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Hourly Load Profile Dataset for Electric Transit Bus Depots in the United States

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Technical Report
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List of Acronyms

BEB	battery-electric bus
DCFC	direct current fast charger
dVMT	daily vehicle miles traveled
GTFS	General Transit Feed Specification
NTD	National Transit Database
VOMS	vehicles operated in maximum service

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1 Introduction

Medium- and heavy-duty trucks and buses are the second-largest source of transportation-related greenhouse gas emissions in the United States (Environmental Protection Agency 2024) and are significant contributors to local air pollution. Transit buses, in particular, operate primarily in dense urban areas, where nearby populations face increased exposure to fine particulates, nitrogen oxides, and other harmful pollutants (Martinez and Samaras 2024; Holland et al. 2021; Liu 2020). Electrifying transit buses presents a clear opportunity to reduce greenhouse gas emissions and improve urban air quality. However, widespread adoption may pose significant energy and infrastructure challenges, which can be mitigated through proactive planning and investment.

Transit bus depots, where electric buses are typically charged overnight or during off-shift hours, can experience concentrated electricity demand as fleet electrification grows. This increased demand may require a combination of targeted grid infrastructure upgrades (particularly in regions with limited capacity), strategic energy management approaches, and coordinated planning across transit agencies, utilities, and policymakers.

Projecting future electricity demand at transit bus depots is critical for effective infrastructure planning. However, existing datasets and methodologies often lack the necessary scope and resolution. To address this gap, this report presents a robust modeling framework and an initial estimation of the hourly electricity demand at transit bus depots across the United States. The resulting depot-level dataset, available at data.nrel.gov/submissions/282, provides valuable insights for infrastructure planning and electricity demand forecasting, supporting the scalable electrification of transit bus fleets nationwide. Further feedback from stakeholders can be incorporated to refine the approach and improve load projections to better facilitate planning.

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2 Methods

The national modeling framework described here builds upon approaches outlined in Bruchon et al. (2024) and Liu (2020). Figure 1 presents an overview of this framework, which includes estimating the depot-level battery-electric bus (BEB) stock, clustering transit agencies on key operational characteristics, developing weeklong transit bus operating profiles, and simulating bus-level charging behavior using the National Renewable Energy Laboratory's EVI-Pro model.

The framework relies on two primary data sources:

- **National Transit Database (NTD):** The NTD serves as a central hub for financial, operational, and asset information from transit agencies across the United States (Federal Transit Administration 2023). The 2021 Annual Database is used to identify the sizes and locations of bus depots, estimate the transit bus population, develop metrics for transit agency clustering, and support the development and sampling of weeklong transit bus operating profiles.
- **General Transit Feed Specification (GTFS):** GTFS is an open standard used by transit agencies to publish their service schedules ("GTFS Schedule") and real-time operations data ("GTFS Real-time"). Both datasets are used in this analysis to generate the transit bus operating profiles for each transit agency cluster.

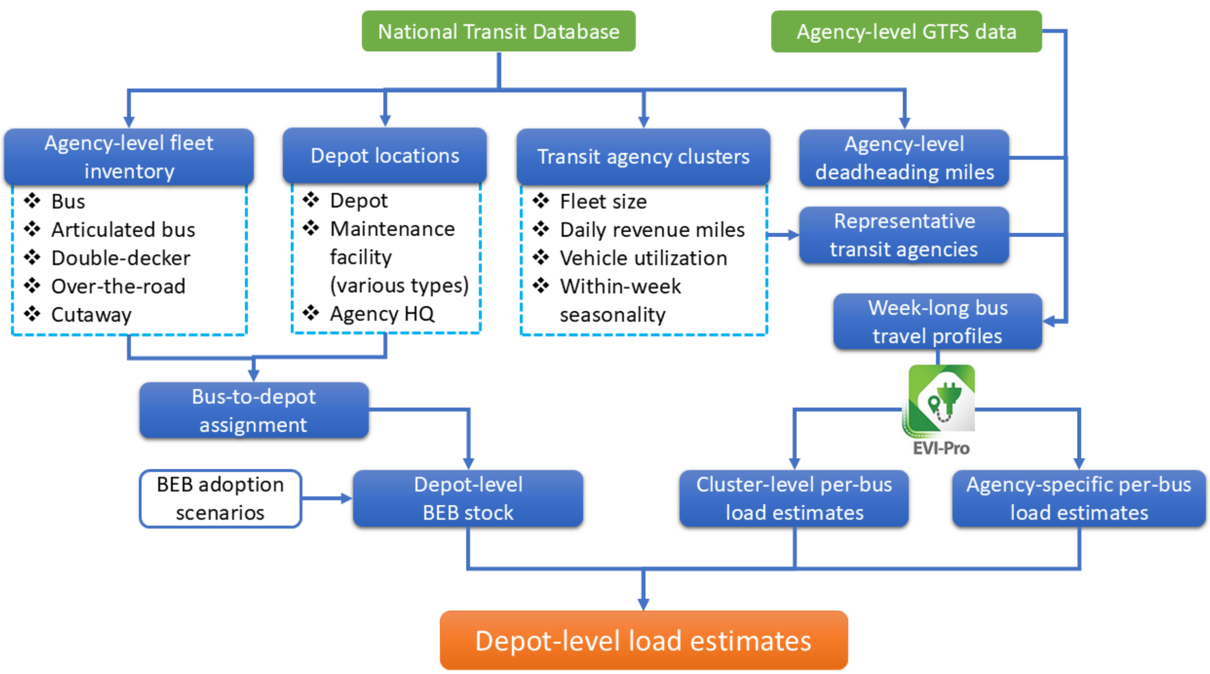

Figure 1. National electric transit bus modeling framework

2.1 Depot Identification and BEB Stock Estimation

Transit bus depots are identified using data from the NTD Facility Inventory table. Facilities primarily serving the following NTD modes are considered: bus ("MB"), commuter bus ("CB"), bus rapid transit ("RB"), and demand response ("DR"). Additionally, the following facility types

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are included: general-purpose maintenance facility/depot, maintenance facility (service and inspection), and combined administrative and maintenance facility.

For transit agencies without facility inventory data, the agency headquarters, as reported in the NTD Agency Information table, is used as a proxy for depot location. Agency-level transit bus populations are estimated as the number of active vehicles with eligible bus body types, including "bus," "articulated bus," "over-the-road bus," "double decker bus," and "cutaway." For agencies with more than one depot, buses are allocated to each location proportional to its geographic footprint (i.e., the total square footage of all facilities at a given location).

According to the NTD 2021 Annual Database, there are 2,393 transit agencies operating more than 106,000 transit buses across 2,735 bus depots in the United States (Figure 2). Depot-level BEB stock is estimated based on the total transit bus population at each depot and scenario-based BEB adoption rates, ranging from 10% to 100%.

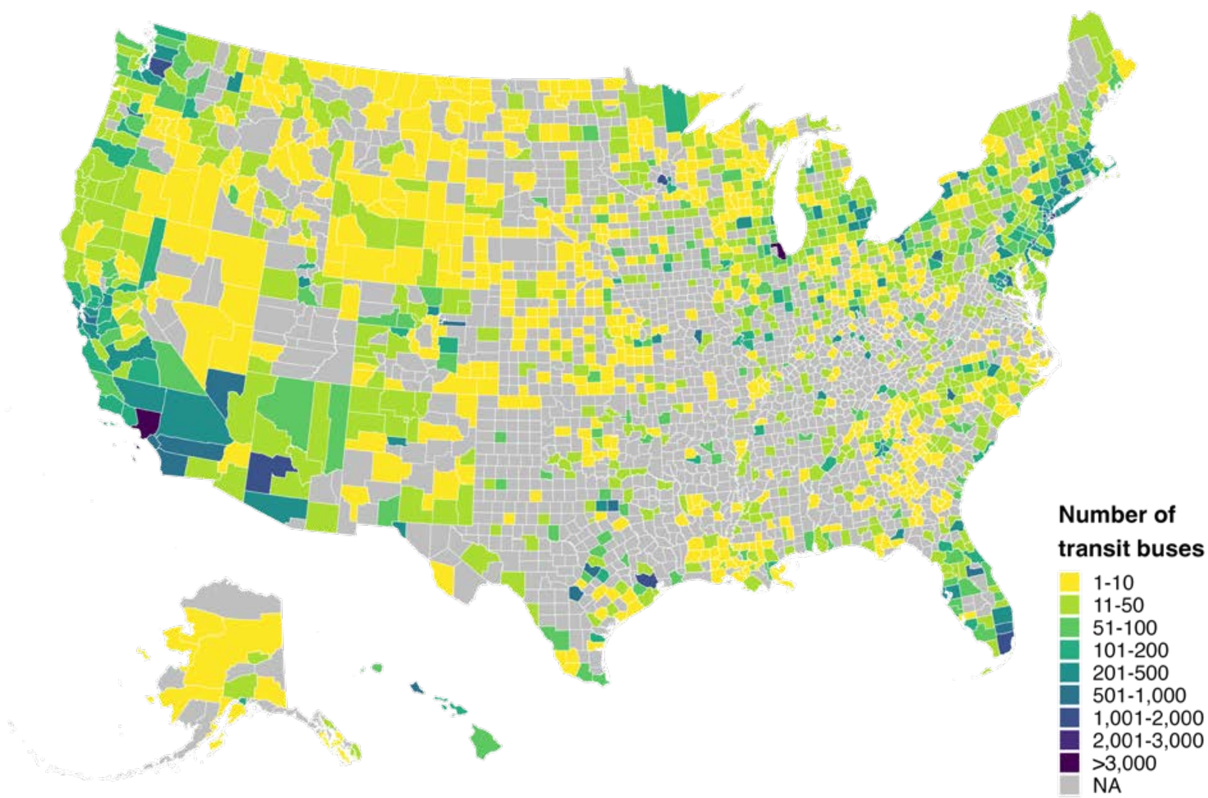

Figure 2. County-level transit bus population in the United States.

Source: Bruchon et al. (2024)

2.2 Transit Agency Clustering

Due to the limited availability of GTFS data, a k-means clustering analysis was conducted to extrapolate bus operations from a sample of representative transit agencies with publicly available GTFS data to the broader population. Following the methodology described in Bruchon

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et al. (2024), the largest U.S. transit agencies are first extracted, with the remaining agencies clustered on the following four variables:

1. **Fleet size:** Number of active buses (NTD Revenue Vehicle Inventory table).
2. **Daily vehicle miles traveled (dVMT):** Average daily revenue miles per operating bus (NTD Service table).
3. **Fleet utilization ratio:** Ratio of buses operated in peak service (i.e., vehicles operated in maximum service [VOMS]) to the number of total active buses (NTD Revenue Vehicle Inventory table). A lower ratio indicates excess fleet capacity.
4. **Weekly seasonality index:** Ratio of the minimum to maximum number of buses in service throughout the week (NTD Service table).

Further details on the clustering methodology are available in Bruchon et al. (2024). In that study, demand-response transit services were excluded from the analysis due to insufficient operational data. However, for this analysis, they are included, with an additional cluster introduced to represent agencies providing these services.

In total, seven transit agency clusters are identified:

1. Large agency.
2. Mid-sized agency.
3. Small agency with high dVMT, weekend service, and high bus utilization.
4. Small agency with high dVMT, weekend service, and low bus utilization.
5. Small agency with high dVMT and no Sunday service.
6. Small agency with low dVMT.
7. Small agency providing demand-response transit services only.

2.3 Weeklong Travel Profile Generation and Sampling

For all agencies in the large agency cluster (Cluster 1) and a reduced set of representative agencies in Clusters 2–6, both GTFS Schedule and GTFS Real-time data are collected to estimate the bus-level operations. GTFS Schedule data provide details on service blocks, which are sequences of trips assigned to a single bus. A bus may complete one or more service blocks during an operating day. However, GTFS Schedule data lack information on vehicle-to-block and vehicle-to-trip assignments. While GTFS Real-time provides this information, its availability is more limited, and data collection is resource-intensive and time-consuming.

To address this, Liu (2020) developed a method to estimate the bus-level trips using service block data from GTFS Schedule, which involved sequencing blocks based on a fixed time interval. This method is refined for this analysis by using GTFS Real-time data from select agencies to calibrate the time interval parameter separately for each agency cluster (Bruchon et al. 2024). Additionally, deadheading miles—non-revenue miles such as travel between depots and route start or end points—are incorporated by disaggregating agency-level deadheading data from the NTD to individual buses and block sequences.

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With the GTFS Schedule datasets from select agencies, calibrated time intervals, and agency-level deadheading data, nearly 50,000 daily transit bus operating profiles are developed: 21,675 for weekdays, 13,705 for Saturdays, and 11,595 for Sundays. Because buses are not necessarily in service every day, it is assumed that those assigned for Sunday service also operate on weekdays and Saturdays. Additionally, for weekday operations exceeding 24 hours, it is assumed that these buses are only used every other day. These daily travel profiles (weekday, Saturday, and Sunday) are then sampled and sequenced into 21,781 unique weeklong travel profiles.

Depot-level travel profiles are sampled from agency-level and cluster-level weeklong profiles (Figure 3). For agencies where GTFS data is utilized, only weeklong travel profiles generated for that specific agency are included in the fixed-route sampling pool. For agencies without GTFS data, weeklong profiles generated for their respective cluster are used as the fixed-route sampling pool. For agencies in Clusters 1 through 6, demand-response travel profiles are sampled from a subset of travel profiles within their respective cluster. For agencies in Cluster 7, demand-response travel profiles are sampled from a subset of travel profiles spanning all clusters. VOMS from the NTD 2021 Annual Database are used to determine the appropriate fleet sample size, though agencies may have more active buses in their fleet than indicated by VOMS.

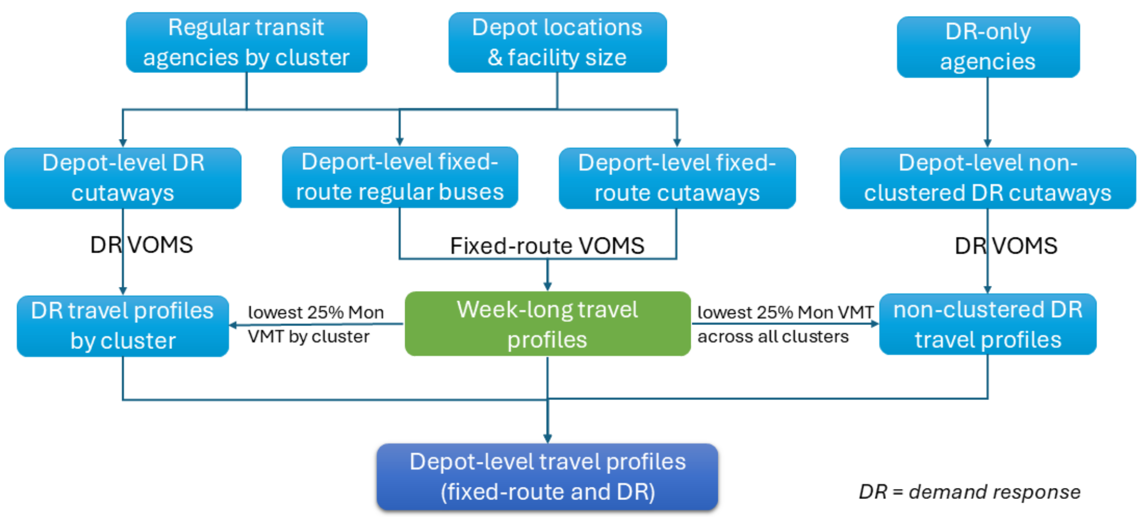

Figure 3. Depot-level travel profile sampling approach

Cutaway buses, which are vehicles with a bus body mounted on the chassis of a van or light-/medium-duty truck, comprise 38% of the total transit bus population. Of these, 86% are utilized for demand-response transit services. In the absence of publicly available demand-response travel data, dVMT for demand-response cutaways are assumed to fall within the lowest 25th percentile of weekday dVMT distributions for each agency cluster. Travel profiles for demand-response cutaways are sampled using the dVMT thresholds in Table 1.

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Table 1. dVMT Thresholds for Demand-Response Travel Profile Sampling

Cluster	25%-tile dVMT
1 – Large agency	61
2 – Mid-sized agency	108
3 – Small agency, high dVMT, weekend service, high vehicle utilization	163
4 – Small agency, high dVMT, weekend service, low vehicle utilization	98
5 – Small agency, high dVMT, no Sunday service	88
6 – Small agency, low dVMT	87
7 – Small agency, demand response transit service only	93

The sampled travel profiles for both fixed-route and demand-response transit services are combined to produce the set of depot-level travel profiles used to simulate BEB charging demand in EVI-Pro. Figure 4 provides examples of weeklong dVMT profiles generated for transit buses at the City of Baltimore and County of Nassau transit agencies.

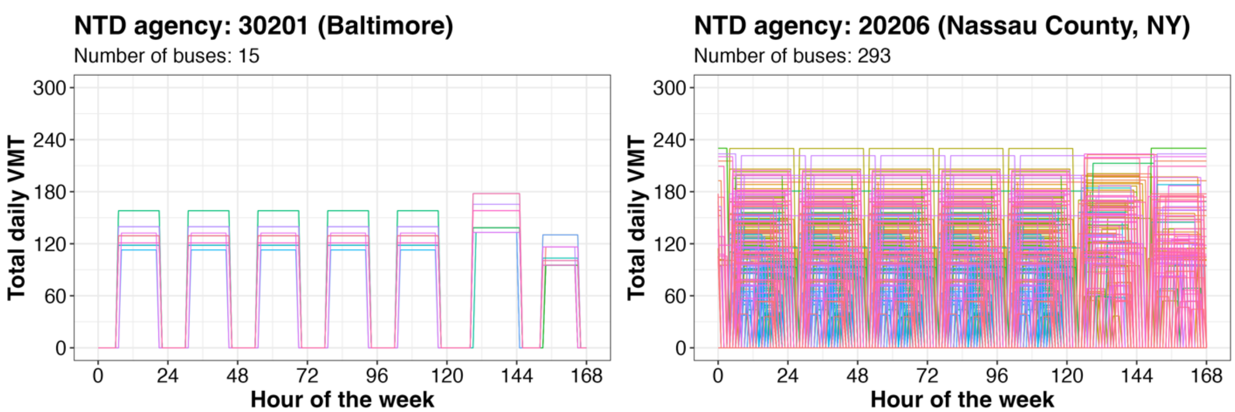

Figure 4. Weeklong bus dVMT profiles at City of Baltimore and County of Nassau transit agencies.

Note: Each line corresponds to an individual bus, with horizontal lines above zero representing the dVMT

2.4 EVI-Pro Inputs

Key inputs for EVI-Pro simulations include vehicle technology attributes (Table 2), charger specifications, and charging preferences. For each one-week travel profile, a BEB technology is selected based on the maximum dVMT observed during the week. Both depot and en-route charging are modeled to ensure that all travel profiles can be completed.

There are trade-offs between installing high-power (e.g., 100–350 kW) direct current fast chargers (DCFC) and lower power options like Level 2 (L2) chargers or 50-kW DCFC at depots. High-power DCFC can support multiple buses per charger and reduce the physical space required for charger installations. However, they come with higher capital costs, grid upgrade expenses, and maintenance requirements. In contrast, L2 chargers and 50-kW DCFC are more cost-effective to acquire, install, and maintain, making them well-suited for overnight depot

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charging. These chargers typically support an EV-to-EVSE ratio of 1:1, meeting the needs of most vehicle-level operations.

In this analysis, it is assumed that transit agencies prioritize overnight depot charging, utilizing either 19.2-kW L2 chargers or 50-kW DCFC, depending on the power required to fully recharge BEBs on their busiest day of the week (i.e., the day with the shortest depot dwell time). En-route charging is assumed to rely on 350-kW DCFC. Additionally, BEB depot charging is assumed to have an efficiency of 88%, with the remaining 12% accounted for by battery conditioning or transmission losses (Voelker 2021).

Charging is assumed to commence immediately upon a bus's return to the depot. For travel profiles with high dVMT, EVI-Pro may simulate both depot and en-route charging to meet operational needs. However, only depot charging demands are included in the final dataset due to uncertainty regarding the address-level locations of en-route charging.

Table 2. BEB Technology Attributes Simulated in EVI-Pro

BEB Technology	Battery Capacity (kWh)	Max. AC Charge Acceptance Rate (kW)	Max. DC Charge Acceptance Rate (kW)[a]	Energy Consumption Rate (kWh/mile)[b]
BEB150	252	19.2	300	1.68
BEB200	336	19.2	400	1.68
BEB300	504	19.2	600	1.68
BEB400	672	19.2	800	1.68

[a] Assuming a 60% charge in 30 minutes.
[b] Based on low technology scenario in Islam et al. (2023).

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3 Transit Bus Depot Electricity Demand Dataset

The final dataset includes hourly 1-week electricity demand profiles for BEBs charging at transit depots across the United States (Table 3). These data are available for 2,735 distinct depot locations and BEB penetration levels ranging from 10% to 100%.

Table 3. Transit Bus Depot Electricity Demand Dataset Description

Feature	Details
Vehicle segment(s)	Transit buses (depot charging only)
Spatial resolution	Transit bus depot level (2,735 total)
Temporal resolution	Hourly weekly (168)
Other features	BEB penetration levels ranging from 10% to 100%

Figure 5 presents examples of hourly 1-week electricity demand profiles for BEBs charging at transit depots for the City of Baltimore (left) and Nassau County, New York (right), transit agencies, with three adoption scenarios.

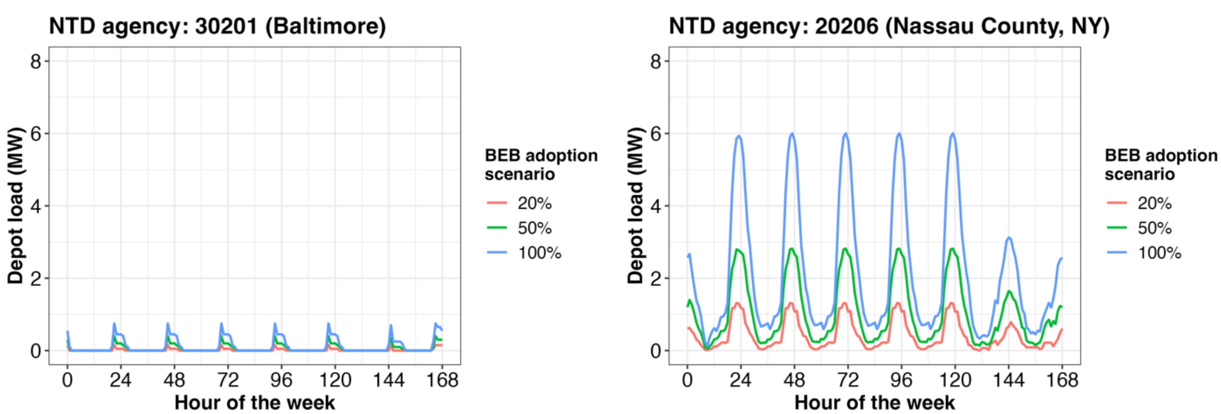

Figure 5. Modeled depot electricity demand at the City of Baltimore and County of Nassau transit agencies for multiple BEB penetration levels: 20% (red), 50% (green), and 100% (blue)

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4 Dataset Guidelines and Limitations

The development of this dataset relies on several assumptions and constraints, introducing important caveats and limitations. First, the weeklong travel profiles are derived from GTFS service block sequences, assuming a uniform between-block time interval for all agencies within the same cluster. In reality, agencies may employ different strategies for assigning service blocks to buses, which can influence operational patterns and BEB charging requirements.

Second, travel profile sampling for demand-response cutaways is based on estimates derived from the NTD Service table and assumptions for average dVMT. Future iterations should incorporate GTFS Flex datasets—a GTFS Schedule extension designed for demand-response transit services—as they become more widely available.

Third, various factors influence the shapes of depot load profiles, including charger power levels, charging start times, vehicle state of charge, and EV-to-EVSE ratios. This dataset represents simplified charging profiles developed using a consistent set of assumptions applied across all transit agencies. In practice, agencies may adopt different strategies for BEB operations and charging.

Fourth, the effects of weather and temperature on BEB energy consumption rates were not considered in this analysis. The estimated electricity demands represent average conditions over a typical week. Future iterations could address this limitation by extending the analysis timeframe and incorporating region-specific energy consumption rates to account for variations caused by local weather conditions.

Lastly, the depot electricity demand dataset focuses exclusively on depot charging loads. While en-route charging demand is simulated in EVI-Pro for high-dVMT profiles, these loads are excluded from the final dataset due to uncertainty about the specific locations of en-route charging infrastructure. Among the 21,781 weeklong travel profiles simulated in EVI-Pro, 38% require en-route charging, which accounts for 30% of the total electricity demand from BEB operations. For this study, en-route electricity demands were not reassigned to depots.

Despite these limitations, this dataset, available at data.nrel.gov/submissions/282, provides a valuable foundation for analyzing hourly depot electricity demand for electric transit buses across diverse U.S. transit agencies and electrification scenarios.

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