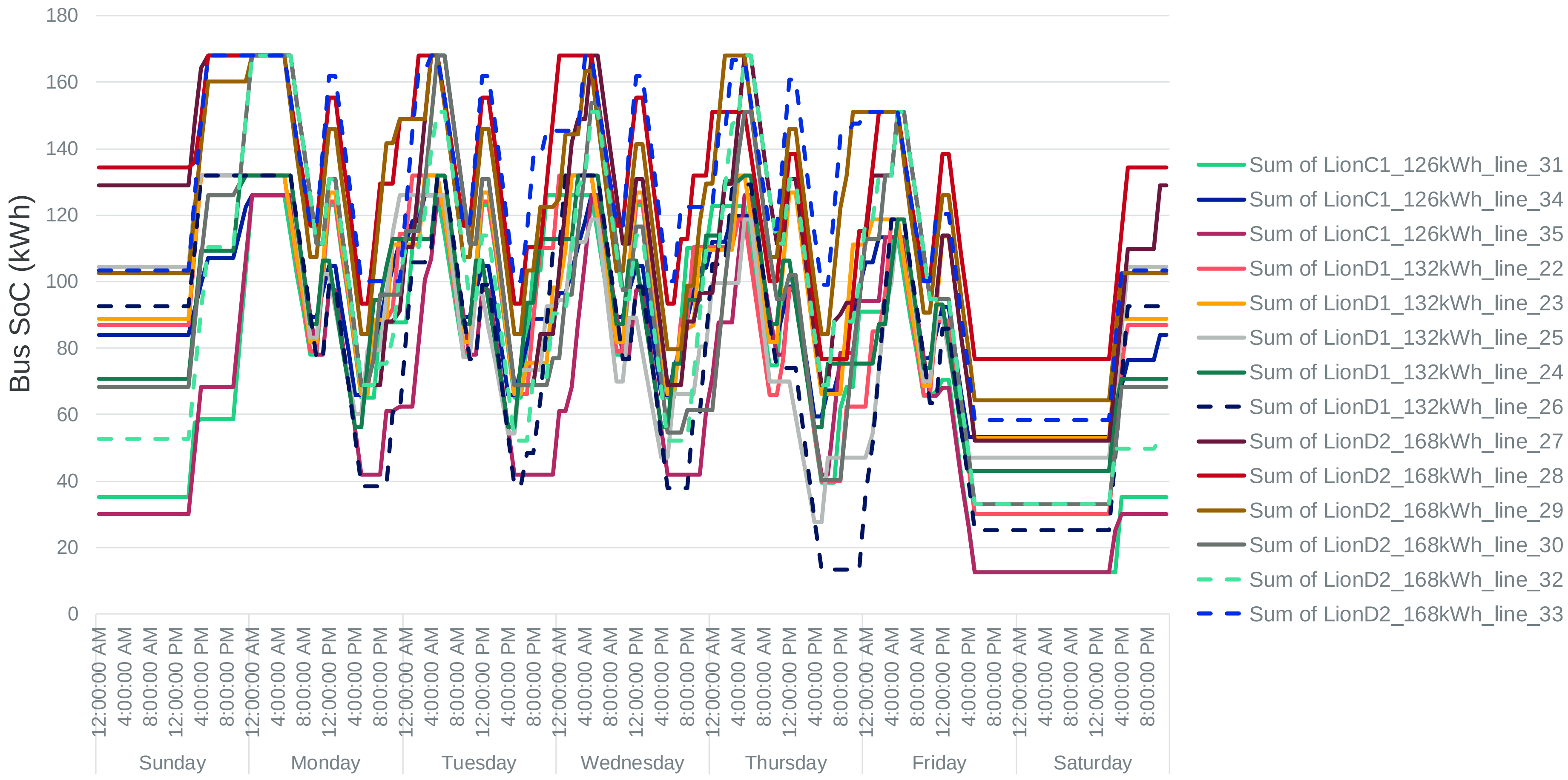


Figure 20: Tiered NEM Credit Balance for Phase 4a

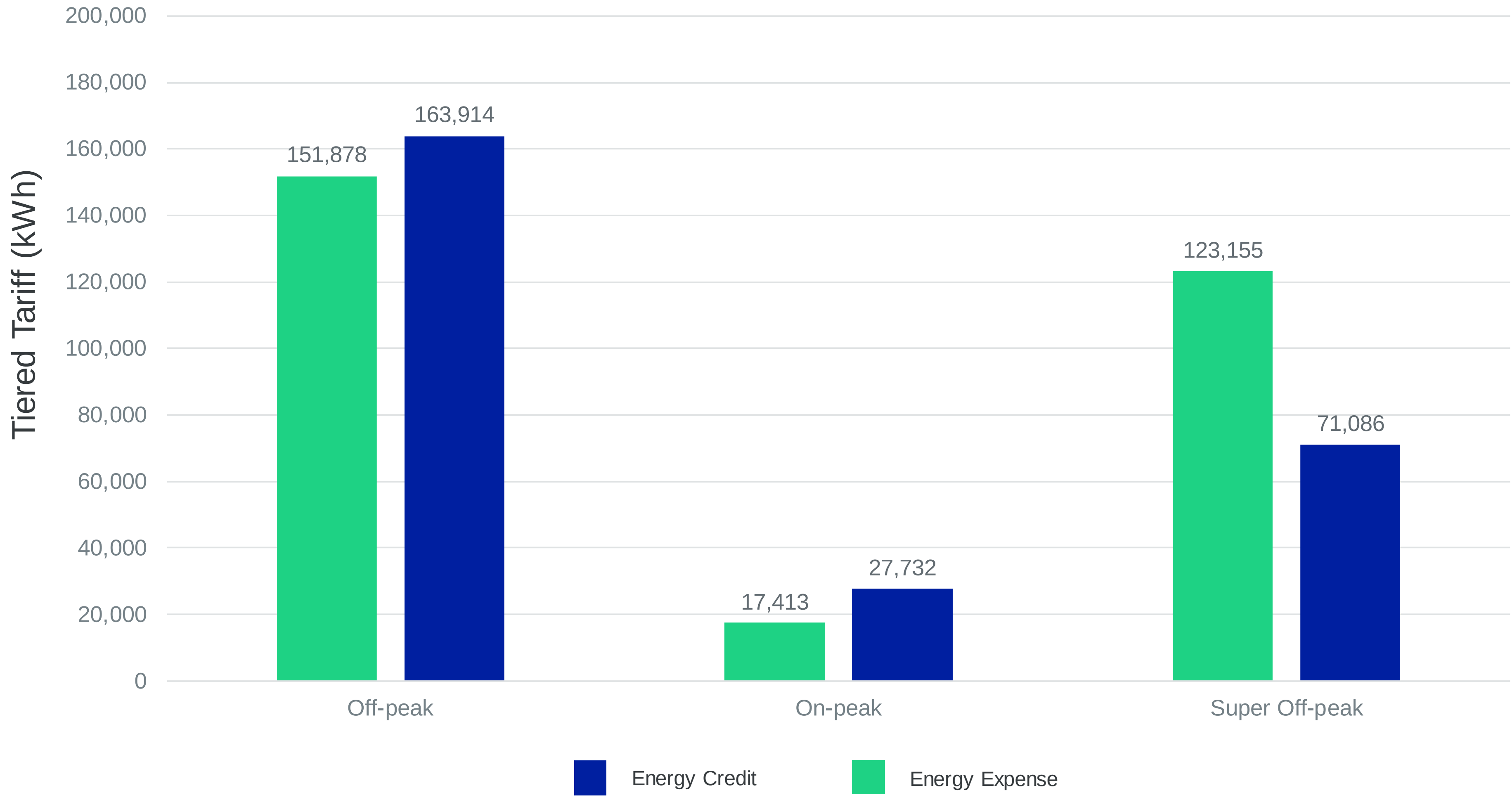
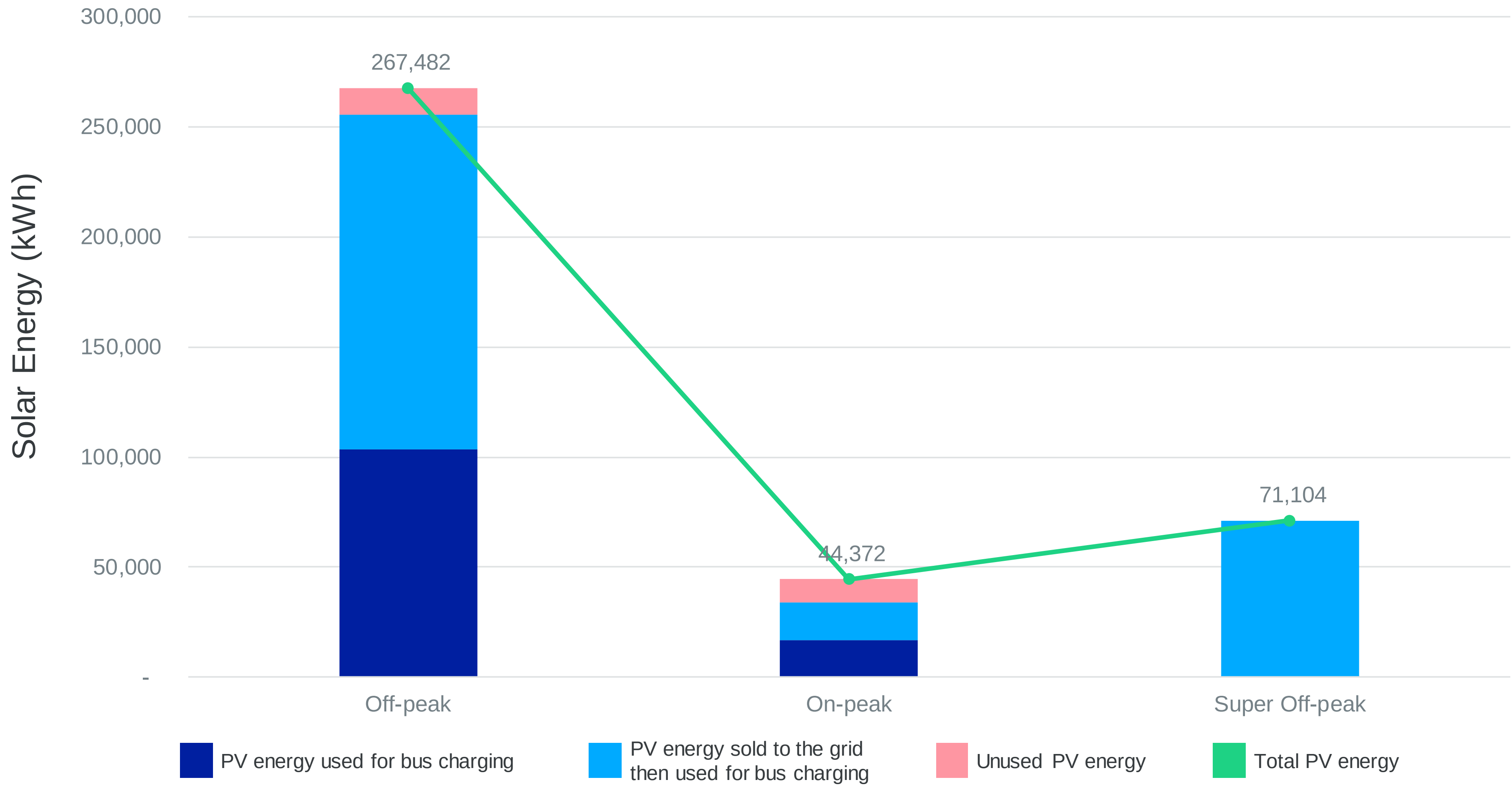


Figure 21: Solar Energy Generation and Consumption for Phase 4a



Phase 4b

The results for optimal technology selection are as follows:

Buses: To serve the 15 routes in Phase 4b, the analysis shows that the optimal bus options are

- 5 Lion C1 buses (77 seats, 126 kWh battery, 100 mile range)
- 7 Lion D1 buses (61 seats, 132 kWh battery, 100 mile range)
- 2 Lion D2 buses (83 seats, 168 kWh battery, 125 mile range)
- 1 Motive & Collins bus (24 seats, 127 kWh battery, 105 mile range)

Bus selection options: Buses are by far the most significant cost item in fleet electrification, so their optimal selection is key. For each route, the electric bus is selected based on three sequential criteria. First, the bus should have sufficient mileage range. Second, among all the bus models with suitable mileage range, the buses seating capacity should be equal or closely matching (always greater than) current bus seat capacity. Finally, among all bus models with suitable range and seat capacity, select the bus that results in lowest TCO.

- By following this process, many of the GUHSD buses have to be upgraded to larger buses with more seat capacity. For example, 40-seat, 46-seat, and 47-seat diesel buses are replaced with 61-seat electric buses. The only exception is for 84-seat diesel buses, where the best option is to actually replace them with 83-seat buses – losing 1 seating space.
- The Table below (*Table 13*) provides further alternatives for GUHSD for bus selection, presenting second-best options from other vendors/automakers that meet range and seat capacity but result in higher TCO.

Table 13: Alternative Bus Options for Phase 4b

Route	Best option	2nd best option	TCO increase ($)
line_36	Lion C1	Thomas Jouley2	*
line_37	LionD1	Thomas Jouley1	*
line_38	LionD1	Thomas Jouley1	*
line_39	LionD1	Thomas Jouley1	*
line_40	Lion C1	Thomas Jouley2	*
line_41	LionD1	Thomas Jouley1	*
line_42	LionD1	Thomas Jouley1	*
line_43	LionD1	Thomas Jouley1	*
line_44	Lion D2	Green Power Beast	*
line_45	Lion C1	Thomas Jouley2	*
line_46	LionD1	Thomas Jouley1	*
line_47	LionD2	Green Power Beast	*
line_48	Lion C1	Thomas Jouley2	*
line_49	Lion C1	Thomas Jouley2	*
line_50	Motiv & Collins	Lion A2	*

** Information redacted for confidentiality*

Chargers: To charge the buses in 4b, the optimal options are

- 14 Blink IQ200 with maximum charging rate of 19.2 kW
- 1 EVBox Business Line with maximum charging rate of 7.7 kW

Onsite DERs: In Phase 4b, we see the investment in a 301 kW solar rooftop PV system. The solar system produces about 408 MWh every year. About 29% of the solar energy is directly used for bus charging, while the remaining 71% 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 277 kW. However, the maximum peak load on the grid does not exceed 158 kW at any point in time. This is because the optimal charging behavior relies on high level of charging from solar PV in the middle of the day, while spreading charging throughout the remainder of the day to minimize energy costs and demand charges; not all buses charge at maximum rate at the same time.

Economics: The total cost of ownership for the electric fleet in Phase 4b over 20 years is detailed in *Table 14* below.

Table 14: Total Cost of Ownership for Phase 4b

Cost	Value ($)	Contribution to TCO (%)
Electric Buses – CAPEX	*	85.6%
Charging Stations – CAPEX	*	2.7%
Charging Stations – OPEX	*	0.7%
Solar PV – CAPEX	*	6.8%
Solar PV – OPEX	*	0.8%
Battery storage – CAPEX	*	0.0%
Battery Storage – OPEX	*	0.0%
Grid energy supply – OPEX	*	3.4%

** Information redacted for confidentiality*

GHG Emissions: The analysis shows that transitioning GUHSD fleet in Phase 4b from diesel to electric reduces the GHG emissions from the buses by about 87%. The total carbon emissions associated with electric bus charging over 20 years is estimated to be 2,000 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 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. Furthermore, the 2,000 MtCO2 factors in only 29% of the onsite solar PV generation used to directly charge the buses; it does not account for the clean energy that was generated by the system and fed into grid.

Optimal Charging

Energy flows: *Figure 22* shows all seven energy flows in and out of the system, on daily basis over the 28th week of the summer season. The results show how the majority of daytime solar generation is fed back into the grid both in the morning and in the afternoon, since the buses are away completing their trip. 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. Grid electricity is used to fulfill remaining charging needs after midnight and in the evening when needed.

Charging profiles: *Figure 23* and *Figure 24* focus on the bus charging profiles. *Figure 23* shows the stack of charging profiles for every bus in Phase 4b, and *Figure 24* shows the sources of electricity used to charge these buses. Some key takeaways:

- Charging is completed to 90% by 5:00 a.m. every weekday, at which point in time the buses may begin their trips. To optimize charging profiles, buses charge during multiple periods on weekdays and weekends.

- During weekdays, bus charging occurs during three time periods: after midnight and through the early morning hours, in the middle of the day after the morning trips, and occasionally also in the evening after the afternoon trips. The maximum charging rate reaches 277 kW, with peak load from the grid at 158 kW.
  - Between 9:00 pm and 5:00 am, the buses charge consistently from the grid, benefiting from off-peak and super-off-peak rates.
  - In the middle of the day, between 10:00 am and 12:00 pm, significant amount of charging occurs. The majority of charging is enabled by solar PV, with additional supply from the grid at off-peak rates.
  - Occasionally, buses charge during on-peak hours between 5:00 pm and 9:00 pm, primarily due to the unique construct of Tiered NEM. To explain this in more depth: solar generation results in NEM credit surplus for the on-peak tier in two occasions: between 4:00 pm and 5:00 pm on weekdays when buses are still “out” completing their trips, as well as on Saturdays and Sundays when buses do not need to charge in the afternoon. That credit surplus is then depleted during weekdays between 5:00 pm and 8:00 pm when buses are back to depot and ready to charge. 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 solar generation and the Tiered NEM construct.
- On weekends (Satuday and Sunday), the buses continue to charge in the morning directly from solar. While all charging can be fulfilled by daytime solar, optimal charging requires that the buses also use grid electricity, during off-peak period. The reason for that is also uniquely attributed to the Tiered NEM construct. The supply of energy from the grid on weekends allows consuming the surplus in NEM credits during the off-peak period.

<u>Buses’ State of Charge:</u> The state of charge (SoC) for all the buses in the fleet follow a similar pattern, regardless of the size of bettery (*Figure 25*).

- As previoulsy noted, charging is completed to 90% by 5:00 am every weekday, at which point in time the buses may begin their trips. Similarly, at no point in time will buses fall between a 10% SoC, providing a energy buffer in case of emergency.
- During the middle of the day, in between the morning and afternoon trips, all buses charge for at least one hour.

<u>NEM Credit Balance:</u>

- As mentioned before, Tiered NEM shifts some of the optimal charging behavior to ensure maximum utilization of solar credits and minimum total cost of ownership. Of the total 408 MWh of electricity generated by the PV system each year, about 120 MWh are used to directly charge the buses and 288 MWh are fed into the grid to generate NEM credits.
- As shown in *Figure 26*, those credits fall under the three tiers: 31 MWh on-peak, 177 MWh off-peak, and 80 MWh super-off-peak. The value of on-peak NEM credits is the highest, followed by off-peak credits and lastly super-off-peak credits. Optimal charging requires energy credits to balance energy expense as closely as possible.
- For Phase 4b, the portfolio of credits is effectively balanced, ensuring maximum utilization of credits throughout the year. Overall, there is less than 9% imbalance (surplus) in credits across all tiers for fleet charging in Phase 2. In other word, only 9% of the credits are not utilized and lost at the end of each year, primarily on-peak and off-peak credits. The 9% lost credit is equivalent to only 6% of the total solar energy in that year.
- *Figure 27* further emphasizes the optimization of solar energy supply and consumption. Within the on-peak and off-peak tiers, only a small fraction of solar energy is not utilized. Within the

super off-peak tier all solar energy is utilized (in addition to substantial amount of grid electricity).

Figure 22: Energy Flows for Phase 4b - Summer

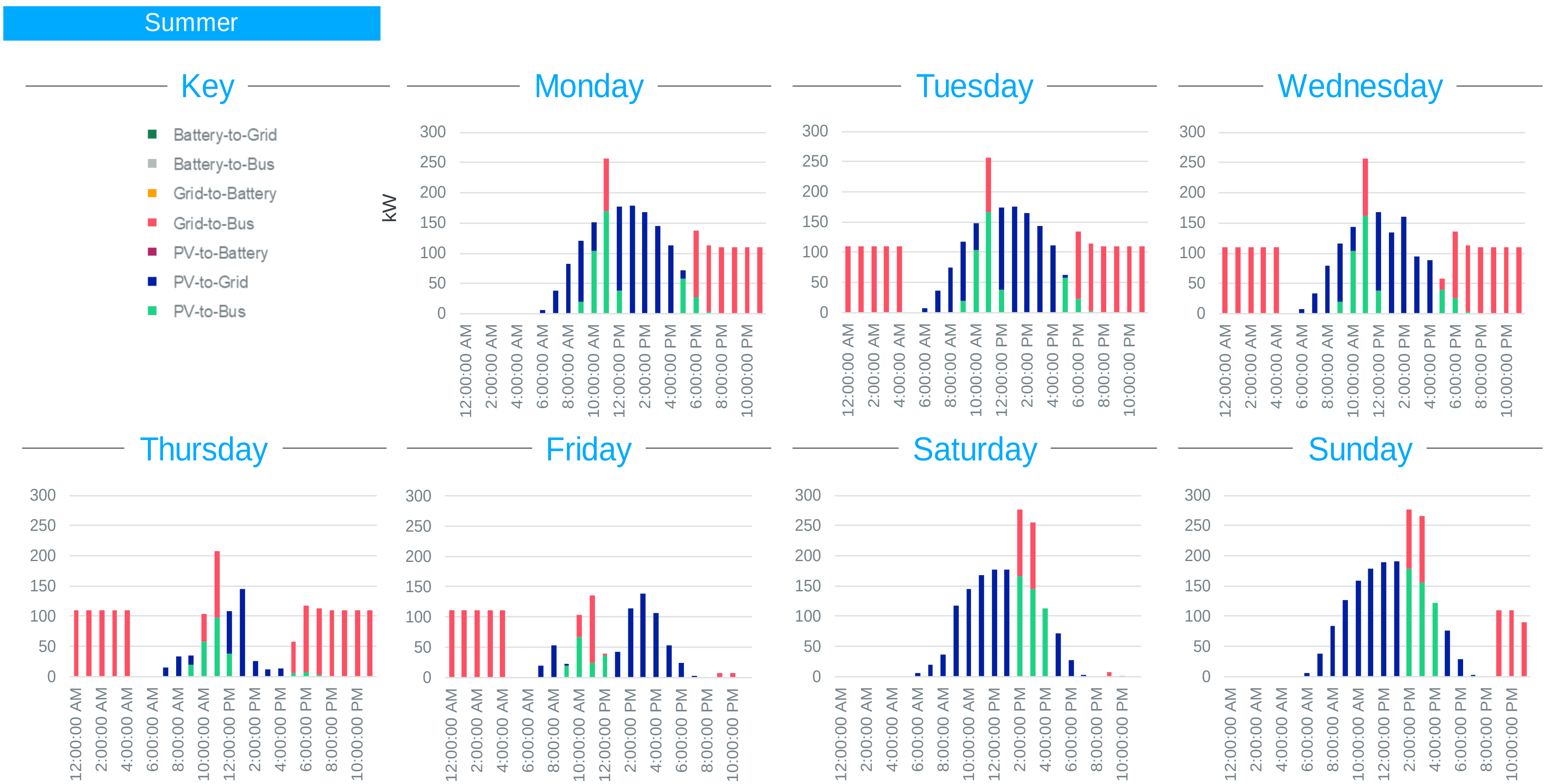


Figure 23: Charging Profiles for Phase 4b – Summer

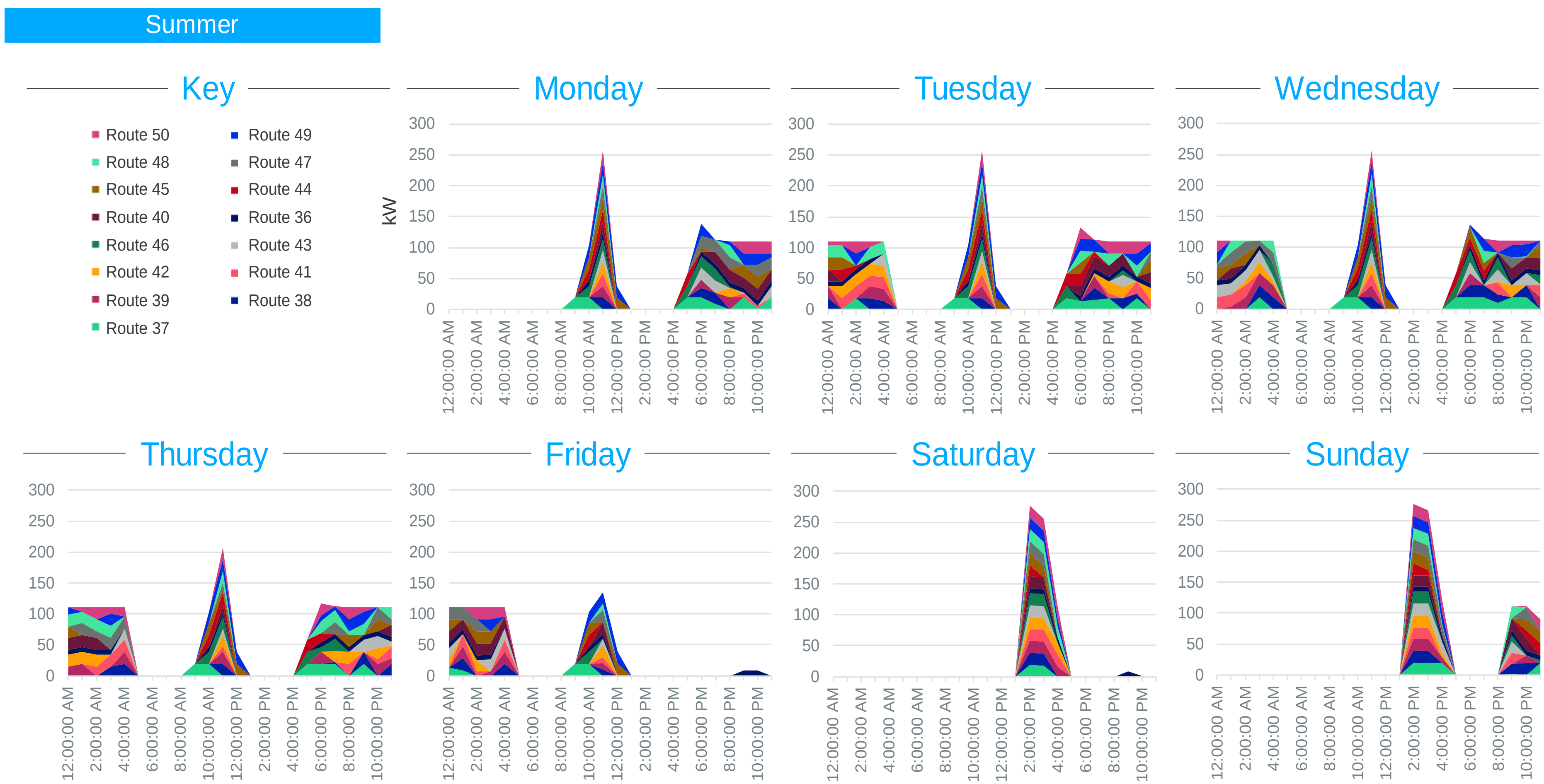


Figure 24: Sources of Energy for Bus Charging in Phase 4b – Summer

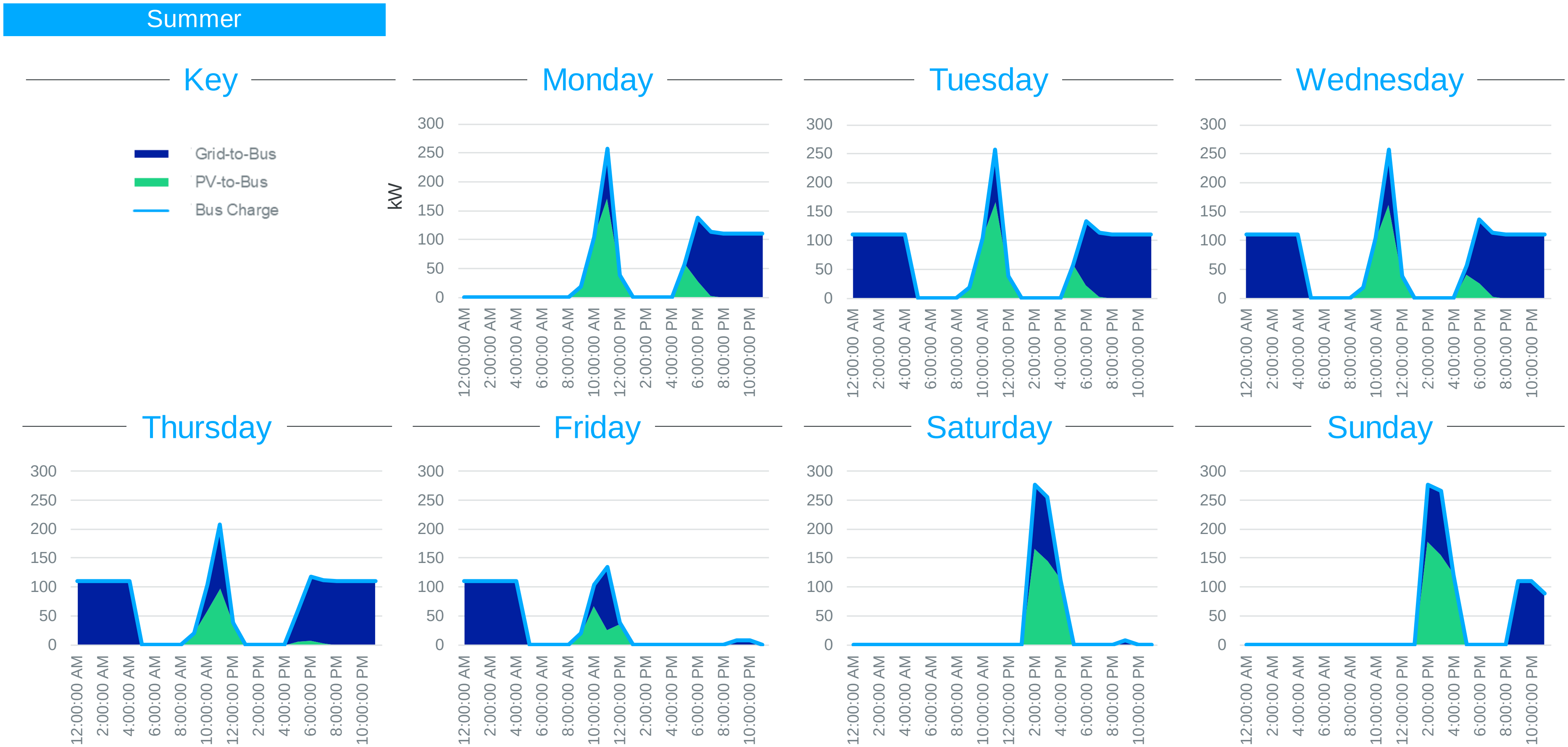


Figure 25: Weekly State of Charge for Phase 4b – Summer

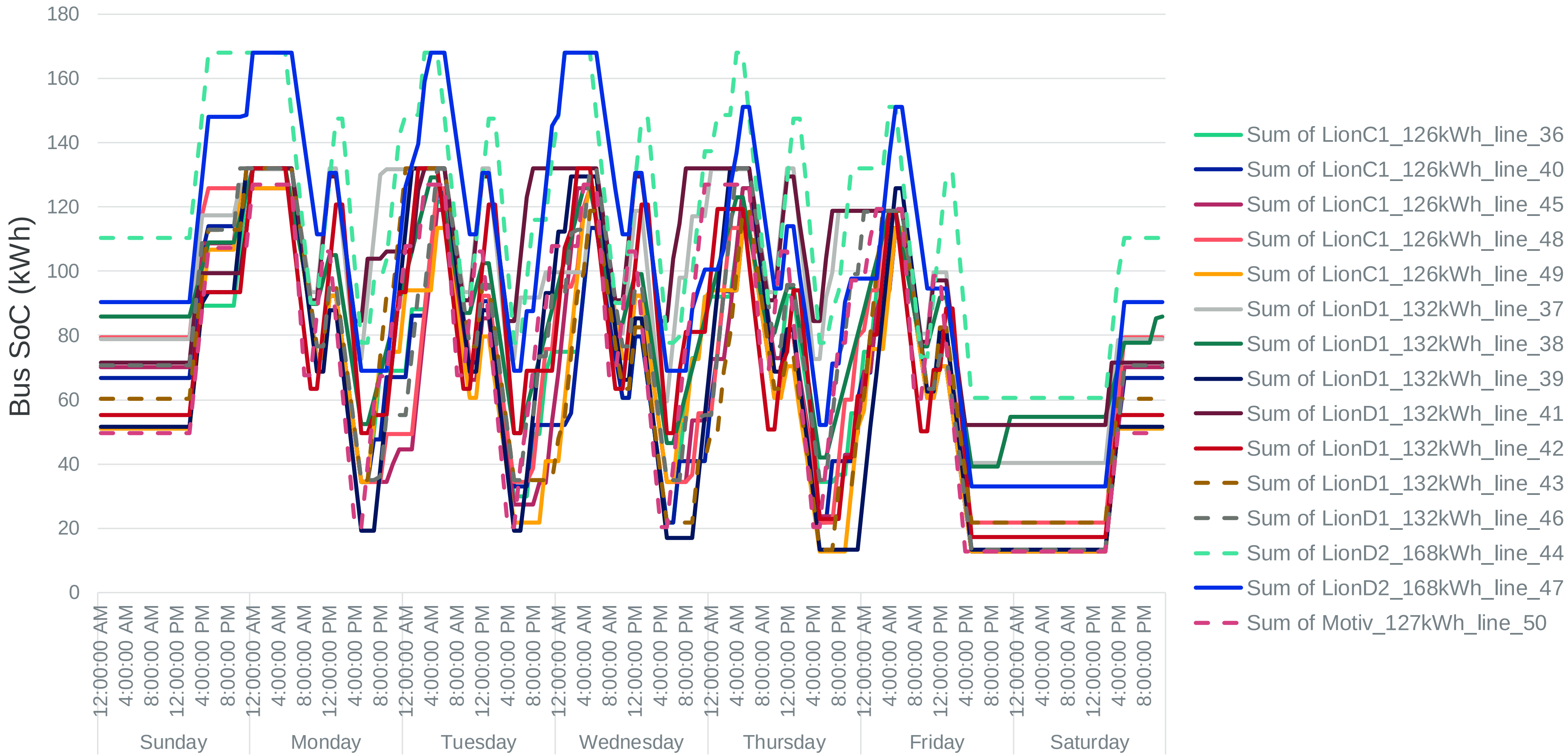


Figure 26: Tiered NEM Credit Balance for Phase 4b

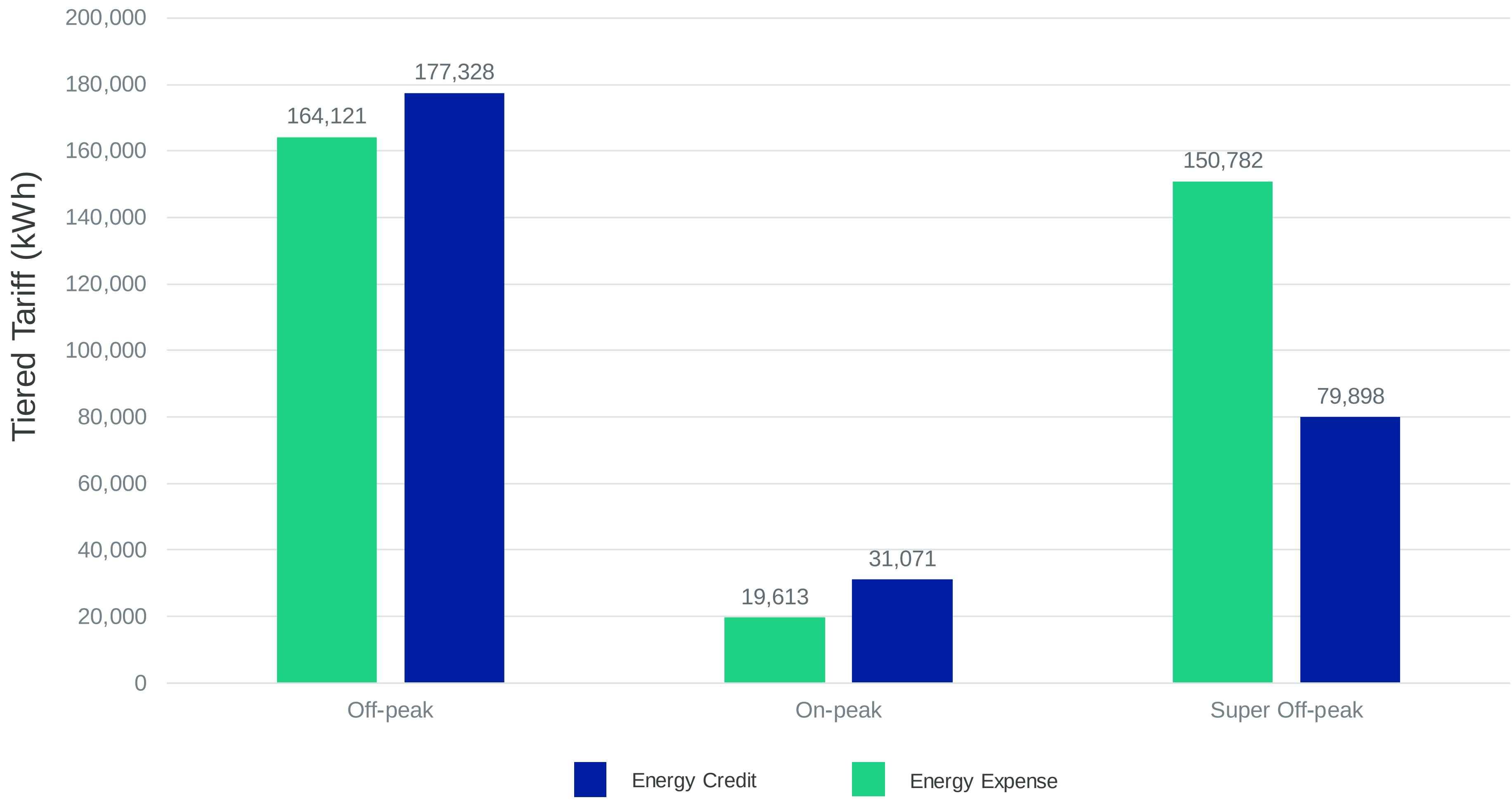
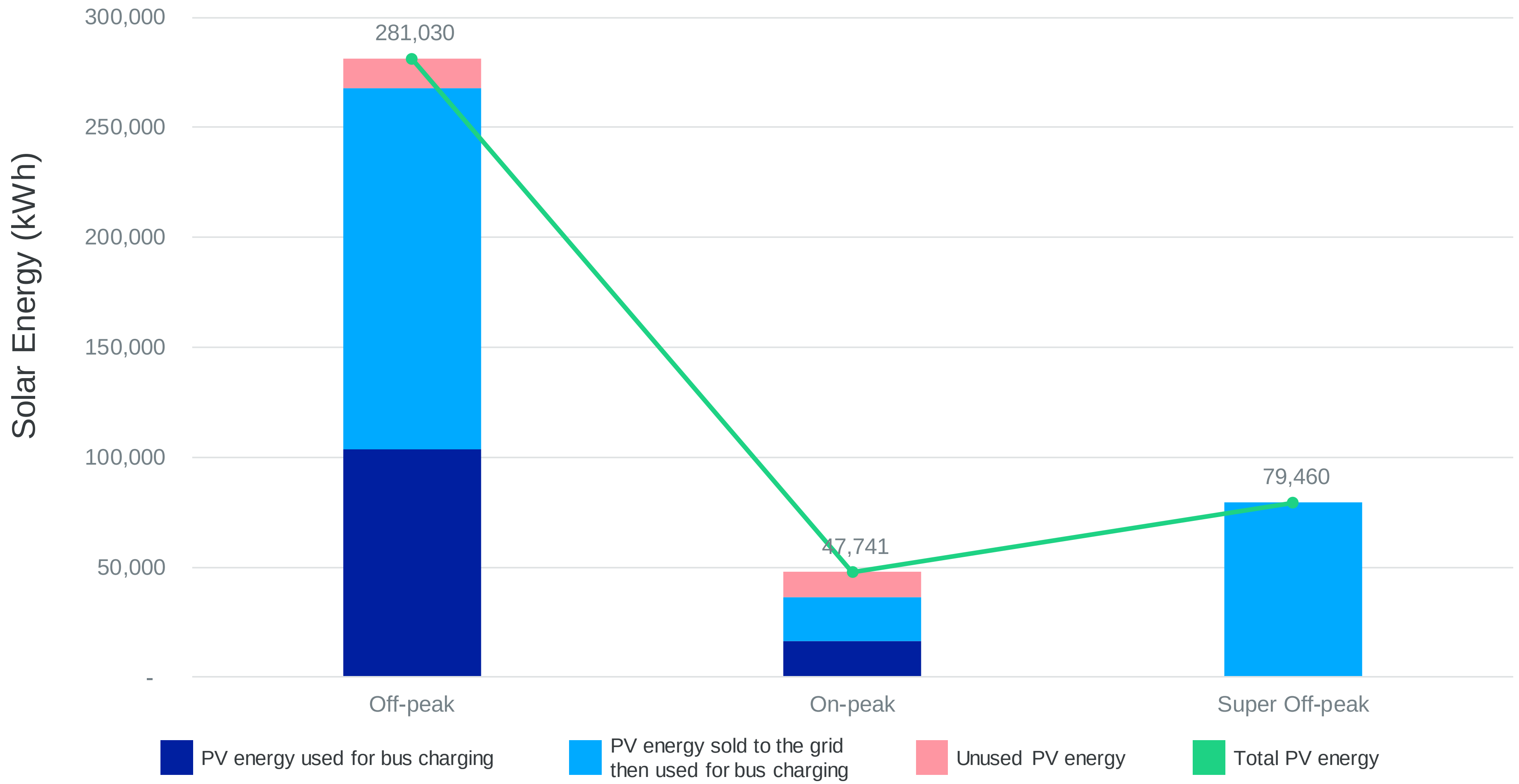


Figure 27: Solar Energy Generation and Consumption for Phase 4b



Procurement Guidelines & Recommendations

Electric Buses

Major takeaways:

1. We recommend limiting the supply of electric buses to no more than two automakers. The two automakers whose product offerings seem to best fit GUHSD fleet needs are either the portfolio of Lion buses, or combination of Thomas//Proterra and Motiv buses.
    - Rationale: Help to reduce service expenses and operational hassle while streamlining implementation.
2. In routes where a bus is barely meeting range & seat capacity needs, a larger bus should be selected: For all phases, diesel buses with original seating capacity of 28 seats could be replaced with 24 seat or 50+ seat buses. The larger buses are selected, to benefit from larger batteries and longer driving range.
    - Rationale: more effective for the future expansion of routes, flexible scheduling, and offering grid services.
3. There is a tradeoff between bus lifetime and purchase unit cost, which has an impact on the TCO of the project. All buses selected for GUHSD electric fleet are promised to have a robust lifetime with 8-12 years warranty.

Questions and confirmation points to include during RFP/Q process:

- OPEX quotes were not readily available from automakers. When issuing a competitive RFP, it is important to acquire concrete information on electric bus OPEX from bidding automakers.
- Similarly, it might be challenging to get detailed visibility into automakers' battery degradation rates. It is important that automakers provide and guarantee battery degradation figures as part of the procurement process. Battery degradation will impact the rate at which vehicles need to be replaced, the ability for a vehicle to service a route, and the overall fleet TCO.
- Confirmation on bus pricing and seating configuration should be emphasized in the RFP/Q process. Prices for bus models may only be provided for one version of the vehicle: with or without wheelchair; with or without range extension, etc. Granular pricing data should be requested for each version and each model.
- It is important to explore all bus warranty options, aiming to understand what is and is not included in them. A major part of this is gaining clarity into the circumstances in which a manufacturer will replace a battery, which is often a major cost in electric buses.
- It is important to confirm what charging stations hardware and charging management software are compatible with the automakers' vehicles.

Charging Stations

Major takeaways:

1. We recommend limiting the supply of EV charging stations to no more than two manufacturers and/or two types. The two charging stations that seem most compatible with GUHSD fleet are AC L2 charging units EVBox Business Line at 7.7 kW and Blink IQ200 at 19.2 kW.

  - Rationale: help to reduce service expenses and operational hassle while streamlining implementation.
2. There should be one dedicated charging spot for each bus. This means either a dedicated charging station or a dedicated charging connector per bus. Though it is technically possible to assign multiple buses to one charging spot, around-the-clock staff attendance would be required to relocate buses on regular basis. The economic savings from fewer chargers are not usually sufficient to justify added operational complexity.
3. Although the charging needs of GUHSD fleet can be met using AC L2 chargers, we recommend at least one additional DCFC charger (with maximum charging rate greater than 50 kW) available for emergency and unplanned maintenance and trips.
4. There is a tradeoff between charger lifetime and per unit cost, which has an impact on the TCO of the project. All EV chargers for GUHSD electric fleet are promised to have a robust lifetime with warranty between 3 and 5 years.

<u>Questions and confirmation points to include during RFP/Q process:</u>

- Quotes for OPEX and EPC for EV charging stations were not readily available from manufacturers. When issuing a competitive RFP, it is important to acquire concrete information on both OPEX and EPC estimates from EVSE manufacturers. EPC estimates may require site visits, and the provided OPEX costs should include networking fees and servicing fees.
- It is important to explore all warranty options, aiming to understand what is and is not covered.
- It is important to confirm what electric buses are compatible with the manufacturers' charging stations. Similarly, it is important to confirm what smart charging software is compatible with the selected chargers.

Energy Supply

<u>Major takeaways:</u>

- Optimizing bus charging based on EV-HP TOU rate ensures compliance with SDG&E's Power Your Drive for fleet program requirements.
- So long as the accounting for onsite solar generation follows Tiered NEM rules, the investment in onsite battery storage is not very favorable. In essence, Tiered NEM allows using the grid as a limited virtual storage system: within each of the three tier (on-peak, off-peak, super-off-peak), credit surplus accumulated during weekends and in the summer is used to cover energy deficits and charge the buses on weekdays and in the winter. However, in this study, excess energy produced by solar during a specific tier cannot be sold during a different tier, e.g.,15 kWh of excess energy produced during off-peak period cannot be sold during on-peak period.
- Battery storage may become more appealing if "aggregated" NEM is available to GUHSD. Under an aggregated NEM structure, all excess solar energy fed into the grid is valued equally, so the solar credits can be used during any time of the day.

<u>Questions and confirmation points to include during RFP/Q process:</u>

- When installing solar, it is important to understand the costs associated with the system and the ownership structures that are available. For example, GUHSD will need to know if it is more cost-effective and operationally-effective to own the solar system or to pay a service fee for a third-party to do so.

- It is important that GUHSD and SDG&E maintain close collaboration, to ensure long-term visibility and guarantee into the utility billing rate and NEM construct that will be applicable for charging the school bus fleet. Ensuring this long-term visibility will allow GUHSD to optimize investment in solar and storage and minimize overall energy expenses.

Appendix

Figure 28: Energy Flows for Phase 2 – Winter

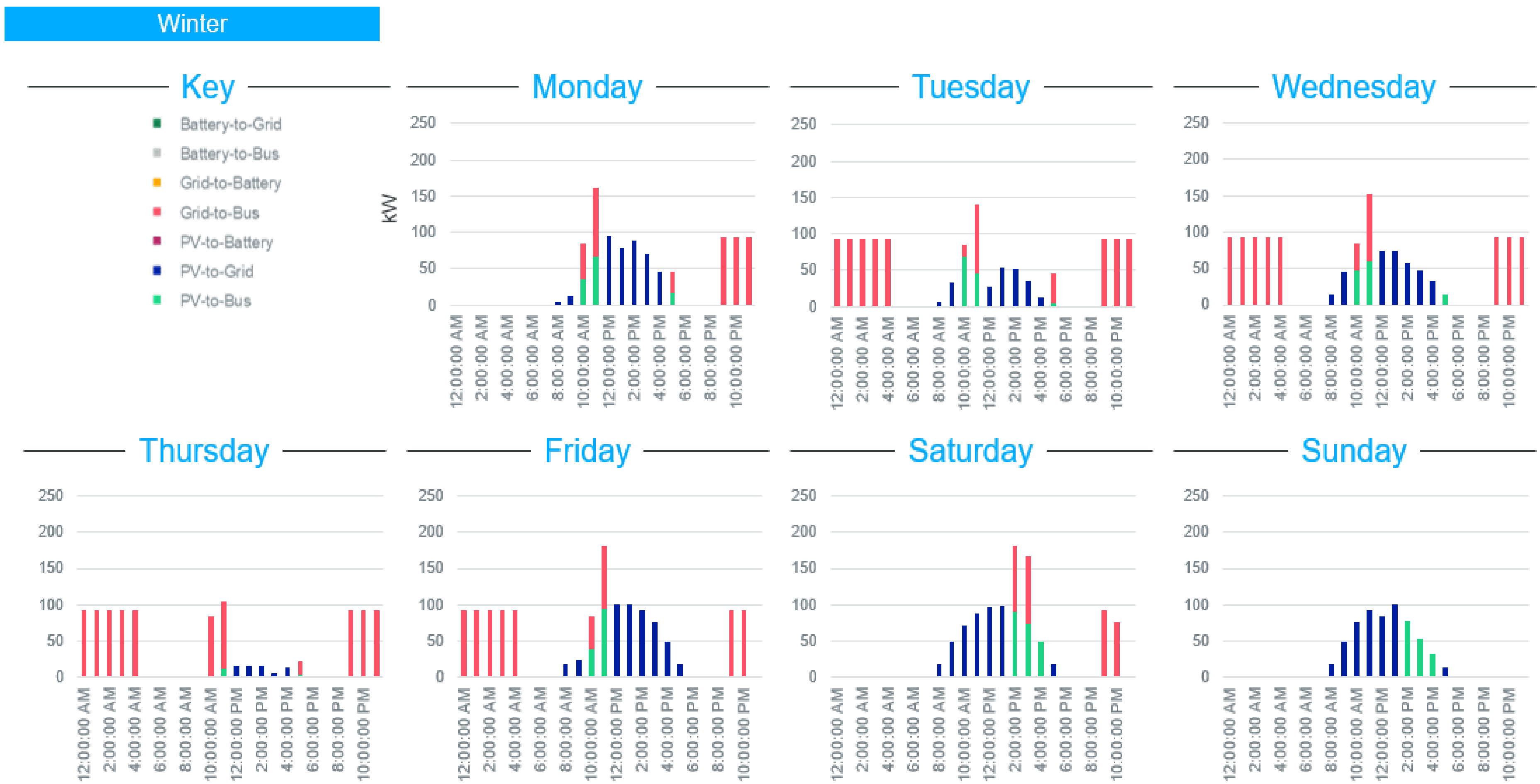


Figure 29: Charging Profiles for Phase 2 – Winter

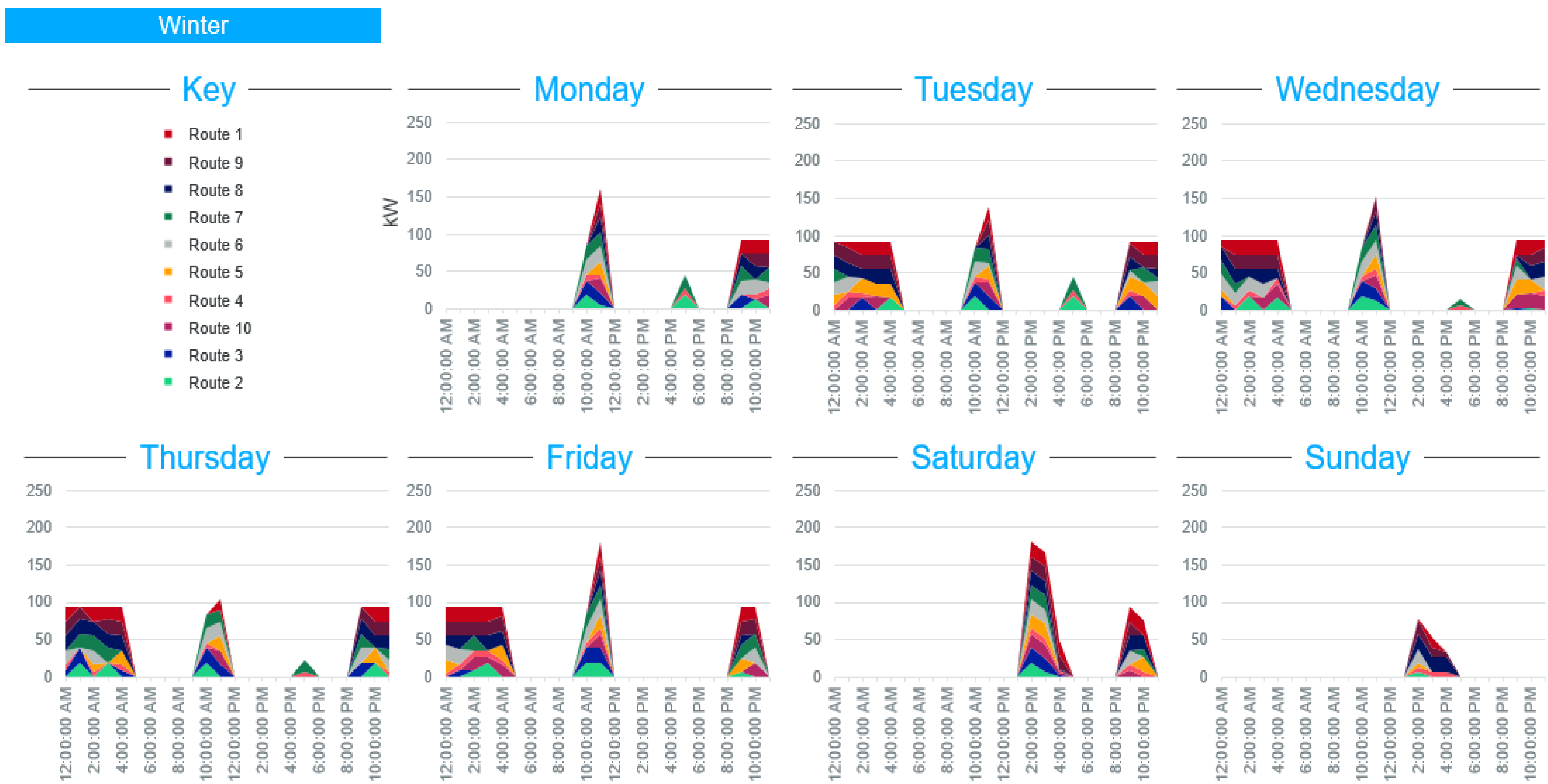


Figure 30: Sources of Energy for Bus Charging in Phase 2 – Winter

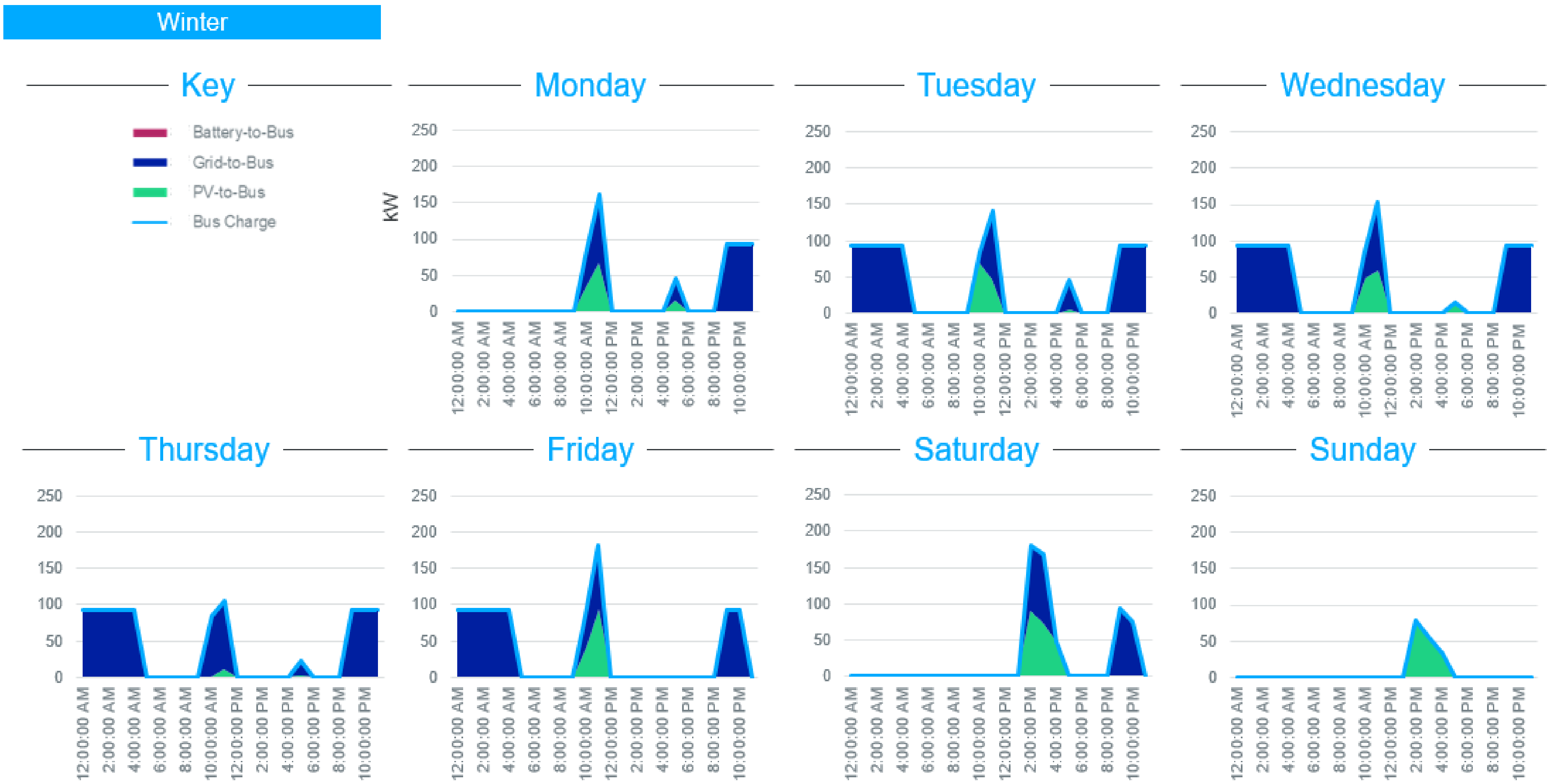


Figure 31: Energy Flows for Phase 3 – Winter

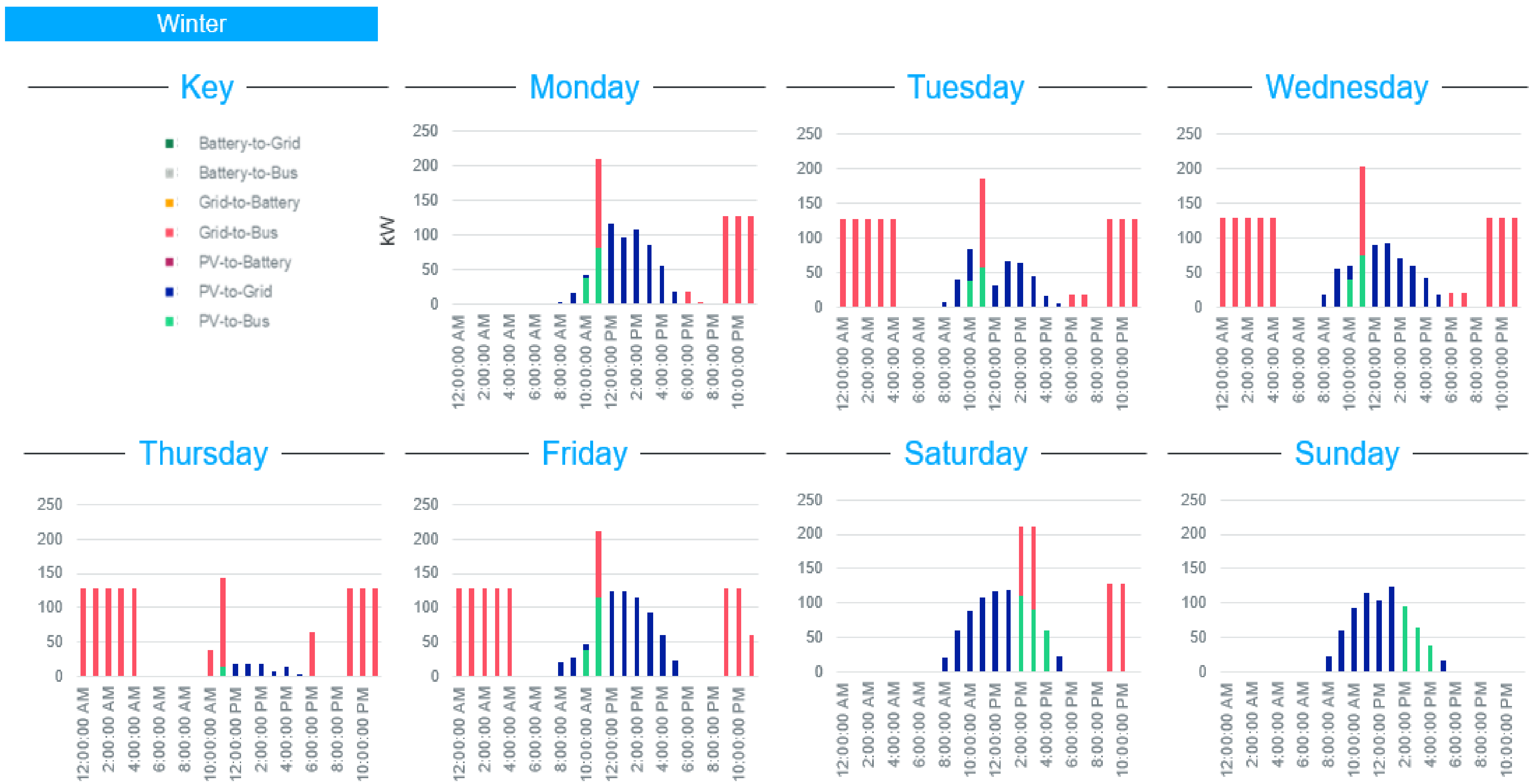


Figure 32: Charging Profiles for Phase 3 – Winter

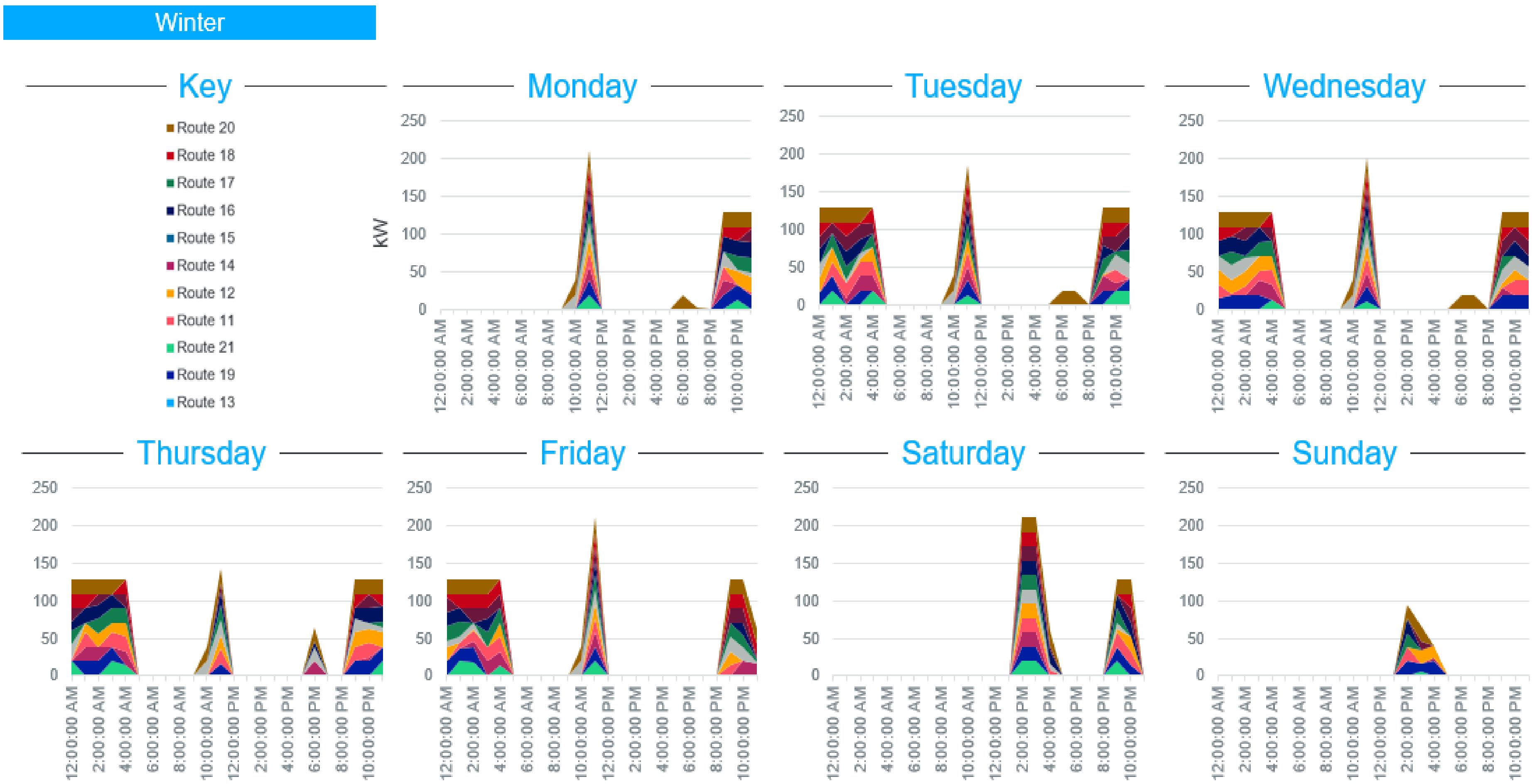


Figure 33: Sources of Energy for Bus Charging in Phase 3 – Winter

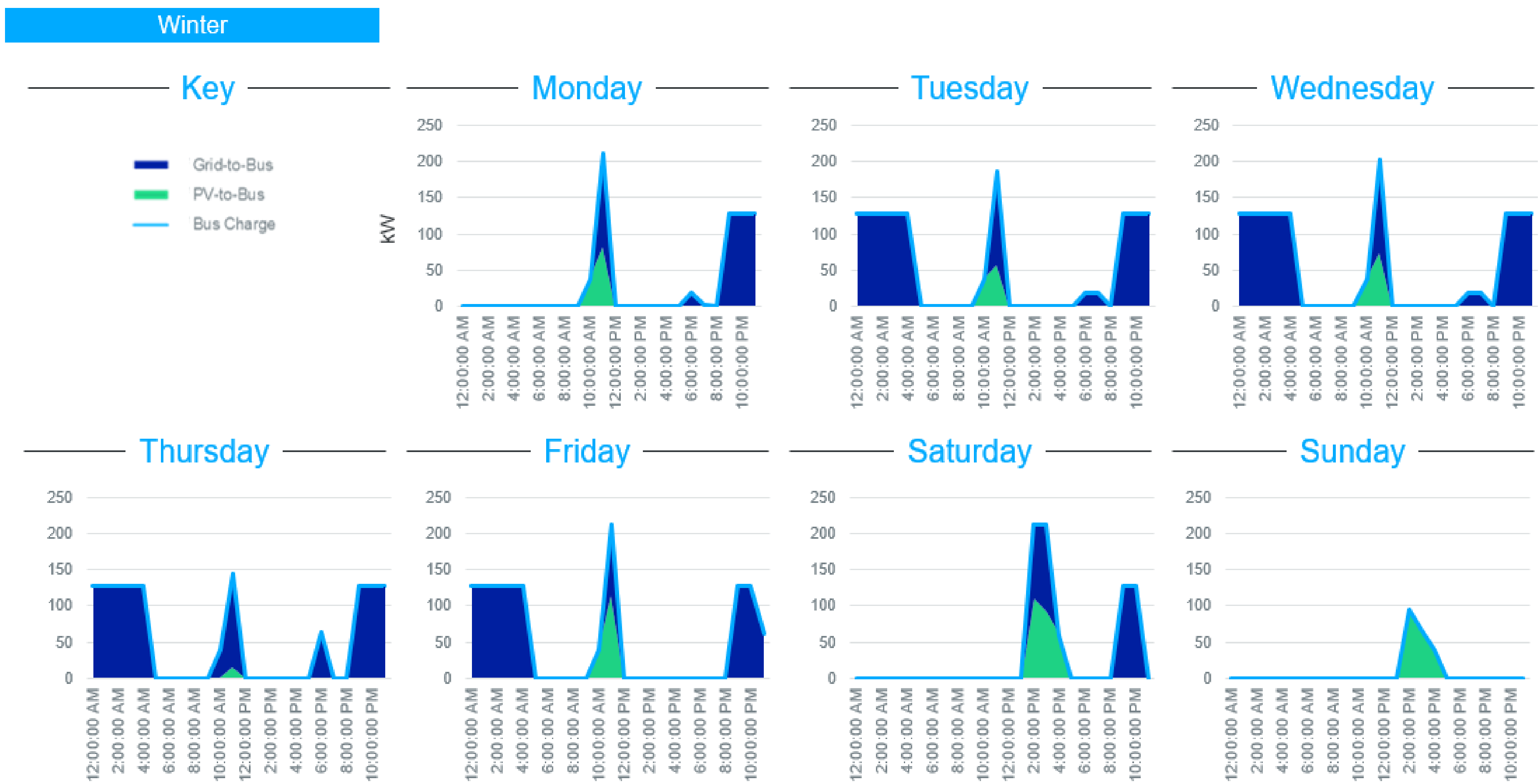


Figure 34: Energy Flows for Phase 4a – Winter

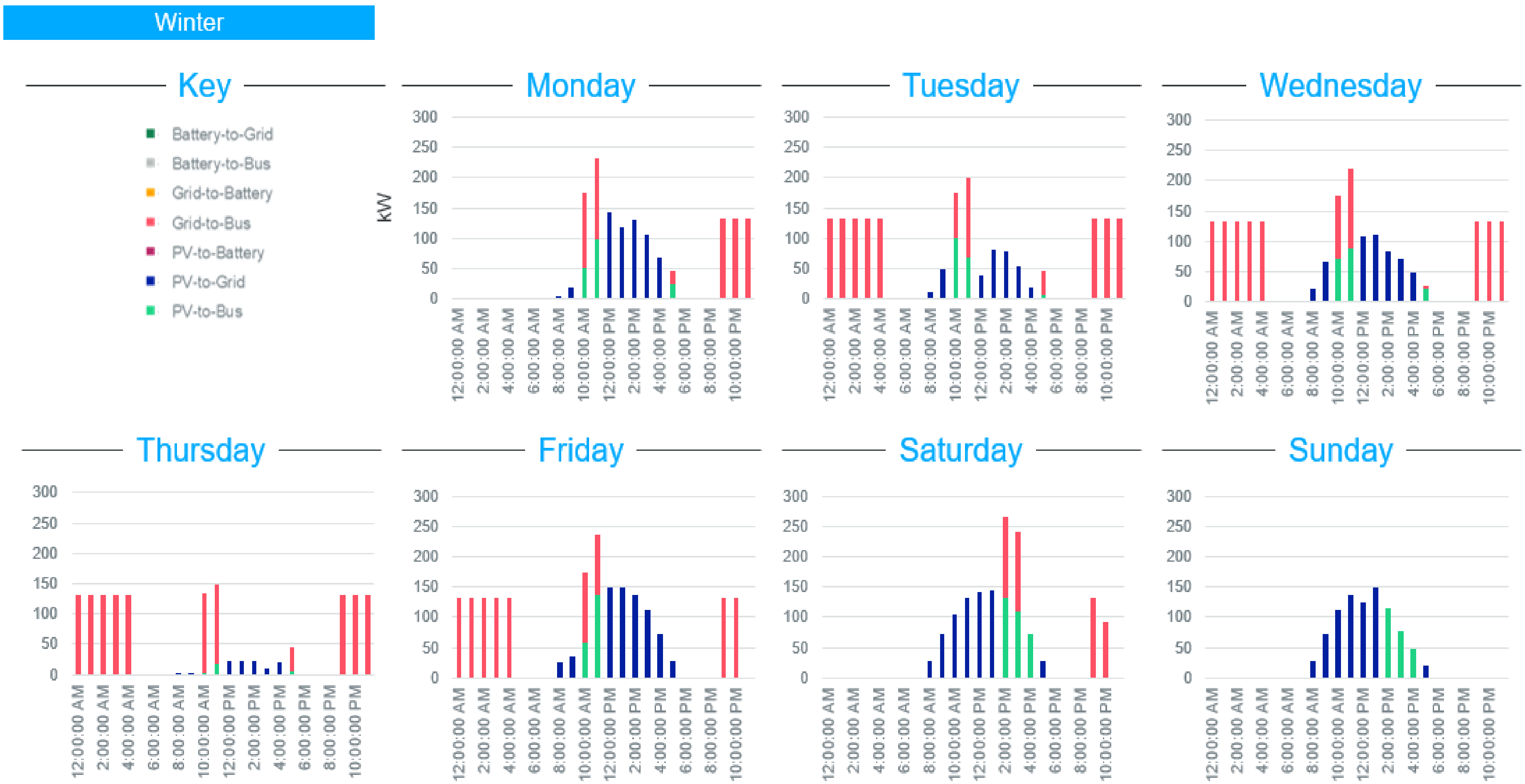


Figure 35: Charging Profiles for Phase 4a – Winter

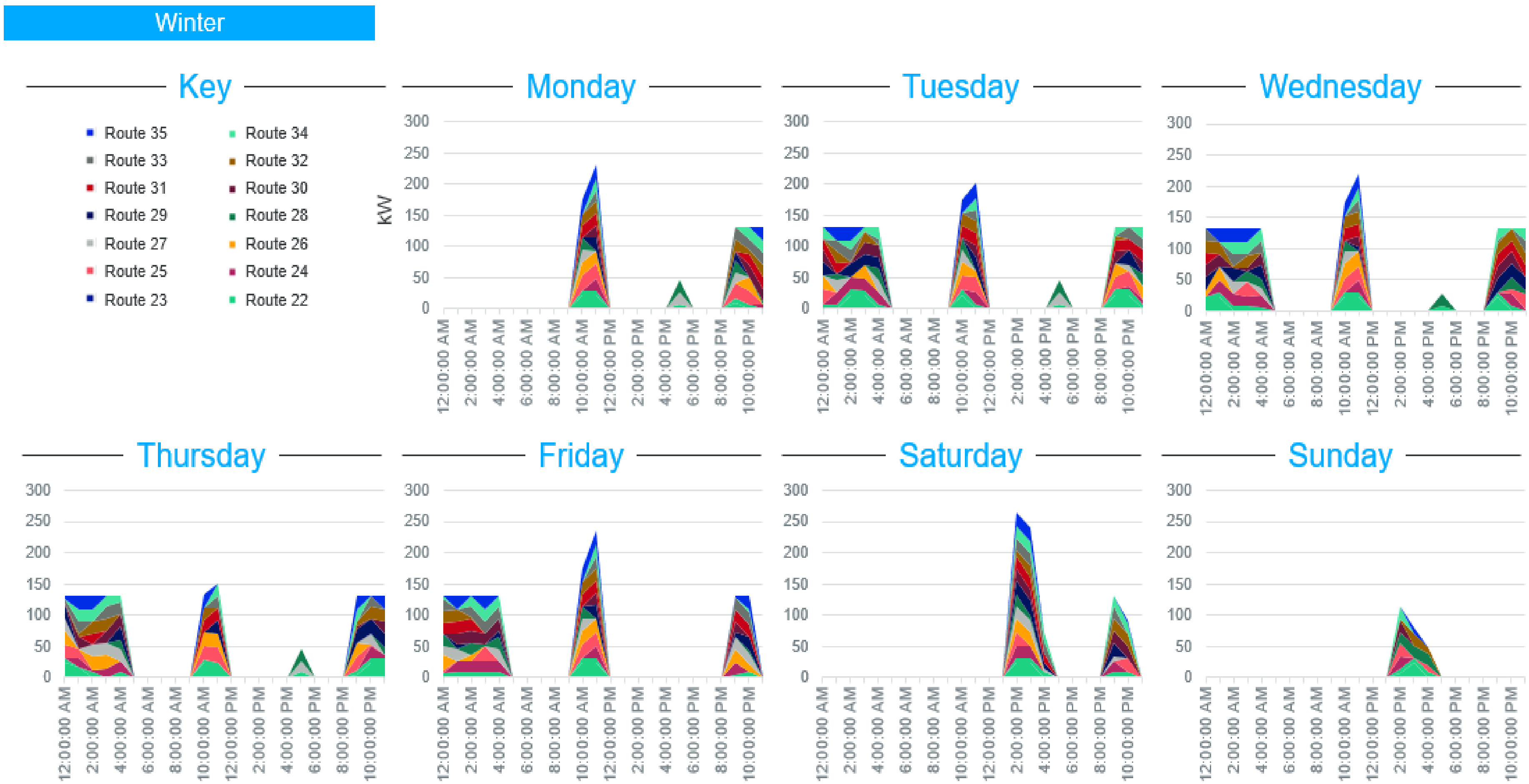


Figure 36: Sources of Energy for Bus Charging in Phase 4a – Winter

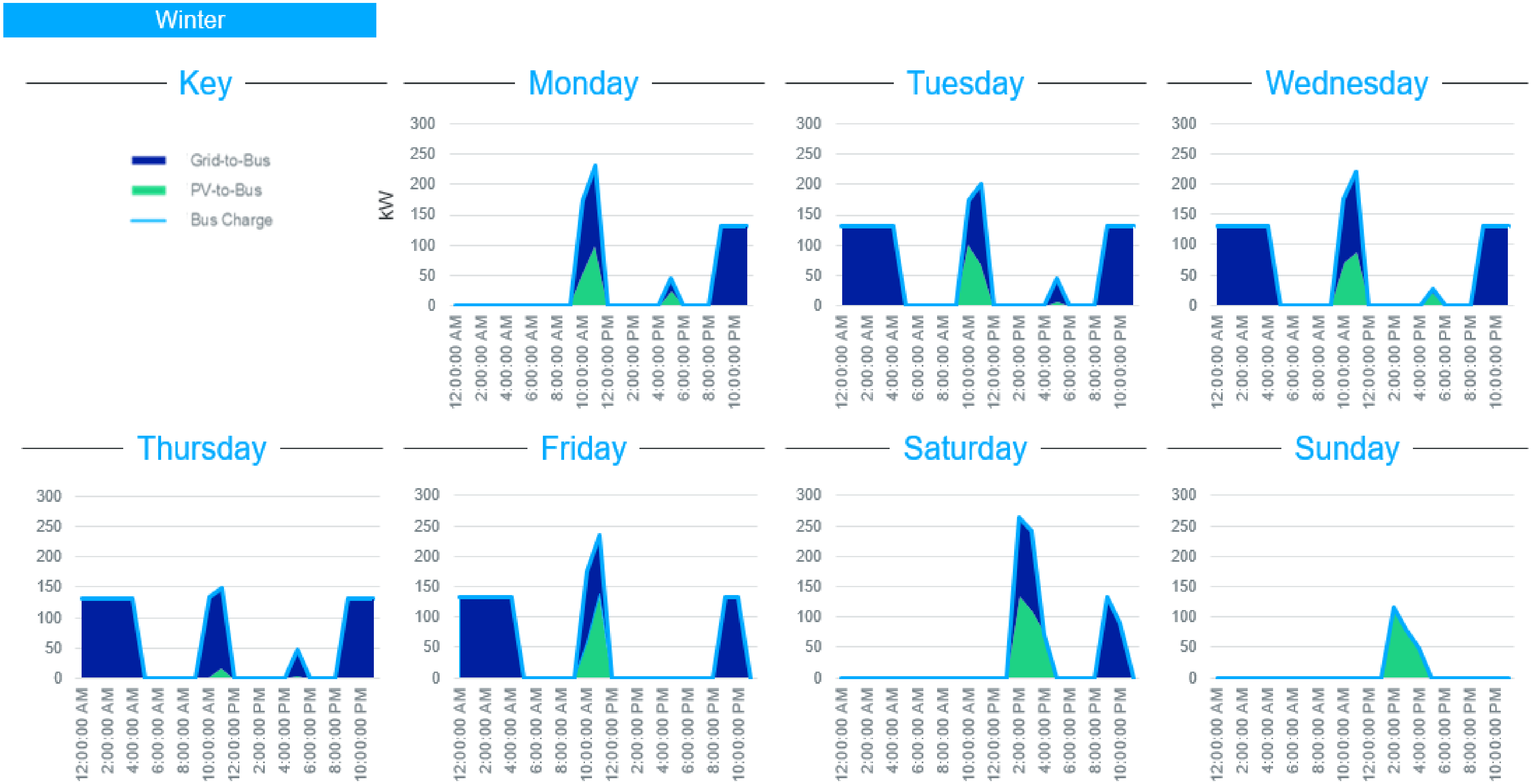


Figure 37: Energy Flows for Phase 4b – Winter

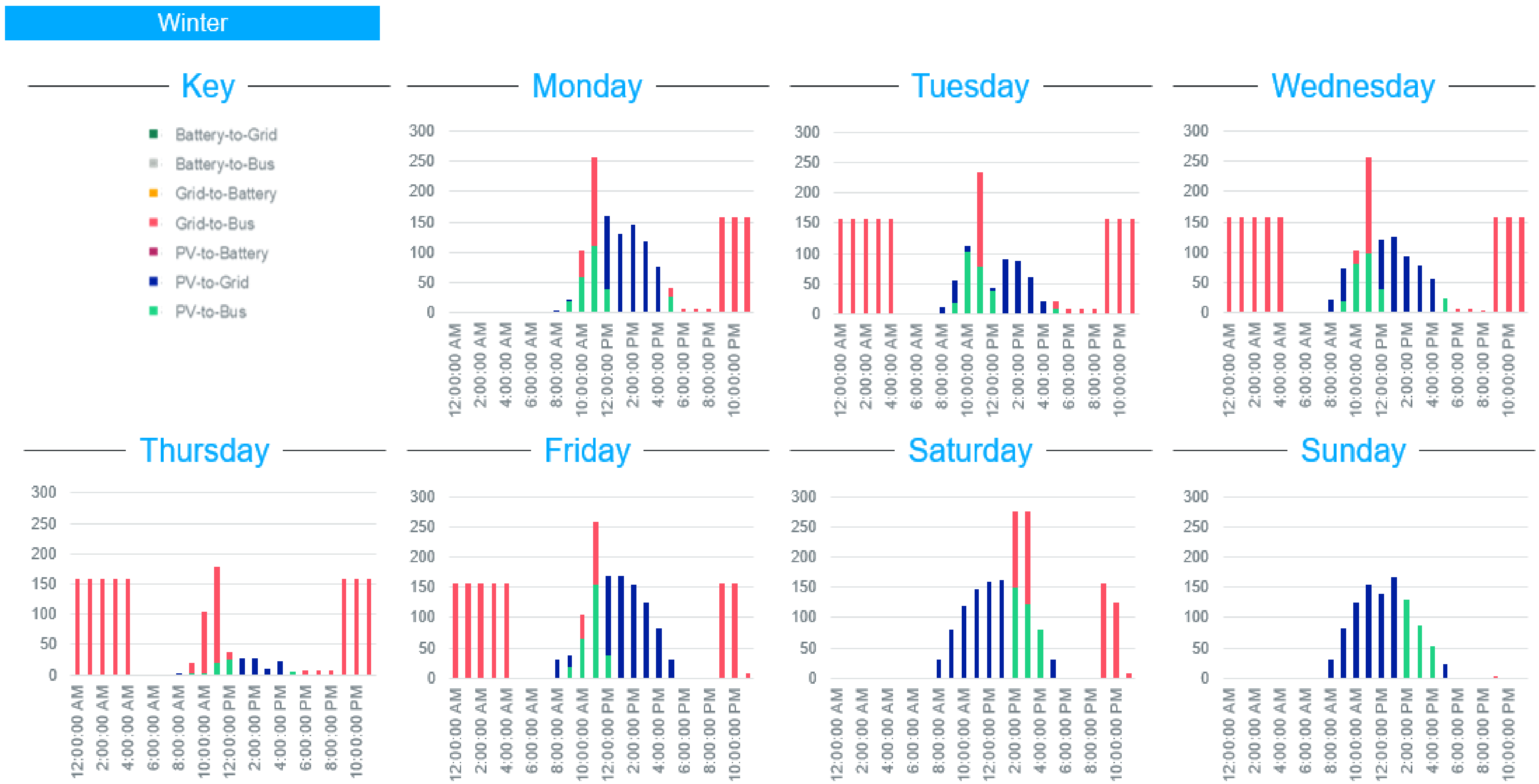


Figure 38: Charging Profiles for Phase 4b – Winter

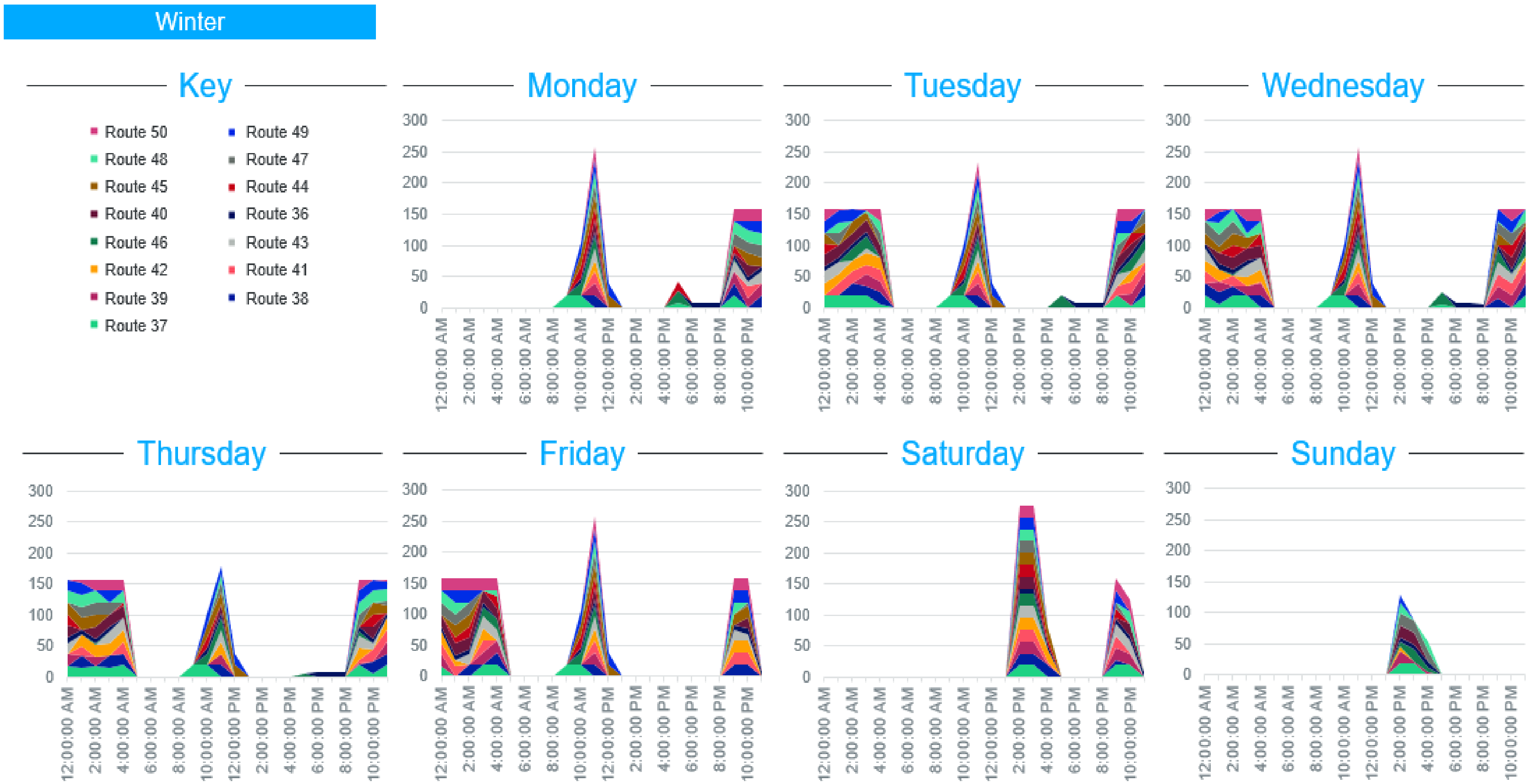


Figure 39: Sources of Energy for Bus Charging in Phase 4b – Winter