Class 8 Truck Electrification Case Study

Summary

This report presents a statewide truck-electrification planning workflow for understanding where battery-electric Class 8 trucking may be feasible in Utah, what charging infrastructure would be required, and which assumptions most strongly shape cost and grid impacts. The goal is not to predict a single truck-electrification future for Utah. Instead, the analysis uses observed truck activity and scenario optimization to identify decision-relevant tradeoffs among vehicle batteries, stationary charging, en-route charging, dynamic wireless power transfer, electricity costs, and grid-upgrade needs.

The workflow proceeds in four parts:

1. **Background**: why truck electrification in Utah requires strategic system-level infrastructure planning in addition to operational deployment-focused fleet or depot-level analysis.
2. **Approach**: how observed truck activity is translated into energy demand, charging opportunities, scenario assumptions, and optimized infrastructure choices.
3. **Results and Observations**: what the analysis implies for cost, infrastructure siting, charging-paradigm tradeoffs, grid impacts, and load profiles.
4. **Limitations and Future Work**: which findings are ready for planning interpretation and which require improved data, scenario design, or implementation analysis.

Most Important Takeaways

- A meaningful portion of modeled Class 8 trucking activity can be electrified at competitive system cost, but achieving that outcome depends on strategic charging-infrastructure design, charging coordination, and grid planning rather than vehicle deployment alone.
- Coordinated optimization produces modeled comprehensive BEV net-present system costs of roughly $0.44 to $0.67 per mile in the low-electrification pathway and $0.86 to $1.37 per mile in the high-electrification path-

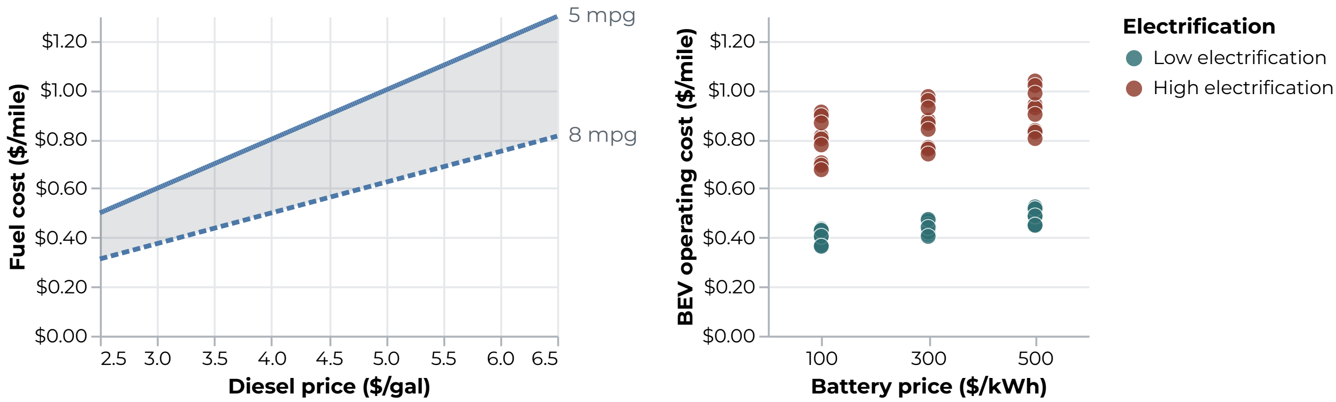

Figure 1: Diesel fuel cost per mile compared with modeled BEV energy and charging-system operating cost per mile. Both panels exclude vehicle capital costs and out-of-scope infrastructure costs.

way. These values are competitive with the modeled conventional-truck comparator in many scenarios, but not uniformly lower across all high-electrification cases.

- Early Class 8 truck electrification can use more existing grid headroom, but higher penetration creates much larger local upgrade needs: Wasatch regional grid-upgrade capacity ranges from about 77 to 213 MW in the low-electrification pathway and about 372 MW to 1.66 GW in the high-electrification pathway.
- Results are most useful for comparing strategies and sensitivities, especially battery cost, dynamic wireless power transfer (DWPT) cost, electrification scale, and Wasatch grid-envelope impacts, rather than prescribing exact construction locations.
- Stationary charging supplies most modeled energy in this limited scenario family, while DWPT appears as a selective complement. This study does not confirm or reject a broader paradigm-shift scenario in which extensive roadway electrification serves light-duty, medium-duty, and heavy-duty vehicles and displaces substantial battery capacity or stationary charging.
- Grid and DWPT findings are the most important areas for future refinement: improved grid data and paradigm-shift roadway-electrification scenarios could materially change planning conclusions.

High-Level Findings

Modeled BEV system costs are approximately $0.44 to $0.67 per mile for the low-electrification pathway (approx. 5% of Class 8 miles electrified) and $0.86 to $1.37 per mile for the high-electrification pathway (approx. 22% of Class 8 miles electrified). Full-system cost per kWh ranges from approximately $0.35 to $0.57 in the low-electrification pathway and $0.45 to $0.72 in the high-electrification pathway.

Fuel-price volatility is outside the scenario optimization, but it can materially change diesel-versus-electric cost comparisons. More stable electricity pricing may provide hedge value for fleets even when point estimates of operating cost are similar.

Battery cost is one of the strongest cost drivers because vehicle battery capital cost is included in the system net present value. Infrastructure cost assumptions still matter, but the effect of those assumptions is moderated by the model's ability to optimize battery sizing, charging behavior, and infrastructure selection together.

Stationary charging supplies the large majority of modeled charging energy in most scenarios. DWPT appears selectively, with median Utah reported-location DWPT energy share near 1% and maximum share near 11% across scenarios. As this is restricted to a subset of Class 8 travel and does not include most other vehicle classes, this result should be interpreted narrowly.

The model selects roughly 86 to 228 Utah infrastructure zones or roadway segments per scenario. Stationary charging zones are comparatively stable, generally around 82 to 100 Utah modeled zones per scenario. These zones should not be interpreted as exact counts of charging stations, parcels, or plugs. DWPT segment selection is much more scenario-sensitive, ranging from 4 to 134 Utah roadway segments per scenario.

Top stationary charging zones include both individual municipalities and joined non-Wasatch municipality zones. Joined-zone names such as Cedar City area or Brigham City area are shorthand labels based on the largest municipality in the joined zone.

High electrification produces a much larger grid-planning signal than low electrification, and local peak-load shapes vary substantially across top charging locations. Grid-upgrade findings should be interpreted carefully because the domain of the grid-upgrade model is a coarse grid-envelope summary restricted to a subset of the Wasatch region.

1 Background

Truck electrification in Utah is a statewide and corridor-scale infrastructure planning problem. Unlike light-duty electrification, where most charging can often be organized around homes, workplaces, and familiar public charging locations, freight electrification must serve high-energy vehicles with demanding schedules, long-distance travel, cross-border movement, and concentrated activity on major corridors. A charging system for trucks therefore has to answer not only how much energy is needed, but where, when, and by which delivery method that energy can be supplied without creating impractical operating burdens or excessive grid impacts.

This study treats truck electrification as a system design problem rather than a fleet-by-fleet depot problem. The modeled trucks travel through Utah, stop at many different types of locations, and may require support beyond a single depot. Some charging can occur while vehicles are already stopped, some can occur through added en-route charging stops, and some can occur while vehicles are moving over electrified roadway segments. Each option has a different cost structure and a different operational role.

The central planning tradeoffs are driven by the fact that no single charging paradigm is obviously sufficient under all conditions. Larger batteries can make trucks more flexible, but they increase vehicle capital cost. Stationary chargers are familiar and modular, but they require dedicated capital and operational investment, dwell time, site capacity, and utility interconnection. En-route charging can enable long itineraries, especially when sharing amortizes capital and operational costs across many users, but it adds downtime and operating cost. Dynamic wireless power transfer (DWPT) can deliver energy while trucks are moving, thus reducing both operational downtime and required battery size and cost, and may eventually support multiple vehicle classes, but it requires high fixed investment and depends strongly on utilization.

That tradeoff is especially important in Utah because the state combines urban freight activity, regional distribution networks, interstate corridors, rural distances, and cross-border freight flows. Charging investments that look attractive at one location may be less useful if they do not serve the timing and geography of actual truck movement. Conversely, infrastructure with a high up-front cost may become more attractive if it serves enough travel across multiple user groups, reduces stationary charging requirements, or improves feasibility for critical routes.

This case study is designed to provide decision support for the major stakeholders involved in truck electrification planning:

- freight carriers and fleet operators making vehicle and operating decisions;
- utilities and grid planners evaluating future load growth and interconnection needs;
- Utah Department of Transportation (UDOT) and transportation planners considering corridor-scale infrastructure strategies;
- municipalities and local economic-development stakeholders affected by charging-site development;
- state policy and incentive program designers evaluating where public support may be most valuable.

The analysis addresses four planning questions:

- What factors most influence the technical feasibility of truck electrification in Utah?
- What factors most influence the long-run cost of serving electrified truck travel?
- Under what assumptions does the model select stationary charging, en-route charging, and DWPT?
- Which results appear robust enough to inform near-term planning, and which require further model refinement?

The sections that follow describe the modeling approach used to answer those questions. Results and observations are presented later in the report and should be interpreted as scenario comparisons under a consistent optimization framework, not as construction-ready site recommendations.

2 Approach

This analysis is organized as a staged planning workflow. Section 2.2 (Energy-Demand Modeling) converts observed Class 8 truck activity into a modeled electricity demand problem. Section 2.3 (Energy Delivery Modeling) defines where and how energy could be delivered through stationary charging, en-route charging, and DWPT. Section 2.4 (Geographic Scope and Candidate Infrastructure) establishes the candidate stationary zones and roadway segments available to the optimizer. Section 2.5 (Scenario Construction) varies the major cost and adoption assumptions. Section 2.6 (Core Economic and Operational Assumptions) defines the lifecycle, cost, electrical, and operational parameters used across the scenario set. Section 2.7 (Optimization Framework) then solves each scenario as a system design problem whose outputs can be compared across costs, infrastructure selections, energy delivery patterns, grid implications, and load profiles.

2.1 Modeling Objective

The objective of this study is to evaluate how Utah Class 8 truck electrification optimization strategies change under different technical and economic assumptions. The model is not intended to forecast one exact market outcome. Instead, it is intended to characterize tradeoffs: how infrastructure choices respond when battery costs fall, when charging infrastructure costs change, when electrification pressure increases, or when DWPT becomes more or less cost-effective.

The analysis therefore uses mathematical optimization to identify the lowest-cost system design that can serve a specified electrified truck population and duty cycle under each scenario. The optimized system may include vehicle batteries, stationary charging infrastructure, en-route charging events, DWPT roadway segments, electricity purchases, grid upgrades, and operating penalties or credits associated with specific charging paradigms.

The resulting outputs are most useful for:

- comparing cost and infrastructure patterns across scenarios;
- identifying assumptions that strongly affect system cost;
- identifying locations and corridors that appear repeatedly across solutions;
- evaluating the relative role of stationary charging and DWPT under selective deployment assumptions;
- guiding future, higher-fidelity analyses with improved grid data, siting constraints, and adoption pathways.

Because the model assumes globally coordinated infrastructure placement and charging behavior, cost results should be interpreted as optimized-system benchmarks. Actual achieved cost per mile would depend on how closely agencies, utilities, infrastructure providers, and carriers can coordinate around efficient siting, utilization, interconnection, procurement, and operations.

2.2 Energy-Demand Modeling

The demand side of the model is built from observed truck telematics. The scoped input dataset includes 8,792 unique trucks, 903,497 trips, and approximately 80.2 million observed truck-miles. The records span May 1, 2023 through May 31, 2023. The telematics are overwhelmingly for Class 8 trucks and cover both short-haul and long-haul itineraries.

These data provide a detailed view of truck itineraries, stop locations, route movement, and mileage. They do not directly observe battery-electric truck charging behavior. Fuel type is not part of the vehicle metadata, but because Class 8 battery-electric adoption remains extremely low to date, the input truck activity is treated as conventional internal-combustion activity that could be electrified under modeled assumptions. For that reason, the analysis estimates electric energy demand from truck movement rather than inferring charging from observed charging events.

Each trip is assigned energy demand using a simplified per-mile energy model. The current analysis assumes:

- electric truck energy intensity of 1.9 kWh per mile;
- conventional fuel economy of 5.7 miles per gallon;
- maximum feasible battery size of 1,500 kWh;
- usable battery capacity of 80% of nominal capacity;
- charging efficiency of 90%.

This simplified energy model does not explicitly represent grade, payload, speed profile, acceleration intensity, HVAC load, or weather. Those omissions are important limitations, but the simplification is appropriate for this stage because the dominant planning uncertainties are larger-scale system uncertainties: adoption level, infrastructure cost, infrastructure utilization, charging zone, and charging paradigm. Future work should refine the truck energy model with additional vehicle classes, route grade, payload, temperature, and speed effects, in line with models supporting fleet-level decisioning studies.

2.2.1 Representative-Day Construction

Solving a corridor-scale mixed-integer optimization problem over the full observed dataset would be computationally prohibitive. The model therefore uses a representative high-demand planning day. For each truck, the workflow identifies the highest-energy day that includes travel through Utah and stacks the selected vehicle-days onto one representative date.

This sampling design is intentionally conservative. It reduces the chance of understating infrastructure need by concentrating demanding vehicle-days into one modeled operating period. However, the representative day should not be interpreted as a measured chronological statewide traffic day. It is a modeled high-demand planning condition used to stress the infrastructure system and support consistent scenario comparison.

Lifecycle costs and levelized metrics are derived from this representative operating condition. As a result, the analysis is better suited for comparing scenarios than for estimating average-day utilization at any individual site. This approach is conservative with respect to infrastructure buildout because it stresses the system with demanding vehicle-days, but it can also overstate utilization and economic payoff if the representative operating condition is interpreted as typical annual behavior.

2.2.2 Electrifiability Screening

Before the final scenario optimizations, the model screens which trucks can be physically served as electric vehicles under permissive charging assumptions. This screening step is separate from the final cost-minimizing solve. Its purpose is to determine whether an itinerary can be electrified under the modeled battery, charging, and timing constraints, not whether electrification is economical in a particular scenario.

The screening step strongly favors electric operation wherever it is physically possible. It temporarily removes most cost barriers and treats charging availability generously so that the result answers a physical feasibility question: can this vehicle-day be served electrically under the modeled charging paradigms? Put another way, this step excludes vehicle duty cycles that cannot reasonably be met by near-term electric trucks from the electric energy and charging needs calculations.

The resulting eligible vehicle set is reused across scenarios. This keeps scenario comparisons stable: differences among scenarios reflect cost and infrastructure tradeoffs rather than changing definitions of which vehicles are considered electrifiable.

The low-electrification pathway requests 40% of eligible trucks, while the high-electrification pathway requests 100% of eligible trucks. In the final scenario design, these pathways correspond to 3,514 electric trucks in the low-electrification case and 8,785 electric trucks in the high-electrification case. On a vehicle-miles-traveled basis, these pathways are approximately 4.5% and 22.7% of Utah combination-truck VMT, respectively, measured against UDOT/FHWA total annual mileage for combination trucks in the state of Utah. These percentages should be interpreted carefully: they describe electrification within the available sample and its approximate relationship to statewide combination-truck VMT, not a prediction that this exact 4.5% or 22.7% slice of Utah truck travel would be the first to electrify in practice.

The partial-electrification pathway is a scenario construction device, not a behavioral adoption forecast. It does not claim that the first trucks to electrify would be selected randomly, by a particular carrier type, or by a specific corridor policy. Future analyses should test targeted adoption pathways such as highest-mileage-first, lowest-cost-first, most-electrifiable-first, carrier-led adoption, and corridor-priority adoption.

2.3 Energy Delivery Modeling

The optimization can deliver energy to trucks through three charging paradigms: stationary destination charging, stationary en-route charging, and DWPT. The model chooses among these options based on vehicle energy needs, timing constraints, candidate zones and segments, infrastructure costs, electricity costs, grid constraints, and scenario assumptions.

2.3.1 Destination Charging

Destination charging occurs where a truck is already stopped. It can represent charging at depots, loading areas, recurring customer locations, logistics facilities, or other stop locations where dwell time is already part of the itinerary.

Destination charging is attractive because it can use existing stop time rather than adding a new charging stop. However, it is limited by dwell availability, maximum charging power, site capacity, and the extent to which charging demand within a modeled zone can realistically share the same physical equipment. In this analysis, destination charging can use up to 2,000 kW during a qualifying stationary event, and the minimum stationary event duration is 300 seconds.

2.3.2 En-Route Charging

En-route charging uses stationary infrastructure but adds a charging opportunity outside the vehicle's original stop pattern. It is modeled as a pull-over charging event along a route, subject to candidate-location proximity and a maximum time allowance.

En-route charging can be important for preserving feasibility on long or difficult itineraries, but it is operationally different from destination charging because it adds time. In this analysis, en-route charging uses 1,000 kW, the route must pass through or come within 1 mile of a candidate zone, the maximum en-route charging time is 30 minutes, and added time is assigned an operating cost of $2.50 per minute.

2.3.3 Dynamic Wireless Power Transfer

DWPT delivers energy while a truck travels over an electrified roadway segment. Instead of requiring a discrete stop, the vehicle receives power during movement. This changes both the operational logic and the infrastructure decision: DWPT is selected by roadway segment and lane-mile buildout rather than by stationary charging site.

In this analysis, modeled DWPT supplies 400 kW to trucks while they travel over selected segments. The model also includes an exogenous light-duty revenue credit for DWPT, reflecting the possibility that electrified roadways could generate value beyond heavy trucks. That credit is intentionally narrow and should not be interpreted as a full model of multi-class roadway electrification.

The same type of passenger-mode revenue credit is not applied to stationary truck charging because shared use is less plausible for most freight charging sites, which are often tied to depots, loading areas, logistics facilities, or other truck-specific access patterns. DWPT, by contrast, is located in the roadway and can more plausibly provide some value to other vehicle classes traveling over the same segment. This does not mean stationary truck charging has no shared-infrastructure potential: truck stops, travel centers, and similar sites may still share grid interconnection, upstream electrical equipment, or power electronics across users even when truck charging stalls and dispensers are dedicated.

The DWPT findings in this report are therefore scoped to selective truck-focused deployment scenarios. They should not be read as evidence against a broader paradigm-shift pathway in which a large share of roadways is electrified and used by light-duty, medium-duty, and heavy-duty vehicles. Such a pathway could substantially reduce required onboard battery range and displace some stationary charging, but it is outside the current scenario set.

2.4 Geographic Scope and Candidate Infrastructure

The optimization starts from a prespecified set of candidate stationary zones and roadway segments. It does not search every possible parcel, interchange, or road segment from scratch. Instead, it asks how much, if any, infrastructure should be installed at each eligible candidate zone or segment under each scenario.

2.4.1 Stationary Charging Zones

Stationary charging candidates are represented as municipality-based or municipality-like zones. This reflects the assumption that charging is more plausible where supporting services, staffing, land access, and grid connections are more likely to exist. In the most trafficked and populated parts of Utah, zones are named municipalities, with the Inland Port represented separately from Salt Lake City. In other parts of the state, nearby municipalities may be grouped to reduce optimization complexity while preserving statewide geographic coverage.

Outside Utah, charging support is represented with state-level buckets rather than detailed local siting. Those out-of-state buckets are allowed so that trucks with cross-border itineraries can remain feasible, but they are assigned a cost penalty to discourage the model from relying on out-of-state infrastructure in a Utah-focused planning study. Reported location-level results retain Utah stationary zones and Utah DWPT segments while excluding out-of-state state-bucket locations. System-level energy and cost denominators still include all energy needed to serve the modeled truck activity.

This distinction is important for interpreting the "UT Energy Share" statistic used later in the report. That statistic measures the share of modeled charging energy served by reported Utah stationary zones and Utah DWPT segments. It is partly a diagnostic of how much supporting infrastructure is still installed and used outside Utah despite the penalty.

2.4.2 Destination-Sharing Penalty

Large geographic zones can create an optimistic modeling artifact. If many truck stops in a broad zone are treated as if they all share one perfectly located charger, the model can underestimate the amount of infrastructure required. To reduce that risk, the analysis applies a destination-sharing penalty.

The penalty increases effective grid or site capacity requirements when charging events within a zone are spatially dispersed. The method uses the actual mapped stop locations for trucks assigned to a zone. Stops that cluster tightly are treated as more likely to share the same physical charging equipment, while stops spread across a larger area receive a larger multiplier because a single charger location would be less likely to serve them all. A factor of 1 means full sharing is plausible. Larger factors mean the model must build more effective capacity to serve stops that are farther apart within the same zone. The penalty is capped to avoid numerical instability and is calculated consistently across scenarios so that scenario differences reflect cost and electrification assumptions rather than changing geography.

2.4.3 DWPT Roadway Candidates

DWPT candidates are Utah roadway segments selected from major roadway categories. The candidate set focuses on motorway, trunk, and primary roads. In practical terms, these categories correspond to controlled-access freeway or interstate-style facilities, high-importance through routes, and major roads connecting important towns, regions, or freight corridors.

Candidate DWPT segments are constructed as non-branching roadway pieces, with intersections, exits, and related network junctions used as natural delimiters. Very long roadway pieces are broken into shorter candidate segments, very short pieces are combined into longer candidates where possible, and low-use candidates are filtered out. In the current analysis, segment lengths are limited to 300 meters through 10,000 meters, and candidate segments must be visited at least 20 times in the modeled activity. This construction improves computational tractability and removes roadway segments that are unlikely to be cost-effective under selective DWPT deployment.

2.5 Scenario Construction

The main scenario set is a full factorial experiment over the uncertainty dimensions most likely to change infrastructure strategy. The design includes two electrification pathways, three stationary charging cost cases, three DWPT cost cases, and three battery cost cases, for a total of 54 scenarios.

The low-electrification pathway represents 40% of eligible input vehicles, corresponding to approximately 4.5% of statewide Utah combination-truck VMT. The high-electrification pathway represents 100% of eligible input vehicles, corresponding to approximately 22.7% of statewide Utah combination-truck VMT.

Stationary charging costs are varied through combined capital and operating assumptions. The three cases combine installation, land-use, hardware, and annual operating costs. The low-cost case uses $500/kW for installation, $1,000/kW for land use, $300/kW for hardware, and $25/kW-year for operations, for a total capital cost of $1,800/kW plus $25/kW-year. The mid-cost case uses $650/kW for installation, $1,000/kW for land use, $400/kW for hardware, and $50/kW-year for operations, for a total capital cost of $2,050/kW plus $50/kW-year. The high-cost case uses $750/kW for installation, $1,000/kW for land use, $500/kW for hardware, and $75/kW-year for operations, for a total capital cost of $2,250/kW plus $75/kW-year. The high-cost case reflects current-cost expectations informed by expert input, while the lower-cost cases represent process improvement, industry learning, and hardware cost reduction.

DWPT costs are varied through lane-mile installation cost, power-related hardware cost, annual operating cost, and the light-duty revenue credit. The modeled system delivers 400 kW to trucks and includes a 100 kW effective light-duty charging stream for the revenue-credit assumption. The high-cost case uses $3.2 million per lane-mile for hardware, $720,000 per lane-mile for installation, and $240,000 per lane-mile-year for operations. The mid-cost case uses $1.92 million per

Table 1: Full-factorial scenario design and modeled uncertainty dimensions.

Factor	Levels and interpretation
Electrification pathway	Two levels: low electrification, representing 40% of eligible trucks, and high electrification, representing 100% of eligible trucks. These levels represent lower and higher adoption pressure.
Stationary charging cost	Three levels: low, mid, and high stationary charging cost. These levels represent uncertainty in stationary charger hardware, installation, land, and operating costs.
DWPT cost	Three levels: low, mid, and high DWPT cost. These levels represent uncertainty in dynamic-charging installation, hardware, operating cost, and revenue-credit assumptions.
Battery cost	Three levels: $100/kWh, $300/kWh, and $500/kWh. These levels represent uncertainty in installed heavy-duty battery cost.

lane-mile for hardware, $612,000 per lane-mile for installation, and $160,000 per lane-mile-year for operations. The low-cost case uses $996,000 per lane-mile for hardware, $504,000 per lane-mile for installation, and $80,000 per lane-mile-year for operations. The corresponding gross capital costs are $3.92 million, $2.532 million, and $1.5 million per lane-mile for the high, mid, and low DWPT cost cases. The credit assumes 50% utilization of a 100 kW equivalent light-duty charging stream at a $0.20/kWh net margin, equal to $87,600 per lane-mile-year. Net annual operating costs are therefore -$7,600, $72,400, and $152,400 per lane-mile-year for the low, mid, and high DWPT cost cases. These assumptions are scenario inputs rather than forecasts.

Battery costs are represented at $100/kWh, $300/kWh, and $500/kWh. The high case reflects the current challenge of installed heavy-duty battery costs, which can remain well above cell-level or passenger-vehicle pack prices because of lower production scale, integration requirements, warranty needs, and thermal management. The low case represents a future in which heavy-duty vehicles gain access to more mature, lower-cost battery supply chains.

Because the electrification pathway is imposed as a scenario requirement, battery cost does not determine how many trucks are electrified in a given scenario. It can, however, affect optimal battery sizing and the tradeoff between vehicle-side storage and infrastructure-side charging support.

2.6 Core Economic and Operational Assumptions

The optimization evaluates costs over a 30-year lifecycle horizon using 2026 dollars and a 4% real discount rate. With 3% annual inflation, this is equivalent to a 7% nominal discount rate. The cost objective includes capital investment, replacement and operating costs where applicable, electricity charges, fuel costs for non-electrified operation, battery capital cost, infrastructure cost, grid-upgrade cost, en-route time penalties, and DWPT revenue credits.

The most important operational and electrical assumptions are summarized below.

The destination and en-route charging-power assumptions play different roles. Destination charging uses a high maximum session power so that the optimization can serve long-haul trucks with short natural stops when necessary, while cost and grid incentives discourage using that upper bound unless it is valuable. En-route charging is represented as a fixed charging-power option, so a lower value is used to avoid assuming that very

Table 2: Core operational, electrical, and tariff assumptions used in the truck scenarios.

Parameter	Value
Electric truck energy intensity	1.9 kWh/mi
Conventional truck fuel economy	5.7 mpg
Fuel price	$3.50/gal
Grid upgrade cost	$300/kW
Maximum battery capacity	1,500 kWh
Usable battery fraction	80% of nominal capacity
Charging efficiency	90%
DWPT power delivered to trucks	400 kW
En-route charging power	1,000 kW
Destination session maximum power	2,000 kW
En-route charging time limit	30 minutes
En-route deviation cost	$2.50/min
Minimum stationary event duration	300 seconds
Electricity tariff	Rocky Mountain Power Schedule 8

high-power charging is available at every potential en-route stop.

Component replacement timelines are included in lifecycle cost accounting:

Component	Replacement timeline
Vehicle battery	8 years
Stationary EVSE	12 years
Dynamic EVSE	25 years
Grid upgrades	30 years

The vehicle-battery replacement timeline should be interpreted as a conservative lifecycle-cost assumption rather than a prediction that all truck batteries would require replacement after eight years. It is closer to a warranty-period planning assumption than a claim about typical realized battery life.

These assumptions define the scenario comparison baseline. They should not be interpreted as final engineering design values for any individual site, corridor, or fleet.

2.7 Optimization Framework

Each scenario is formulated as a system optimization problem. The model decides which trucks are electrified, how large batteries need to be, where charging infrastructure is installed, how much charging occurs by time and location, which DWPT segments are selected, and what grid upgrades are required to support the resulting load.

The objective is to minimize long-run system cost while meeting the imposed electrification pathway and preserving physically feasible vehicle operation. Depending on the scenario and selected infrastructure, the objective includes:

- electricity energy charges;
- electricity demand charges;
- time-varying demand charges;
- vehicle battery costs;
- stationary charging infrastructure capital and operating costs;
- DWPT capital and operating costs;
- grid-upgrade costs;
- en-route charging time penalties;
- light-duty DWPT revenue credits.

The main physical and operational constraints ensure that each modeled electric truck maintains feasible battery state of charge, charges only when a modeled opportunity is available, respects destination dwell limits, respects en-route stop time and proximity limits, receives DWPT energy only on selected roadway segments, and does not exceed selected charger, site, or grid-envelope capacity.

The model also uses practical capacity controls to avoid unrealistic concentration of many charging events into a single infrastructure block. Simultaneous-event limits, site-integer limits, utilization-factor assumptions, and destination-sharing penalties all serve this purpose. These controls make the optimized solution more conservative than a formulation that assumes all demand in a zone can be perfectly pooled at one charger.

The final output of each scenario is an optimized infrastructure and operations design under that scenario's assumptions. The results identify economically attractive patterns and sensitivities, but they are not construction-ready engineering designs. Local siting, land ownership, utility interconnection, permitting, reliability, redundancy, and fleet operating constraints require separate validation before implementation.

3 Results and Observations

The results below summarize the full 54-scenario experiment. They are organized around planning questions rather than solver mechanics: cost outcomes, infrastructure siting, the balance between stationary charging and DWPT, grid-upgrade implications, and temporal load behavior.

Unless otherwise noted, location-level results use the Utah reporting geography described above. Utah stationary charging zones and Utah DWPT road segments are retained, while out-of-state state-bucket charging locations are excluded from siting tables. System-level cost and energy denominators still include the supporting energy needed to complete modeled cross-border itineraries.

3.1 Scenario Set and Quality Checks

All 54 scenarios in the factorial experiment completed successfully. The organized outputs passed all required quality checks: 540 required checks and 216 diagnostic checks were recorded with no failed checks in the reported output set.

The quality-control checks cover the main accounting relationships needed for interpretation: scenario completion, energy and cost consistency, distance totals, and the location-reporting rule that removes out-of-state state-bucket locations from Utah siting outputs while retaining all within-Utah stationary zones and DWPT segments.

This gives enough confidence to compare scenarios across the major factors in the design. It does not eliminate the broader modeling limitations described in the Approach section; rather, it indicates that the reported scenario outputs are internally consistent under the model assumptions.

3.2 System Cost Outcomes

Modeled BEV system costs are relatively compact within each pathway, but the high-electrification pathway carries a much larger vehicle and infrastructure burden. In the low-electrification pathway, all-in BEV system cost ranges from approximately $0.44 to $0.67 per mile. In the high-electrification pathway, all-in BEV system cost ranges from approximately $0.86 to $1.37 per mile. Median all-in BEV cost is approximately $0.56 per mile for the low-electrification pathway and $1.12 per mile for the high-electrification pathway. These all-in values differ from the BEV operating-cost values shown in Figure 1 because they include vehicle battery purchase, battery replacement, and penalized out-of-state infrastructure and grid-upgrade proxy costs. After removing those components for comparison with diesel fuel-only cost, the BEV operating-cost range is approximately $0.36 to $0.52 per mile in the low-electrification pathway and $0.68 to $1.04 per mile in the high-electrification pathway.

These values are full-system BEV costs, not retail charging prices, utility rates, or charger-only

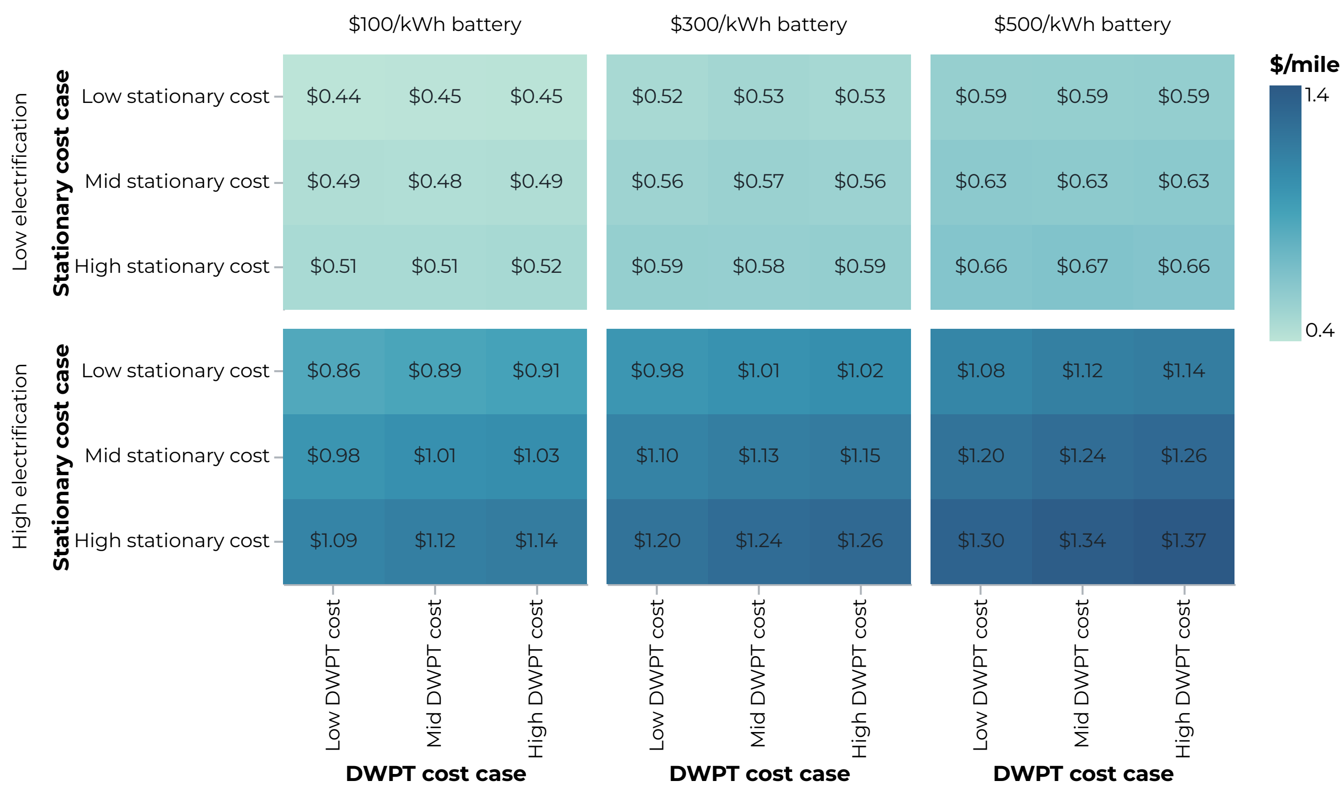

Figure 2: Modeled BEV system cost per mile across electrification pathway, battery cost, stationary charging cost, and DWPT cost assumptions.

costs. They include vehicle battery costs, charging infrastructure, electricity, grid upgrades, replacement costs, infrastructure operations, modeled operating penalties or credits, and the penalized supporting infrastructure that the model is allowed to install outside Utah for cross-border itineraries. The high-electrification pathway is also not simply "more of the same" activity as the low-electrification pathway: it includes the harder-to-serve eligible trucks that remain after the lower-adoption pathway is filled, so higher cost per mile reflects both scale and the composition of electrified travel. This may indicate that some eligible high-mileage or operationally difficult trucks are not the most cost-effective near-term candidates for electrification, though evaluating alternative adoption trajectories was outside the scope of this scenario set.

Full-system cost per kWh ranges from approximately $0.35 to $0.57 in the low-electrification pathway and $0.45 to $0.72 in the high-electrification pathway. The compactness of these ranges within each pathway should be read partly as a result of optimized system coordination. The model is able to adjust battery sizing, infrastructure selection, charging timing, and charging paradigm together, which dampens the cost impact of any single unfavorable assumption. Real-world implementation would not necessarily achieve the same degree of coordination.

Figure 2 shows the full BEV cost-per-mile pattern across electrification pathway, battery cost, stationary charging cost, and DWPT cost. The lowest-cost outcomes occur when battery, stationary charging, and DWPT assumptions are all favorable. The highest-cost outcomes occur when battery costs and charging-infrastructure costs are unfavorable. The high-electrification pathway has a much higher cost range because it electrifies a larger and more demanding share of modeled Class 8 activity.

Figure 3 summarizes median system cost by the varied scenario axes, with individual scenario points shown to indicate the spread around each median. Battery cost is one of the clearest cost drivers because the modeled battery-cost span

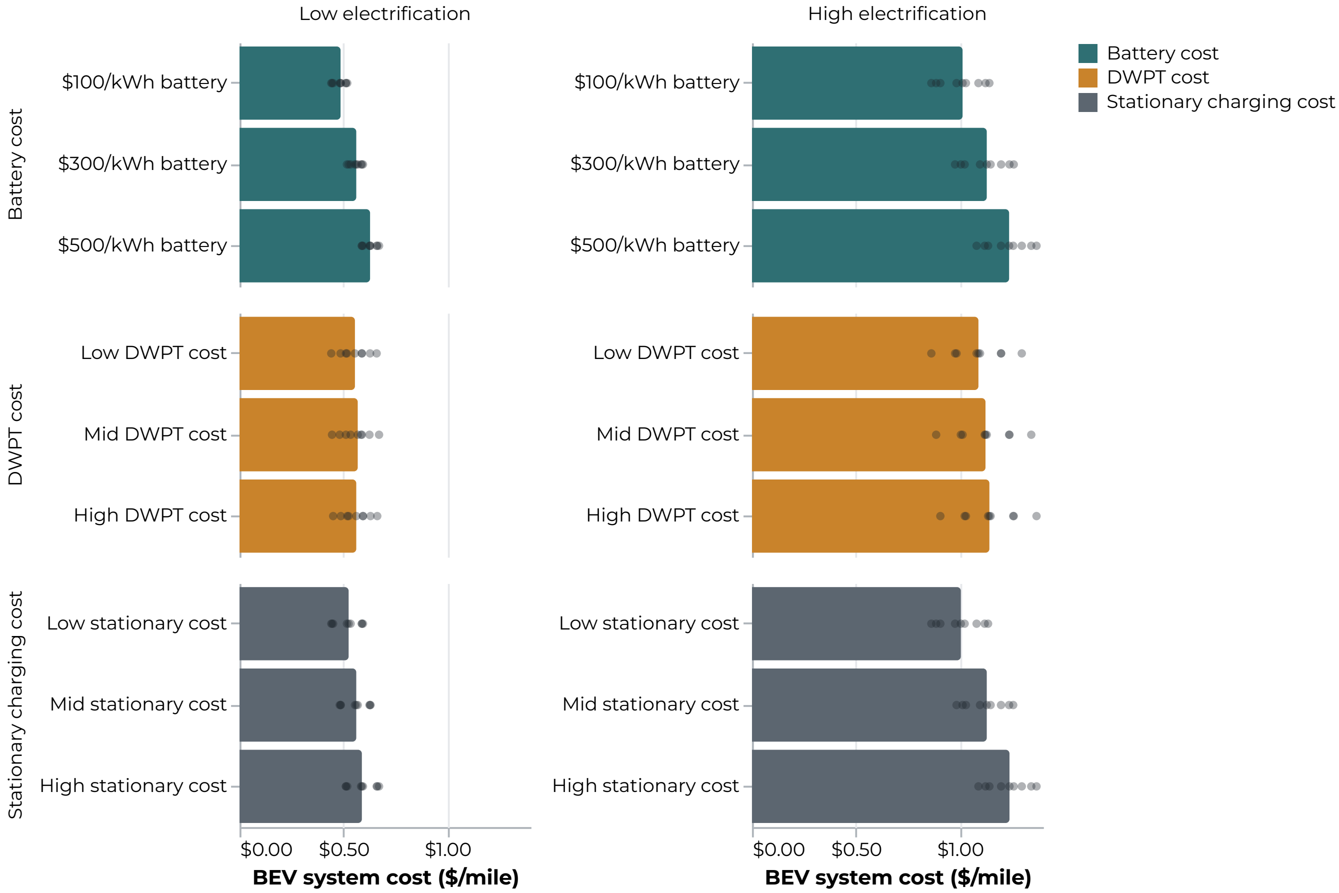

Figure 3: Median modeled BEV system cost by scenario factor, with individual scenario outcomes shown as points.

Table 3: Selected low-cost, reference, and high-cost scenarios for the low electrification pathway.

Role	Stationary	DWPT	Battery	BEV $/mi	$/kWh	UT Energy
Lowest cost	Low	Low	$100/kWh	$0.441	$0.345	98.3%
Reference	Low	Low	$300/kWh	$0.517	$0.409	98.3%
Highest cost	High	Mid	$500/kWh	$0.671	$0.574	98.1%

is large: the high-cost case is five times the low-cost case on a dollars-per-kWh basis. The stationary charging cost span is much narrower, and even the DWPT cost span affects only infrastructure that is selected in a subset of scenarios. Infrastructure cost assumptions still matter, but their effect is generally smaller than the battery-cost effect in the median summaries because the optimization can rebalance across battery sizing, stationary charging, DWPT, and charging location choices. The sensitivity patterns are similar across the low- and high-electrification pathways, though high electrification creates a broader range of outcomes.

The tables below anchor the cost results with selected scenario examples: the lowest-cost, reference, and highest-cost scenario in each electrification pathway. The reference rows in these tables are also the reference scenarios used in later reference-scenario figures. They should be interpreted as central comparison points within the scenario design, not forecasts or preferred pathways.

Table 4: Selected low-cost, reference, and high-cost scenarios for the high electrification pathway.

Role	Stationary	DWPT	Battery	BEV $/mi	$/kWh	UT Energy
Lowest cost	Low	Low	$100/kWh	$0.863	$0.454	94.9%
Reference	Low	Low	$300/kWh	$0.977	$0.515	94.6%
Highest cost	High	High	$500/kWh	$1.369	$0.721	94.2%

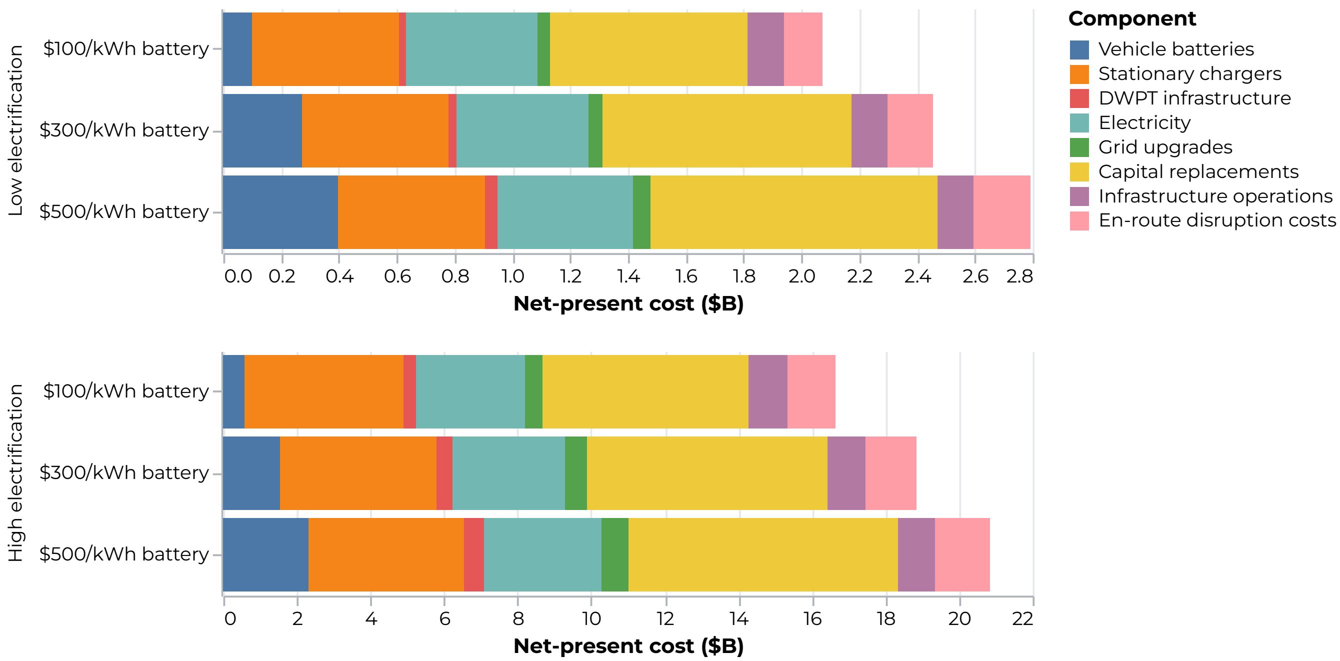

Figure 4: Net-present system cost by electrification pathway, battery-cost scenario, and major cost component.

Scenario rows show the lowest-cost, reference, and highest-cost examples within each pathway. Stationary and DWPT columns report cost-case assumptions; UT Energy is the share of modeled charging energy served by reported Utah stationary zones and DWPT segments.

The "UT Energy" column reports the share of modeled charging energy served by Utah stationary zones and Utah DWPT segments. Because out-of-state state-bucket infrastructure is allowed but penalized, this statistic is useful as a diagnostic: it shows how much charging energy still relies on supporting infrastructure outside the reported Utah location geography.

Figure 4 decomposes net-present system cost into the major cost components represented in the optimization for the default stationary and DWPT cost assumptions, while varying battery cost. The comparison makes the battery-cost sensitivity more explicit by showing low-, mid-, and high-battery-cost scenarios within each electrification pathway. Stationary chargers and electricity are among the largest direct charging-system cost drivers, while vehicle batteries and capital replacements (of batteries, charging infrastructure, and grid infrastructure) are major full-system components. DWPT infrastructure and grid upgrades are meaningful but generally smaller than the dominant stationary, electricity, battery, and replacement categories in these scenarios.

Figure 5 shows how selected battery sizing changes with pathway, battery cost, and DWPT cost assumptions. Lower battery-cost assumptions generally make larger batteries more attractive relative to infrastructure dependence, while high battery-cost assumptions push the optimization toward smaller vehicle batteries and greater reliance on charging opportunities. These battery sizes should be interpreted as continuous optimization outcomes, not as procurement

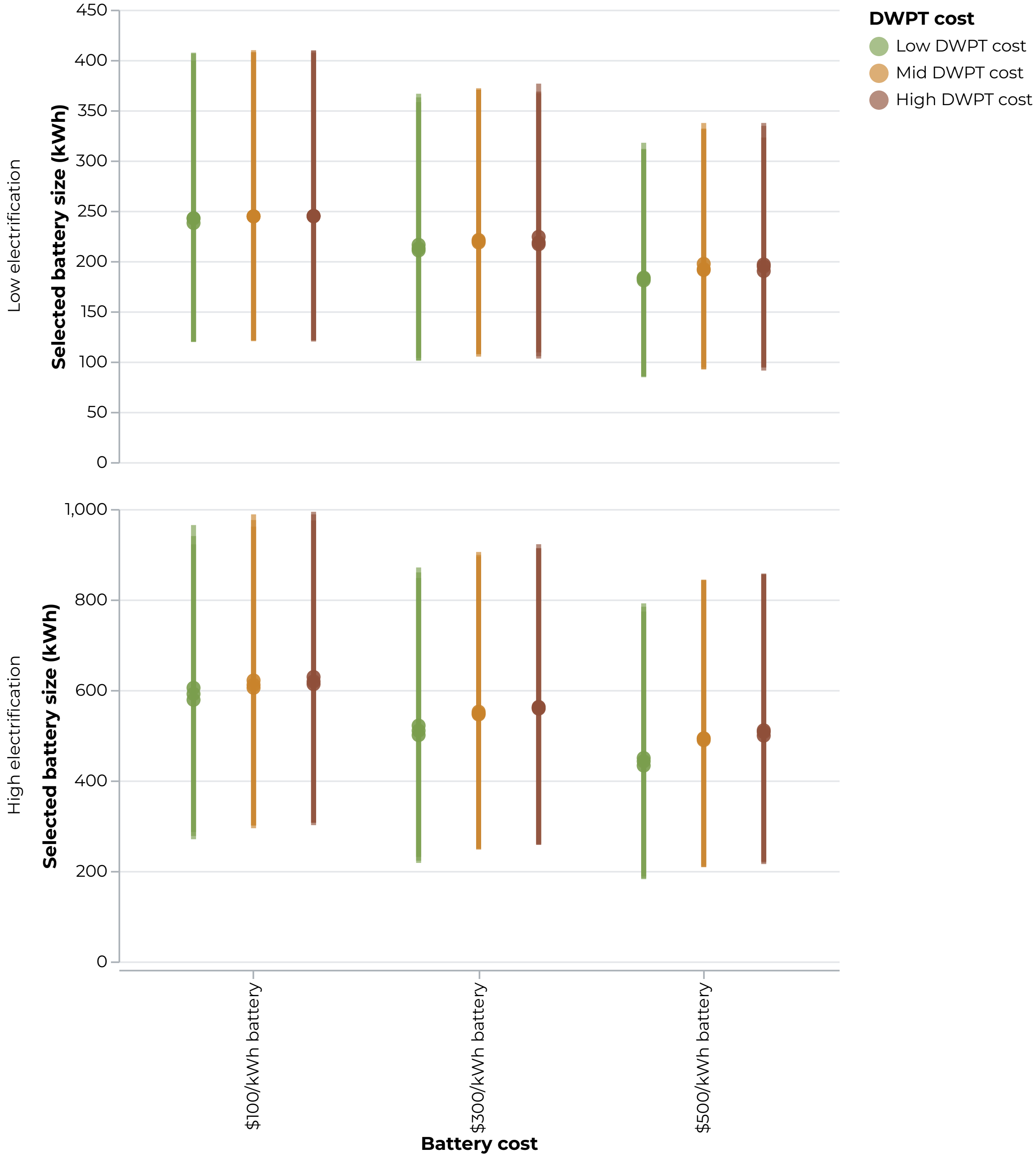

Figure 5: Selected battery-size distribution by pathway, battery cost, and DWPT cost case.

recommendations or claims about the discrete battery-pack configurations that would be available in the vehicle market.

The continuous battery sizes in Figure 5 are useful for optimization because they reveal the economic tradeoff between onboard storage and charging infrastructure without forcing the result into a small number of current commercial pack configurations. They should not be interpreted as market-ready procurement specifications. Real vehicle purchases would use discrete model offerings, packaging constraints, warranty terms, payload tradeoffs, and manufacturer availability that are outside this planning model.

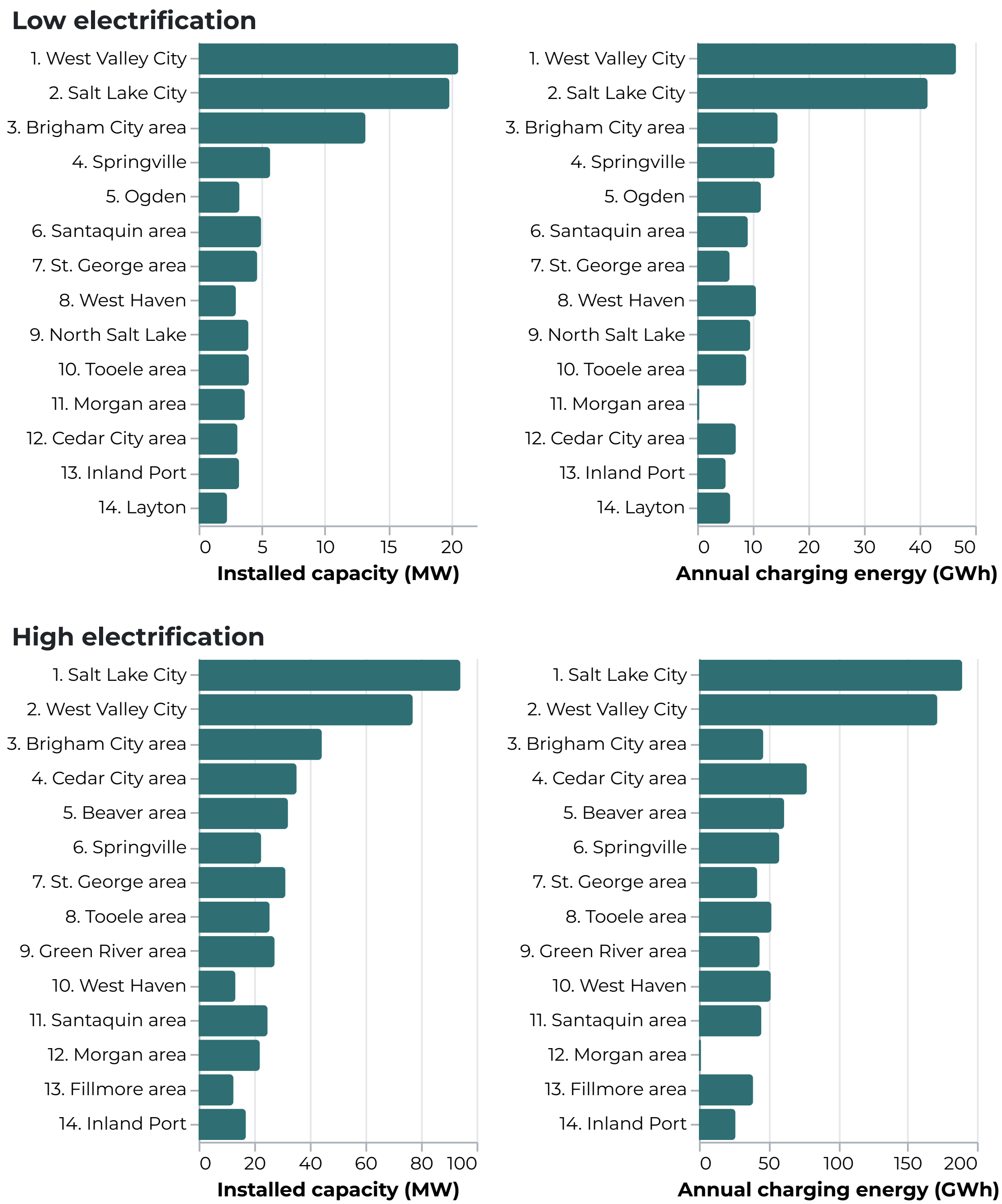

Figure 6: Largest selected stationary charging zones by installed capacity and annual charging energy in the reference scenarios.

3.3 Infrastructure Siting and Utilization

Across the scenario set, the model selects between 86 and 228 Utah infrastructure zones or roadway segments. Stationary charging appears at 82 to 100 Utah modeled zones per scenario, while DWPT selection is much more scenario-sensitive, ranging from 4 to 134 Utah roadway segments per scenario. Selected DWPT buildout has a median of about 43 lane-miles and ranges from approximately 10 to 562 lane-miles. The stationary zone counts are optimization geographies, not counts of discrete charging stations or chargers.

This pattern suggests that stationary charging is the most stable near-term charging paradigm in the modeled system, while DWPT is a more contingent strategy that expands or contracts sharply with cost assumptions, electrification pressure, and interactions with battery economics.

Figure 6 compares the largest selected stationary charging zones by installed capacity and annual charging energy in the reference scenarios. Salt Lake City and West Valley City are consistently prominent, reflecting the concentration of truck activity and charging opportunity in the urban freight system. Several joined non-Wasatch municipality zones also appear among the largest zones, especially under high electrification. These joined-zone labels, such as Cedar City area or Brigham City area, represent grouped nearby municipalities named after the largest municipality in the zone; the appendix table documents the municipalities included in each joined zone. Large capacity totals for a zone should be interpreted as charging capacity distributed across that modeled geography, not necessarily as one physical station with the full zone-level capacity.

Installed capacity and energy throughput are related, but they are not identical. The highest-throughput zones overlap with the highest-capacity zones, but the lists are not the same. This distinction matters for planning because a large zone may be selected to cover a high peak or difficult operating pattern, while another zone with less capacity may deliver more annual energy through steadier utilization. High electrification also elevates several rural or joined-zone locations that serve long-distance freight movement. This is an important planning signal: a statewide truck charging network is not only an urban capacity problem. Rural and corridor-adjacent locations may become strategically important even if their local population or land-use intensity is much lower than the Wasatch Front.

Figure 7 shows the distribution of zone-level breakeven charging costs for selected stationary zones in the reference scenarios. Here, breakeven cost is the constant charging price at a location that would make the location-specific net-present cost equal zero. The calculation reflects modeled local infrastructure, electricity, grid-related costs where assigned, and delivered energy. Many selected stationary zones fall within a relatively low breakeven-cost range, while the right tail represents zones selected for coverage, timing, or operational feasibility rather than low standalone cost. These breakeven values should be interpreted as model diagnostics, not as retail rate recommendations.

Figure 8 shows that selected infrastructure is not uniformly utilized. Utilization is reported here as an annualized load factor: annual charging energy divided by installed charging capacity times 8,760 hours. The histogram counts scenario-location observations pooled across the scenario set, not unique physical charging sites. Some selected locations serve high-throughput roles, while others appear to support coverage, timing, or feasibility needs. This helps explain why selected zones can have higher breakeven costs even when they remain useful in the optimized network. Low utilization should therefore not be interpreted automatically as a model error or an unnecessary site: some locations may be selected because they enable difficult itineraries, create network coverage, or serve narrow but important timing needs. In deployment, these strategically useful but lower-utilization locations may require different ownership, tariff, or public-support structures than high-throughput charging hubs. Very high utilization, especially above roughly 50%, should also be interpreted cautiously because it would require strong operational coordination, reliable charger availability, and managed arrival patterns to avoid queues or missed charging windows.

Figure 9 connects the top-capacity and top-throughput views by comparing installed capacity, annual energy, and utilization for the 14 largest reference stationary zones in each pathway. High-capacity locations are not always the highest-utilization locations, and similar annual energy can imply different installed capacity requirements.

Figure 10 shows the destination-sharing penalty applied to stationary zones. A sharing penalty factor of 4 means the zone is modeled as requiring four times the effective destination-charging capacity that would be needed under perfect sharing. This is a dispersion-adjusted proxy, not a direct estimate of the number of charging sites or plugs that would ultimately be required within

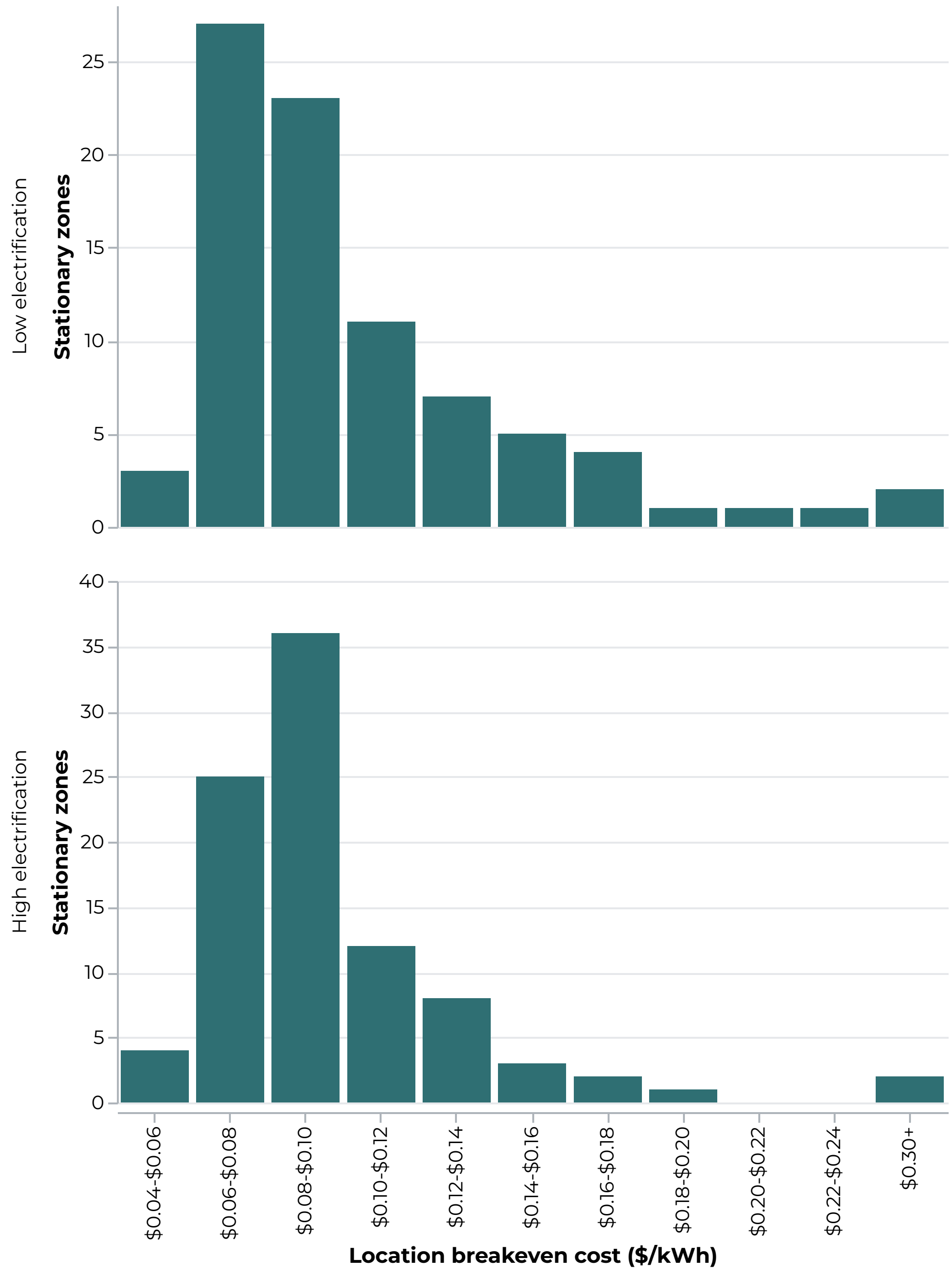

Figure 7: Distribution of zone-level breakeven charging costs for selected stationary zones in the reference scenarios.

the zone. Many zones have modest penalties, but the right tail indicates locations where modeled stop opportunities are more spatially dispersed. The penalty reduces the risk of treating all stops in a broad zone as if they could share the same physical charger.

3.4 Stationary Charging, En-Route Charging, and DWPT Tradeoffs

Utah reported-location throughput is dominated by stationary charging across the modeled scenarios. Across the scenarios, Utah reported-loca-

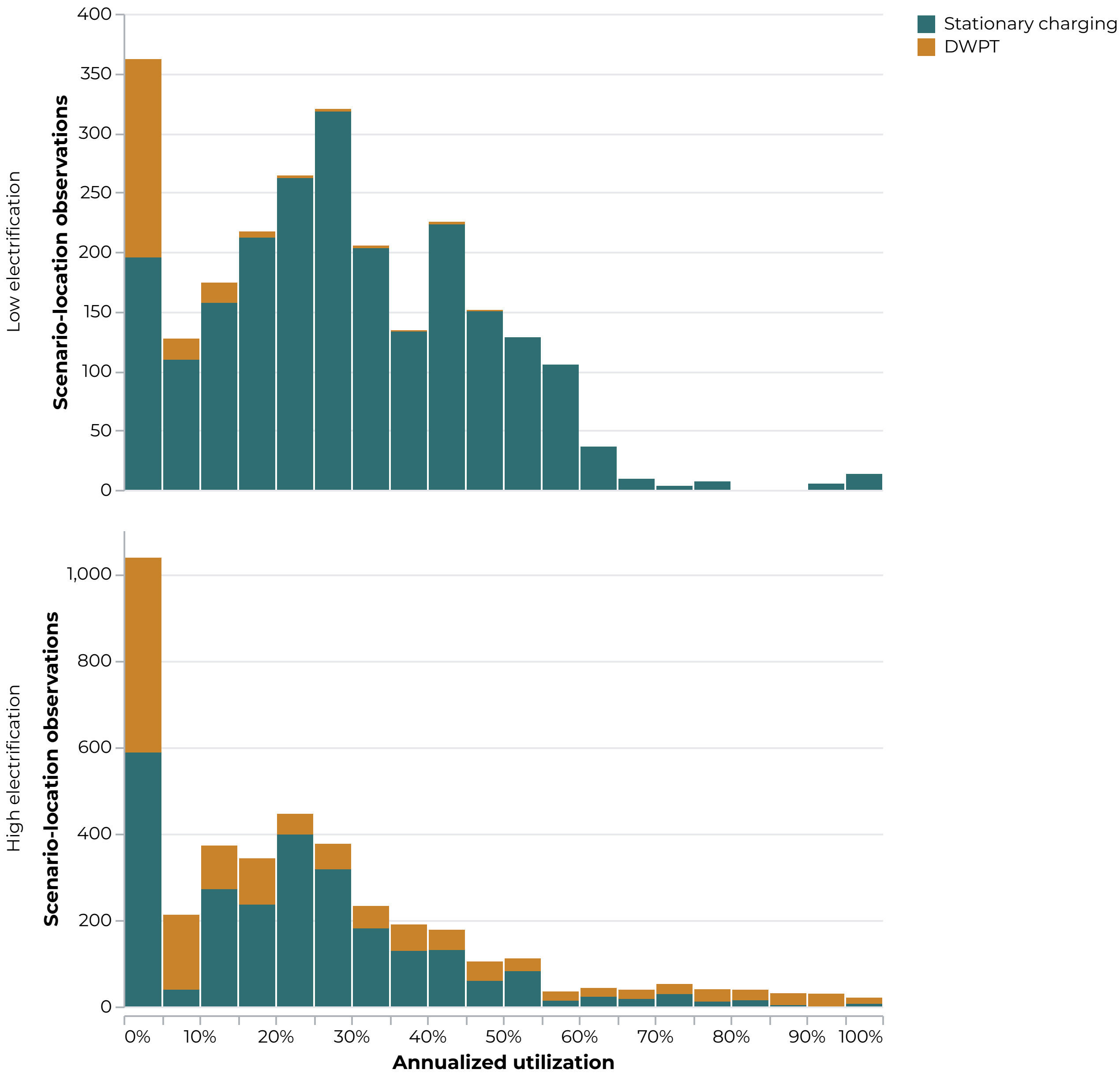

Figure 8: Selected-location annualized utilization distributions by pathway and infrastructure paradigm.

tion DWPT energy share ranges from effectively 0% to about 11%, with a median near 1%. DWPT appears most strongly when dynamic charging costs are favorable and when electrification pressure is high.

Figure 11 separates destination charging, en-route charging, and DWPT energy for the high battery-cost scenarios. Destination charging supplies the largest share of energy, while en-route charging provides a visible feasibility and flexibility role for more difficult itineraries. DWPT remains smaller in energy terms under these selective-deployment assumptions, but its share is scenario-sensitive and rises when DWPT cost assumptions are favorable. In this figure, greater DWPT use generally reduces both stationary destination charging and en-route charging shares rather than substituting cleanly for only one stationary charging mode.

Figure 12 shows en-route reliance as both an energy-delivery pathway and an operational time burden. Scenarios with higher en-route shares imply more itinerary disruption even when the full system remains optimized. En-route charging

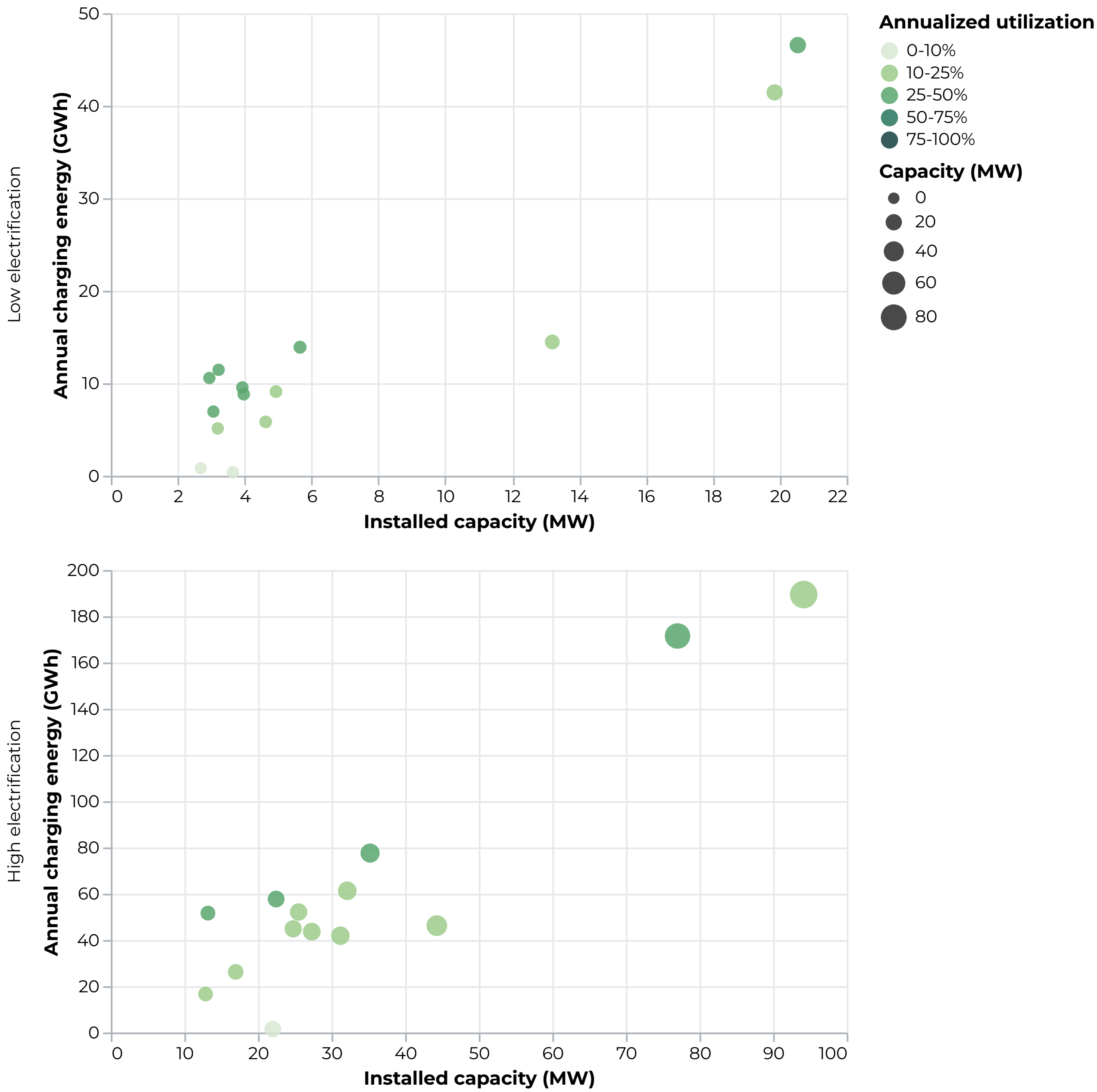

Figure 9: Installed capacity, annual energy, and annualized utilization for the largest reference stationary zones.

can look modest in energy-share terms while still creating a meaningful operational burden through added deviation time.

Figure 13 reports mutually exclusive vehicle charging-mix categories. Each modeled vehicle is assigned to one category based on which charging event types it uses at least once. A category involving en-route charging does not mean the vehicle relies solely on en-route charging unless the category is specifically "En-route only"; for example, "Dest/En-route/DWPT" means those vehicles use all three charging event types somewhere in their modeled itineraries.

Figure 14 shows how selected DWPT lane-miles vary across scenario assumptions. DWPT buildout is strongly scenario-sensitive. Low DWPT cost assumptions produce much larger lane-mile selections, and battery cost also affects selected DWPT buildout, indicating an interac-

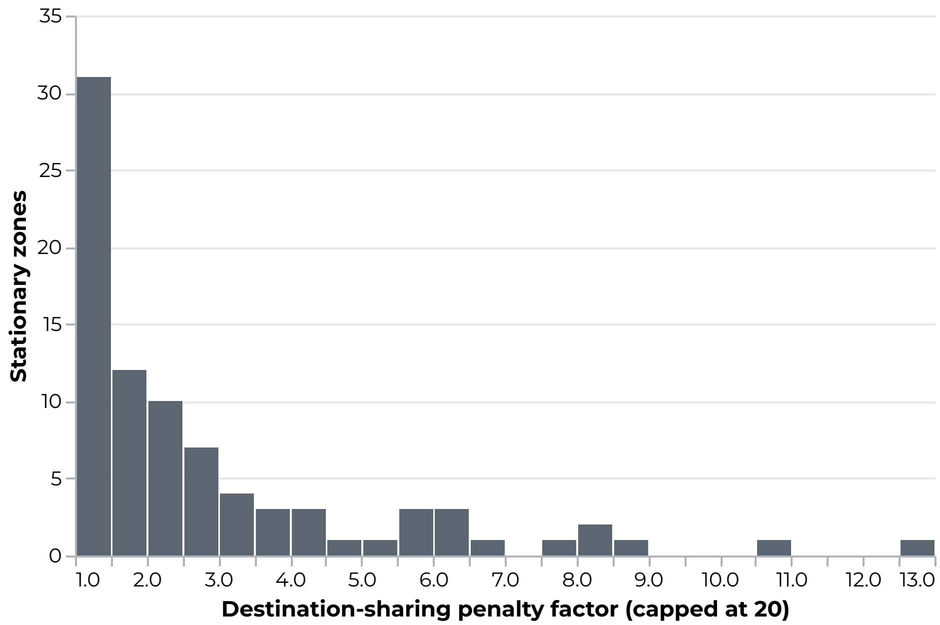

Figure 10: Distribution of destination-sharing penalty factors for stationary charging zones.

tion between vehicle-side and infrastructure-side economics.

The relationship between stationary charging and DWPT is not a simple one-for-one substitution. Figure 15 compares stationary charging capacity and selected DWPT lane-miles across scenarios. In the high-electrification pathway, the leftward drift of points as DWPT lane-miles increase indicates that DWPT can displace some stationary charging capacity. Even so, scenarios with substantial DWPT buildout can still require substantial stationary capacity because the two paradigms serve different events, locations, and timing needs. In this scenario family, DWPT is best interpreted as a corridor and feasibility tool within a mostly stationary charging system.

Figure 16 breaks reference-scenario net-present cost into major cost components by charging paradigm. Stationary charging dominates cost contribution largely because it dominates delivered energy. The cost breakdown also differs by paradigm: DWPT is more exposed to demand charges and grid upgrades in the reference scenarios, illustrating that stationary charging offers more opportunity for siting, scheduling, and managed-charging control, while DWPT load is more tightly coupled to traffic flows and road segments. DWPT cost contribution is smaller in the reference scenarios than its strategic importance might imply, which reinforces the value of separating energy delivered, infrastructure selected, and cost contribution in the interpretation.

The DWPT conclusion should also stay scoped. These scenarios evaluate selective truck-focused DWPT deployment, not a paradigm-shift roadway-electrification future in which large shares of major roads are electrified and used by many vehicle classes.

3.5 Grid Upgrade Implications

The grid-upgrade results in this report are Wasatch grid-envelope outputs, not statewide utility engineering estimates. They are useful for comparing scenario patterns, but they should not be interpreted as a full-state grid-upgrade plan. Grid upgrades are also upgrades to shared grid assets, not upgrades owned by or uniquely attributable to individual charging locations.

Within that Wasatch rollup, grid-upgrade capacity ranges from about 77 to 213 MW in the low-electrification pathway and from about 372 MW to 1.66 GW in the high-electrification pathway. The jump from low to high electrification is much larger than the variation within the low-electrification pathway, which indicates that adoption scale is a first-order grid-planning driver.

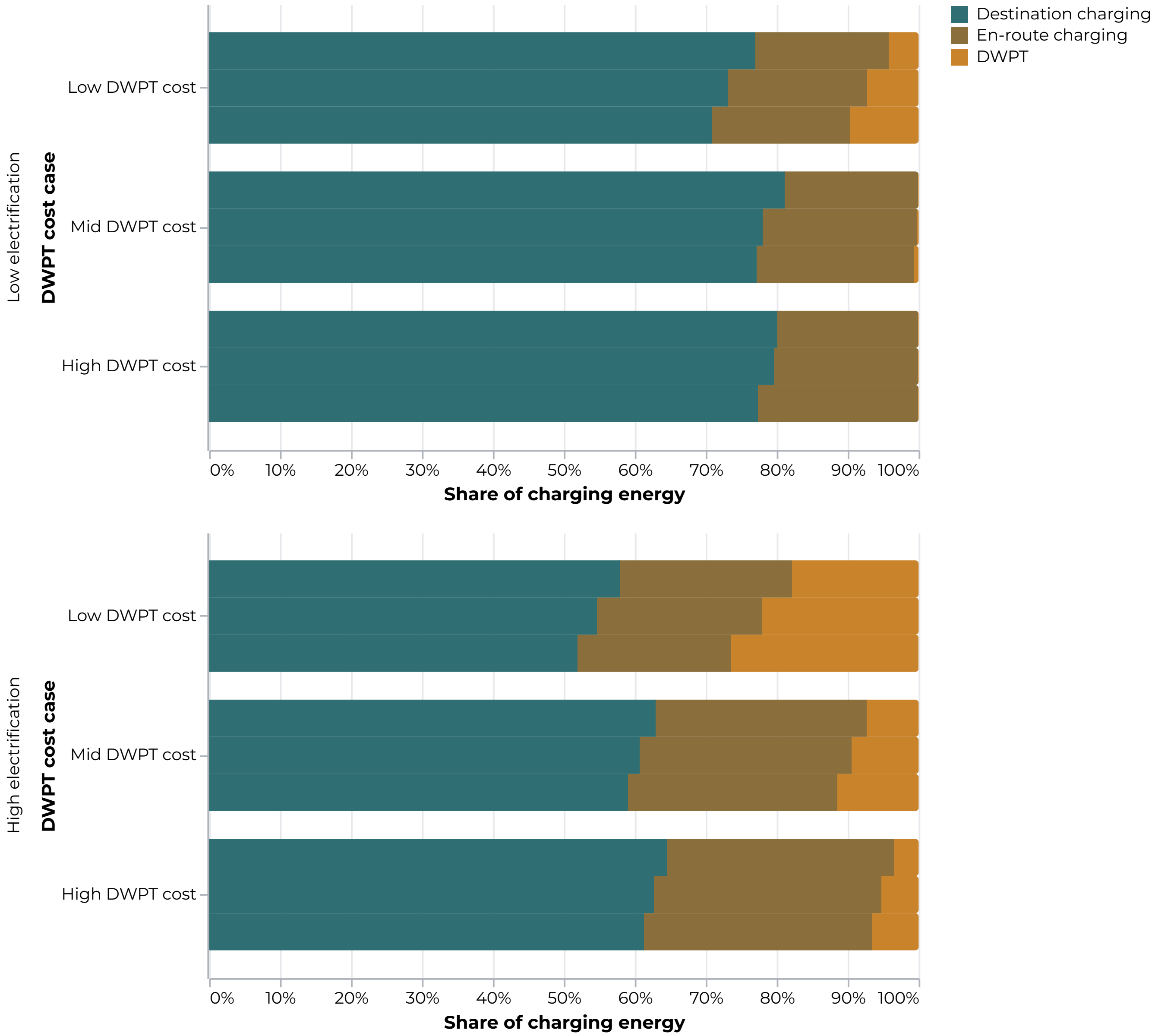

Figure 11: Charging-energy shares for destination charging, en-route charging, and DWPT under the high battery-cost scenario, by pathway, DWPT cost, and stationary charging cost.

Figure 17 shows Wasatch grid-upgrade capacity by pathway, DWPT cost, battery cost, and Wasatch DWPT energy share. Required grid-upgrade capacity rises sharply in the high-electrification pathway. Scenarios with higher Wasatch DWPT energy share also tend to require larger grid upgrades under the current grid-envelope assumptions.

Figure 18 shows the relationship between Wasatch DWPT energy share and Wasatch grid-upgrade capacity. The relationship is generally positive, but it is not purely linear. Scenarios with little DWPT use require similar grid-upgrade capacity, while scenarios with higher DWPT energy share tend to create a much larger grid-upgrade signal. One likely mechanism is that DWPT has high power intensity and less charge-management flexibility than the stationary charging paradigms under this optimization structure. A truck has at least five minutes to charge at a qualifying stationary stop, but may have less than one minute to receive energy on a selected DWPT segment. The optimizer minimizes peak

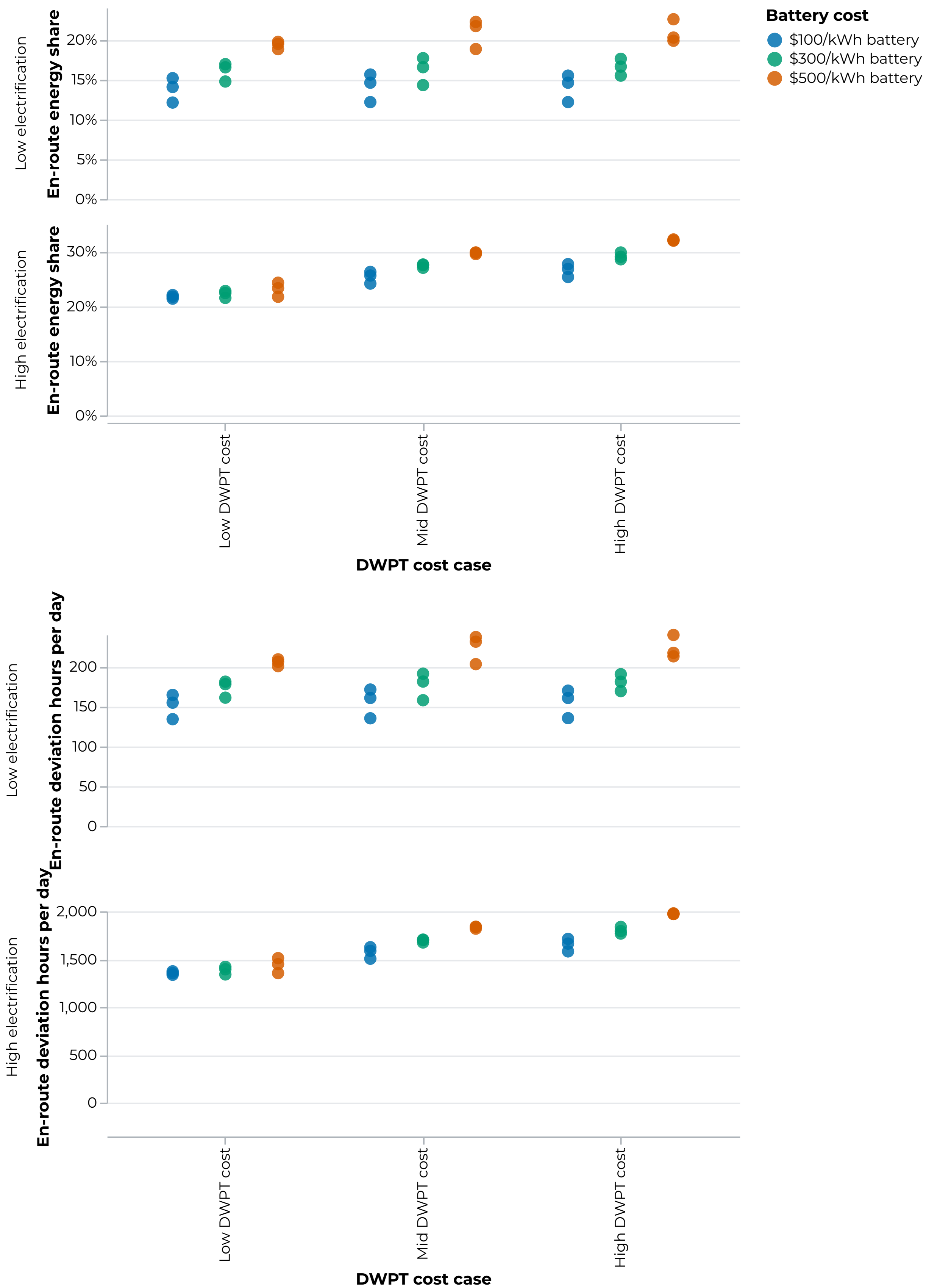

Figure 12: En-route energy share and en-route deviation hours per day across scenario assumptions.

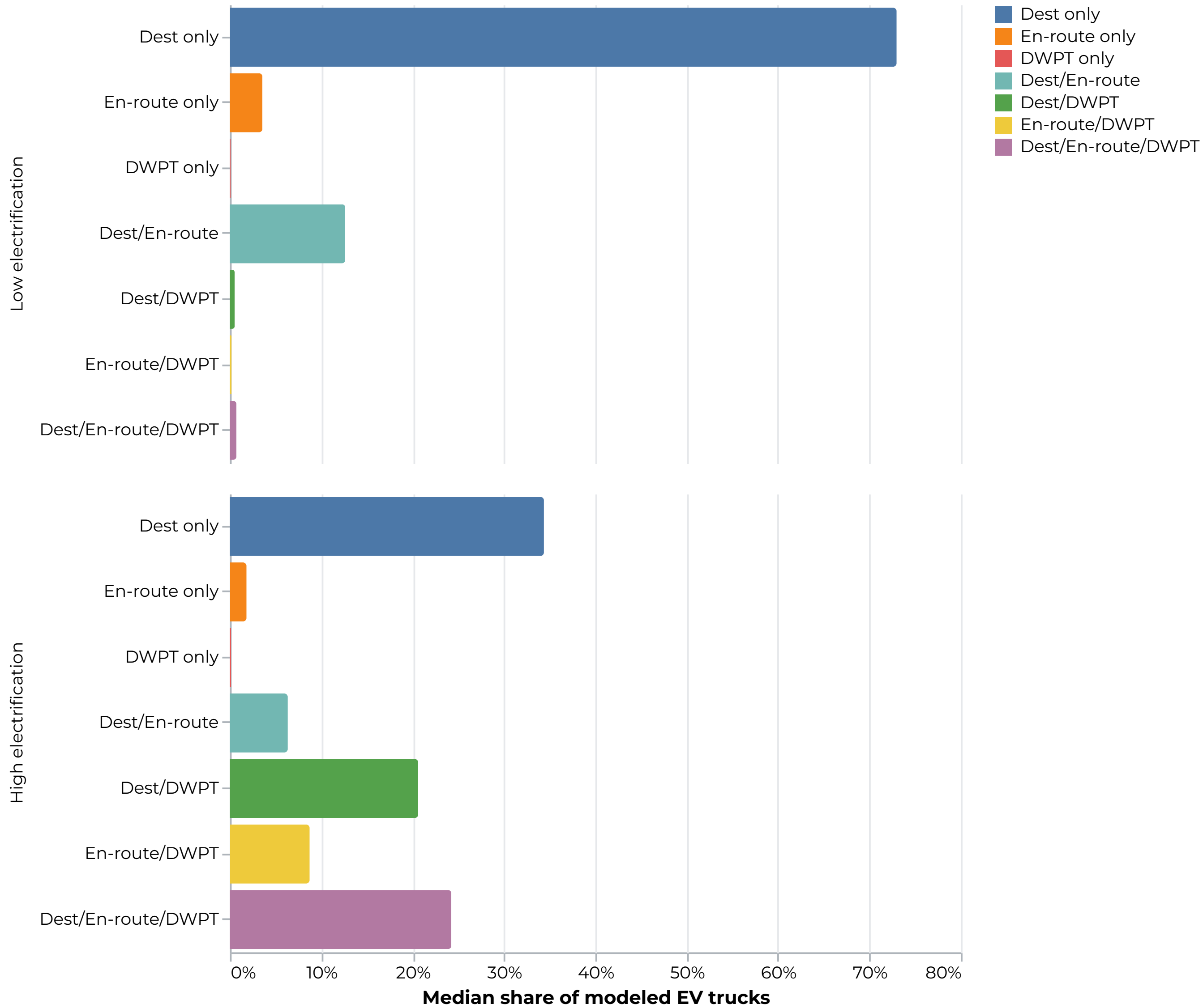

Figure 13: Modeled vehicle shares by mutually exclusive charging-event mix and electrification pathway.

load and grid upgrades where it can; stationary charging gives it more timing flexibility to do so, while DWPT load is more tightly tied to traffic timing and roadway segment traversal. The peak-management actions available at stationary sites would themselves require significant real-world coordination, so less coordinated deployment could increase infrastructure needs and grid upgrades even for stationary charging. Pathway, battery cost, and stationary infrastructure selection all interact with DWPT reliance. This is one of the clearest areas where future analysis should improve: newly available detailed grid capacity and usage information can replace the coarse grid-envelope approximation used here.

3.6 Load Profiles and Temporal Charging Behavior

The representative peak-day load outputs show that electrification scale creates a much larger grid-planning signal than most within-pathway cost sensitivities. Systemwide representative peak-day load ranges from approximately 41 to 90 MW in the low-electrification pathway and from approximately 363 MW to 1.15 GW in the high-electrification pathway. Median systemwide scenario peak load is approximately 46 MW in the low-electrification pathway and 546 MW in the high-electrification pathway.

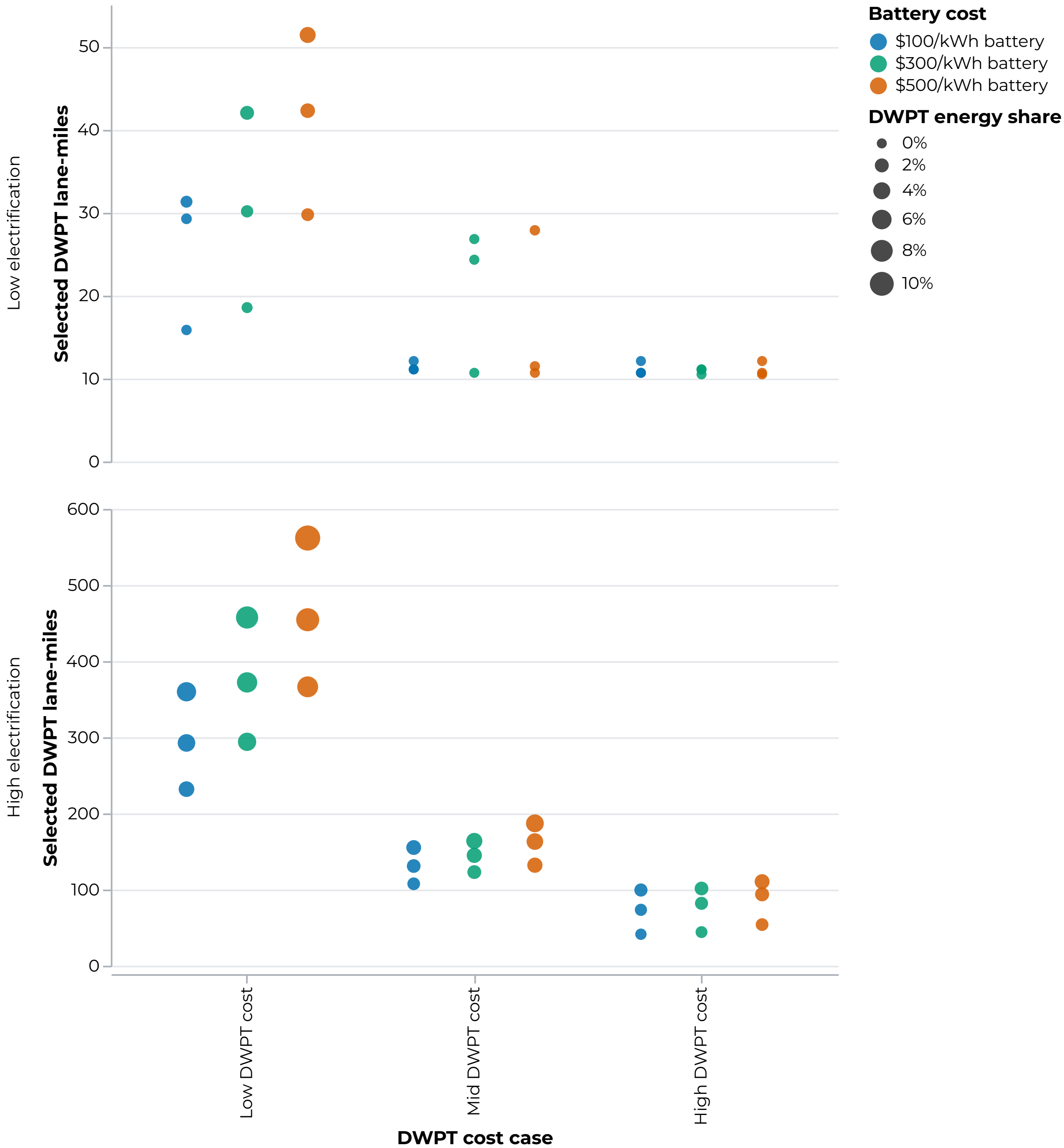

Figure 14: Selected DWPT lane-miles across scenario assumptions.

Within each electrification pathway, stationary charging peak load is comparatively bounded, while DWPT peak load varies much more sharply with dynamic-charging cost assumptions. Median stationary peak load is approximately 41 MW in the low-electrification pathway and 292 MW in the high-electrification pathway. Median DWPT peak load is approximately 1 MW in the low-electrification pathway and 253 MW in the high-electrification pathway.

Figure 19 shows representative peak-day load by pathway and charging paradigm across scenarios. The transition from low to high electrification dominates the visual pattern. Within each pathway, DWPT peak load is the more scenario-sen-

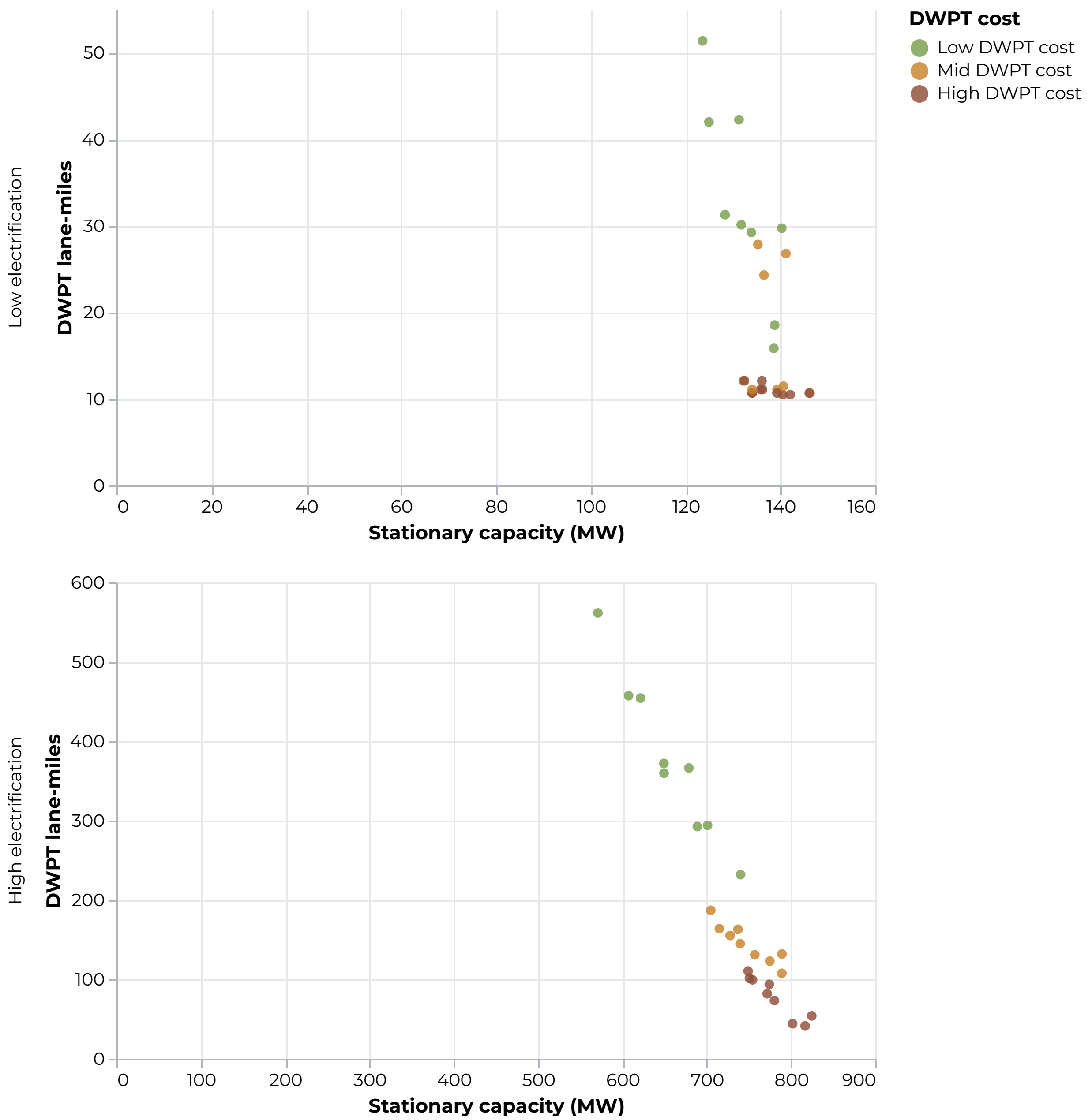

Figure 15: Stationary charging capacity compared with selected DWPT lane-mile buildout across scenarios.

sitive component, reflecting the way dynamic-charging cost assumptions change infrastructure strategy.

Figure 20 shows the 24-hour statewide charging load by paradigm for the reference scenarios. Stationary and DWPT loads have different temporal shapes, which matters for tariff design and utility planning. DWPT load falls to zero overnight in the reference profiles, which is partly an artifact of the single-day simulation structure rather than a general claim about all possible DWPT operations. The afternoon and evening dip in modeled load reflects the optimizer shifting charging away from peak-pricing periods where it can do so.

The representative-day load profile should be interpreted as a stacked high-demand modeled day, not an observed chronological statewide average-day load curve. It is useful for stress-testing infrastructure implications and comparing sce-

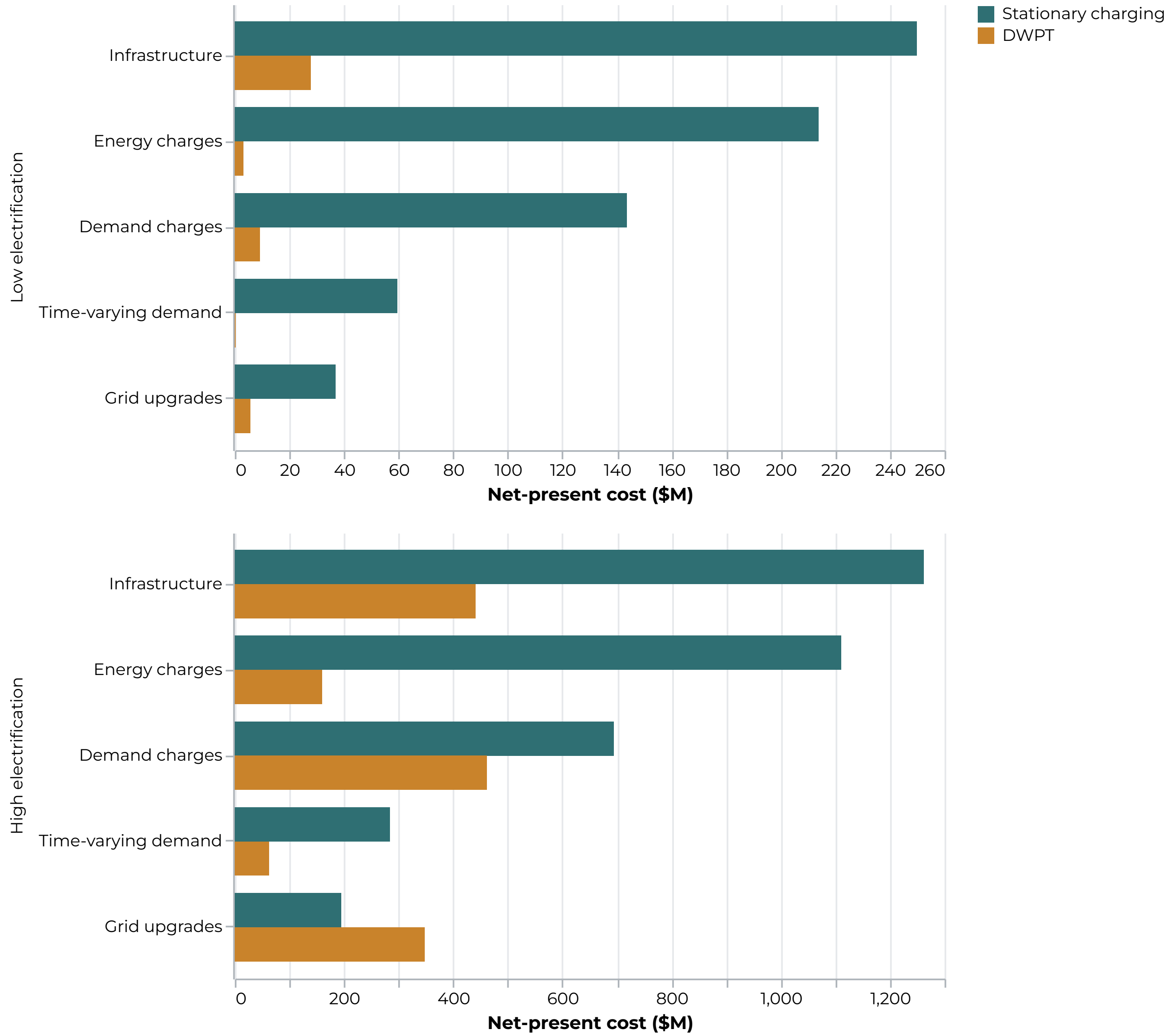

Figure 16: Reference-scenario net-present cost contribution by charging paradigm and cost component.

narios, but it is not a prediction of hourly load on a particular calendar day.

3.7 Planning Interpretation

Three planning lessons stand out from the scenario results.

First, stationary charging is the most consistently selected charging paradigm in the modeled Utah Class 8 truck-electrification system. It supplies most modeled charging energy, appears consistently across scenarios, and remains substantial even when DWPT is selected. Within the scope of this scenario family, near-term planning should therefore prioritize candidate stationary charging zones, utility interconnection processes, and operational coordination around freight stop locations.

Second, DWPT is a selective complement in this scenario family. It becomes more attractive when dynamic-charging costs are low, when electrification pressure is high, and when vehicle-side battery economics interact favorably with roadway charging. The results do not imply that DWPT is inherently limited to a small role; they

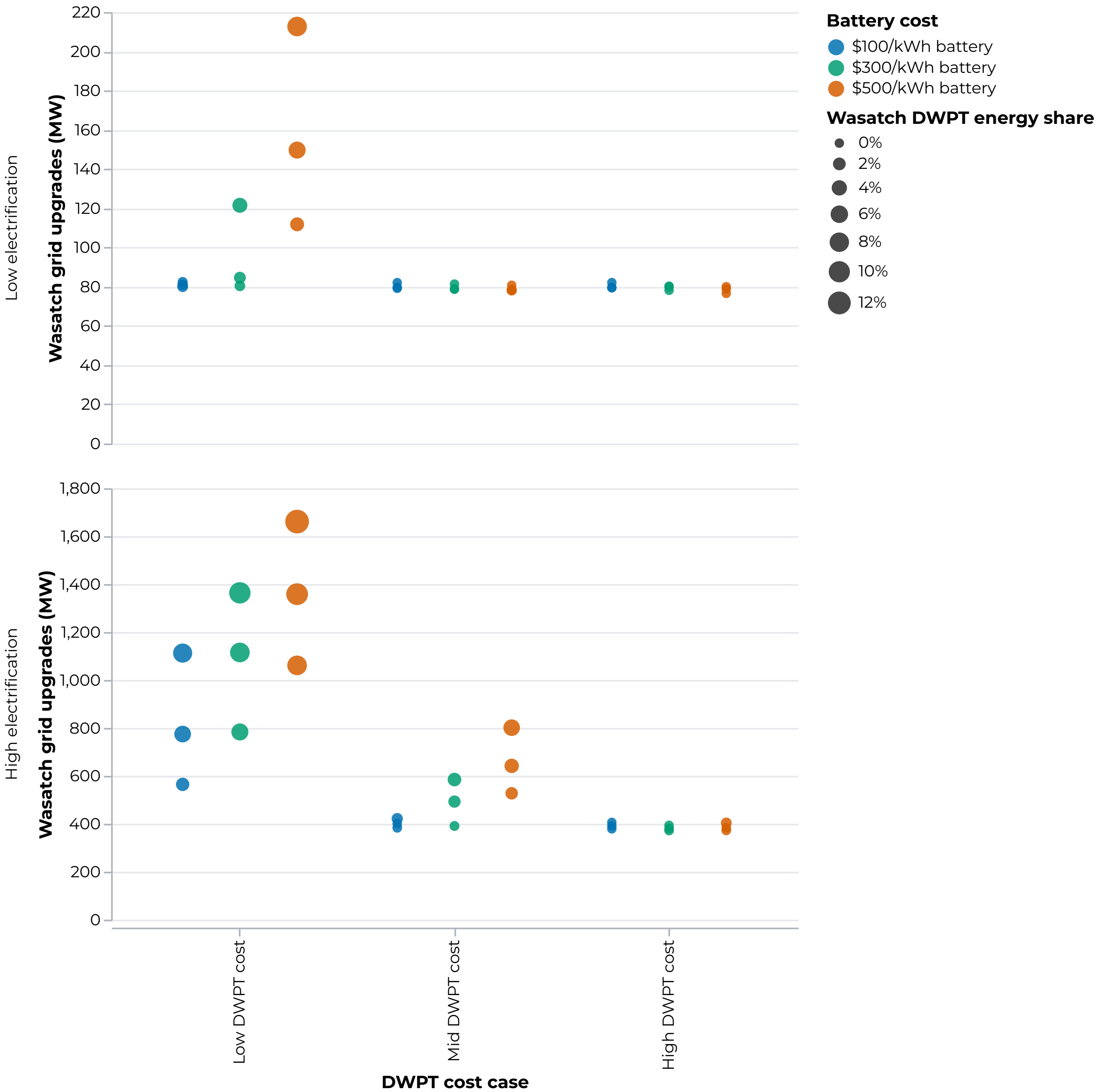

Figure 17: Wasatch grid-upgrade capacity by pathway, DWPT cost, battery cost, and Wasatch DWPT energy share.

show that under the modeled selective deployment assumptions, DWPT does not broadly replace stationary charging.

Third, grid impacts scale sharply with electrification pressure and are sensitive to charging paradigm. The Wasatch grid-envelope results and representative-day load profiles both show that high electrification creates a qualitatively different utility-planning problem than low electrification. Detailed grid capacity and usage data should be incorporated before translating these results into utility upgrade plans.

Overall, the model is best used to compare scenarios and identify robust patterns, not to prescribe exact site-by-site buildout. The compact cost-per-mile range is encouraging, but it reflects optimized coordination across infrastructure placement, battery sizing, and charging

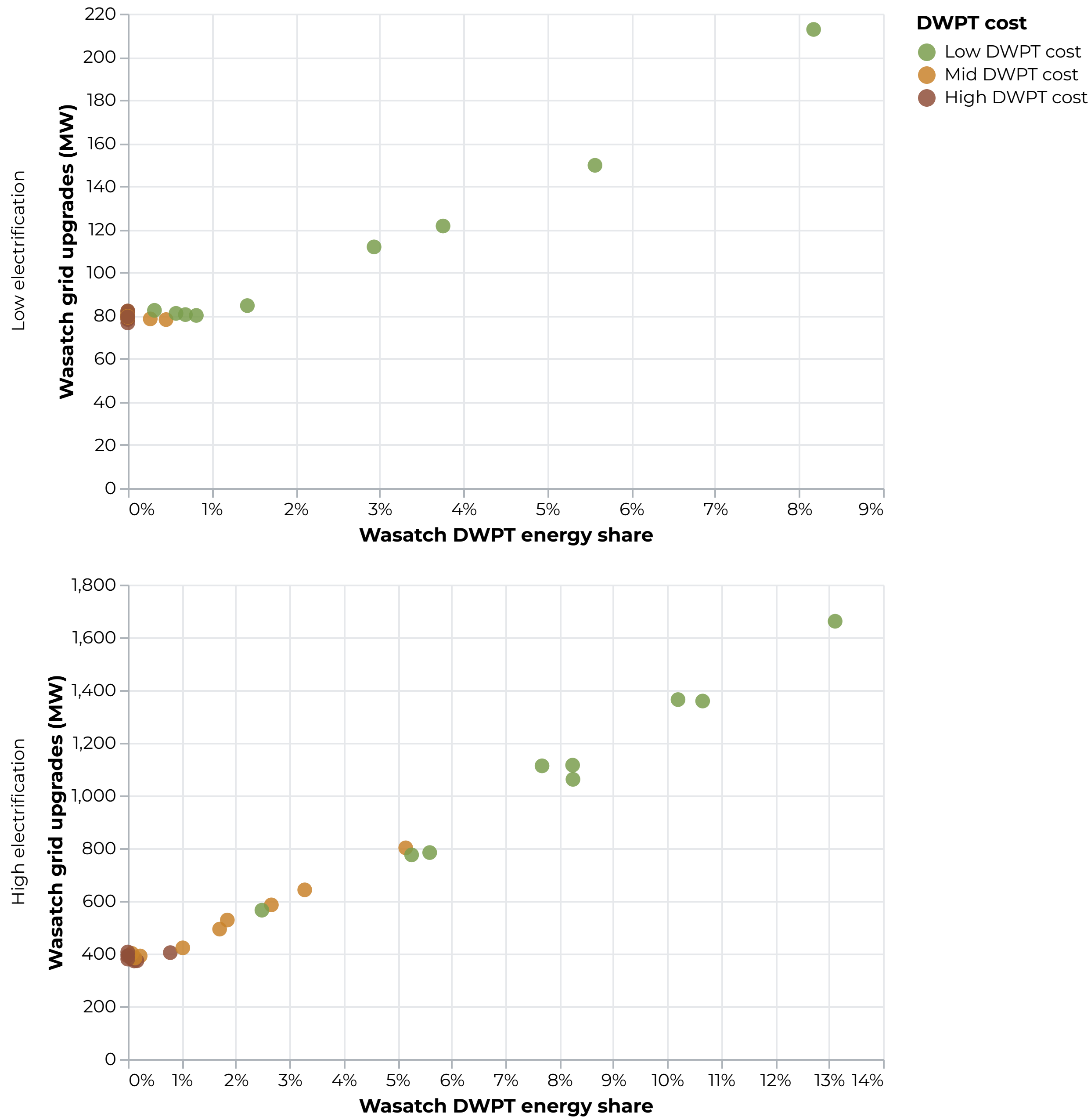

Figure 18: Relationship between Wasatch DWPT energy share and Wasatch grid-upgrade capacity.

behavior. It should be interpreted as a lower limit on what might be achieved under highly coordinated implementation, not as a guarantee of practical deployment cost. Practical deployment will face land availability, permitting, interconnection timing, carrier preferences, financing constraints, and imperfect information that are not quantified in this analysis.

4 Limitations and Future Work

The scenario results provide a useful planning baseline, but they should be interpreted as outputs from a structured optimization model rather than as a deployment plan. The most important limitations fall into four categories: energy-

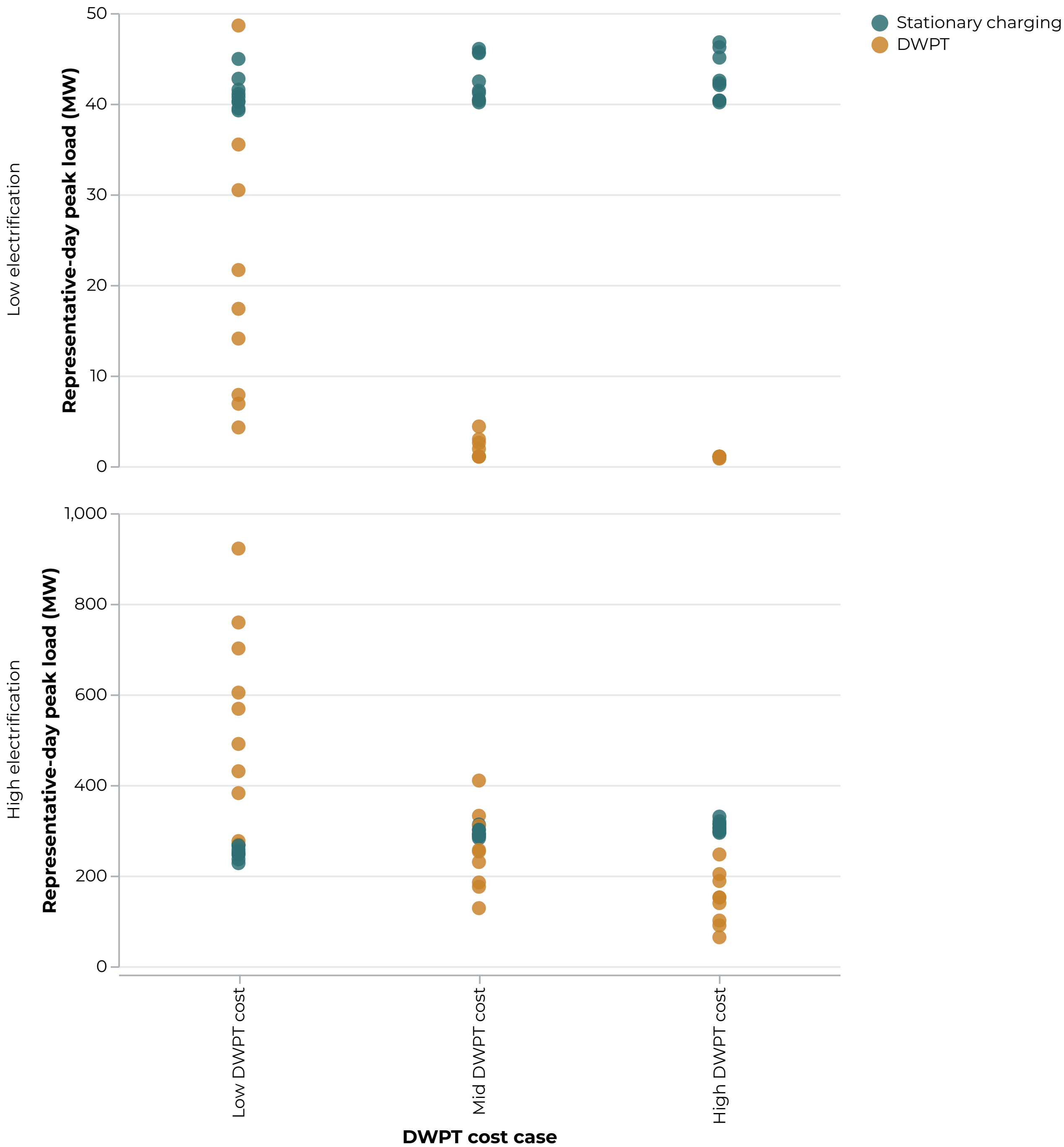

Figure 19: Peak load by pathway and charging paradigm across scenarios.

demand fidelity, data representativeness, implementation realism, and scenario scope.

4.1 Model Limitations

The truck energy model uses a simplified per-mile energy assumption. It does not explicitly vary energy consumption by grade, payload, speed profile, acceleration intensity, HVAC demand, or weather. This is acceptable for a first statewide planning comparison, but it limits route-level precision and may understate the importance of specific corridors or operating conditions.

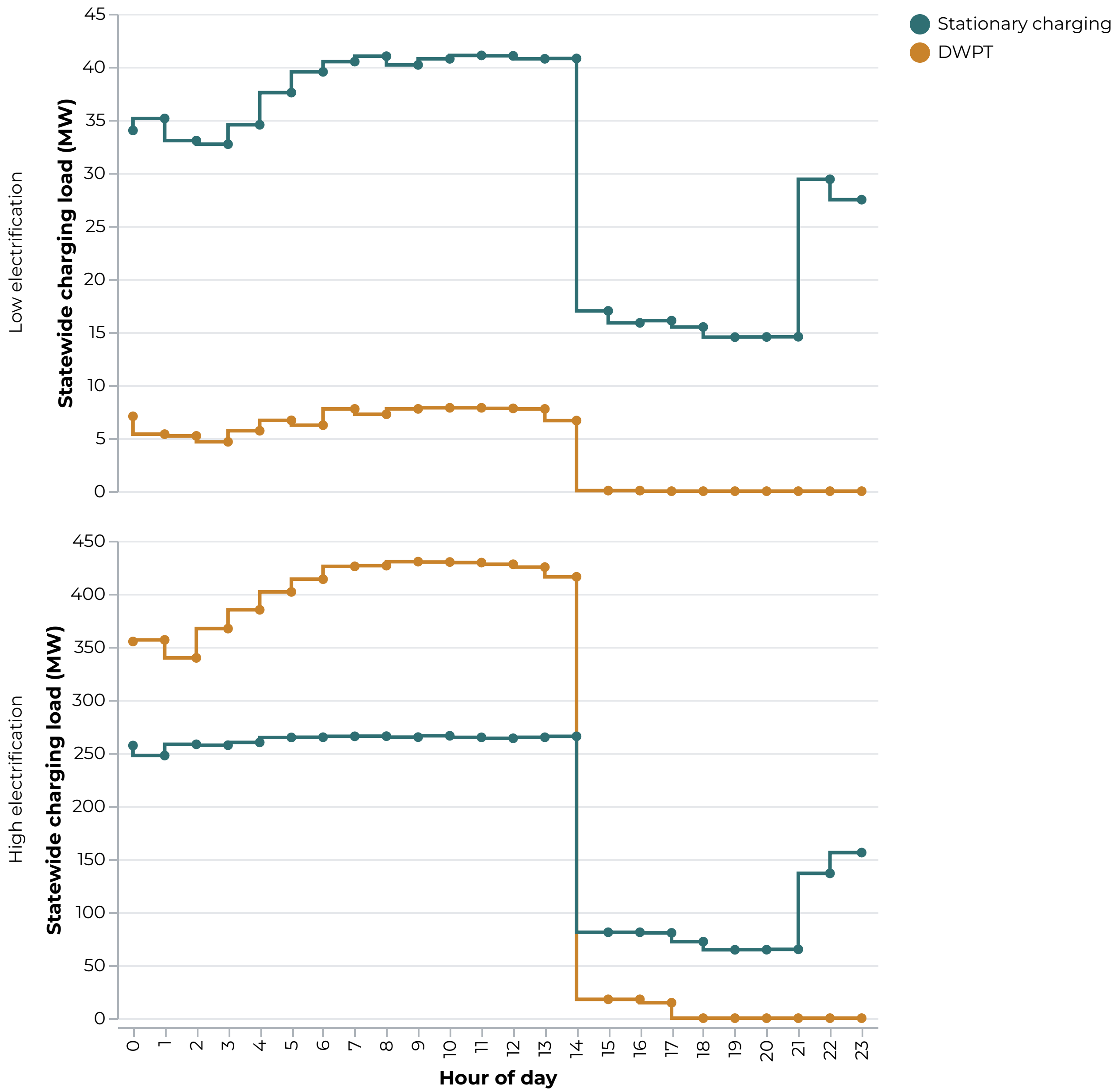

Figure 20: 24-hour statewide charging load by paradigm for the reference scenarios.

The representative-day construction is intentionally conservative. It stacks high-demand vehicle-days to stress the infrastructure system, which reduces the risk of underestimating infrastructure need. At the same time, it is not an average chronological traffic day, so results should not be interpreted as average-day utilization or a prediction of load on a specific calendar day.

The input telematics provide a strong empirical basis for truck movement and stop patterns, but they do not represent every freight operator, private facility constraint, land-ownership issue, or depot-access rule in Utah. Local siting feasibility remains a separate planning step.

The optimization assumes a degree of system coordination that is difficult to achieve in practice. Globally optimized infrastructure placement and charging behavior identify a lower limit on achieved cost per mile because real deployment will involve fragmented fleet decisions, utility upgrade timelines, land ownership constraints, procurement rules, permitting delays, financing constraints, and imperfect information. This work does not estimate the cost penalty associated with those implementation frictions.

Grid representation is also limited. The grid-upgrade outputs currently use a coarse and geographically limited Wasatch grid-envelope approximation, not detailed statewide feeder, substation, interconnection, or hosting-capacity analysis. The values are useful for comparing scenarios, but they should not be treated as utility engineering estimates.

The scenario set does not evaluate a paradigm-shift DWPT pathway with extensive roadway electrification and broad use by light-duty, medium-duty, and heavy-duty vehicles. The modeled DWPT role is limited by heavy-duty truck-focused adoption scenarios and a narrow exogenous light-duty revenue credit. As a result, the scenario set cannot estimate how much stationary charging or onboard battery capacity might be displaced under a much broader roadway-electrification paradigm.

Finally, all future cost trajectories result from scenario assumptions and are not forecasts. Battery, stationary charging, DWPT, tariff, and revenue-credit assumptions should be revisited as market evidence improves.

4.2 Future Work

The highest-priority next step is to improve grid representation. Future iterations should replace the coarse Wasatch grid-envelope approximation with detailed and comprehensive grid capacity and usage information that is now available for planning analysis. This would support full-state grid-upgrade reporting, better location-level interconnection screening, and more credible utility-facing conclusions.

Future work should also add a paradigm-shift DWPT scenario family. That scenario family should represent broad electrification of major roadways, endogenous use by light-duty, medium-duty, and heavy-duty vehicles, and vehicle designs that can rely on reduced onboard battery range. The key comparison would be whether high roadway utilization can offset roadway infrastructure cost while displacing stationary charging capacity and vehicle battery capacity.

Additional electrification pathways should be tested beyond the current low- and high-electrification cases. The current partial-electrification pathway is a useful scenario construction device, but it is not an adoption forecast. Future runs should evaluate targeted sequencing rules such as highest-mileage-first, lowest-cost-first, most-electrifiable-first, corridor-priority adoption, and carrier-led deployment.

Future work should also test the sensitivity of these results to broader truck-activity samples. The current sample provides a useful empirical basis for scenario comparison, but it is still a partial view of Utah freight activity. A broader sample could change which itineraries appear most electrifiable, which locations appear repeatedly, and how the first several percent of statewide truck VMT might actually electrify.

Truck energy modeling should be refined with grade, weather, payload, speed, duty cycle, vocation, and vehicle-class segmentation. Those additions would improve route-level interpretation and make the model more useful for evaluating specific corridors, seasonal operating conditions, fleet types, and use cases.

The model should also be paired with stakeholder-specific scenario views. Utilities need load timing, coincidence, and interconnection detail. Transportation planners need corridor investment priorities. Fleets need procurement and operating-cost interpretation. Policy designers need sensitivity to incentives, tariffs, and cost-sharing structures. A single optimization output can support all of these audiences, but each requires a different reporting lens.

Future work should also evaluate tariff and operating strategies more explicitly. For example, avoiding time-of-use or demand-charge periods may reduce electricity costs but could require more infrastructure, larger batteries, or less DWPT use if charging is shifted away from otherwise valuable operating windows.

Finally, future model iterations should be paired with ongoing stakeholder engagement and field evidence where possible. Targeted carrier interviews, site reviews, interconnection studies, and pilot deployments would help validate the modeled charging opportunities and identify practical barriers that are not visible in the current data. DWPT assumptions should be updated as the technology matures, deployment costs become better documented, and operating performance is demonstrated at larger scale. Broader transportation paradigm shifts, including automation or other changes to freight operations, could also alter the relative value of battery capacity, stationary charging, en-route charging, and roadway electrification.

5 Appendix and Supplementary Material

5.1 Joined Municipality-Zone Membership

Some non-Wasatch Utah charging locations are represented as joined municipality zones. These zones reduce optimization complexity while preserving statewide geographic coverage. Each joined-zone label is based on the largest municipality in the reconstructed zone. The joined zones are modeling simplifications and may not align perfectly with freight-corridor groupings, utility service territories, or local planning boundaries.

The table below documents the municipality membership of those joined zones so that labels used in the infrastructure and load-profile figures can be interpreted consistently.

Table 5: Municipality membership represented by each joined reporting zone.

Joined Zone Name	Municipalities Joined
Altamont area	Altamont
Antimony area	Antimony
Beaver area	Beaver
Big Water area	Big Water
Blanding area	Blanding
Bluff area	Bluff
Boulder area	Boulder
Brigham City area	Amalga, Bear River City, Brigham City, Clarkston, Corinne, Cornish, Deweyville, Elwood, Farr West, Fielding, Garland, Honeyville, Hyde Park, Hyrum, Lewiston, Logan, Mantua, Mendon, Millville, Newton, Nibley, North Logan, Paradise, Perry, Plain City, Pleasant View, Plymouth, Portage, Providence, Richmond, River Heights, Smithfield, Tremonton, Trenton, Wellsville, Willard
Cedar City area	Brian Head, Cedar City, Enoch, Kanarraville, New Harmony, Paragonah, Parowan
Circleville area	Circleville, Junction, Kingston
Delta area	Delta, Hinckley, Leamington, Lynndyl, Oak City
Duchesne area	Duchesne
Dutch John area	Dutch John
East Carbon area	East Carbon
Emery area	Emery
Enterprise area	Enterprise
Escalante area	Escalante
Eureka area	Eureka
Fillmore area	Fillmore, Holden, Kanosh, Meadow
Garden City area	Garden City, Laketown
Green River area	Green River
Hanksville area	Hanksville
Heber City area	Brighton, Charleston, Daniel, Francis, Heber City, Hideout, Independence, Interlaken, Kamas, Midway, Oakley, Park City, Park City, Wallsburg
Hooper area	Hooper
Howell area	Howell

Table 6: Municipality membership represented by the remaining joined reporting zones (continued).

Joined Zone Name	Municipalities Joined
Kanab area	Kanab
Koosharem area	Koosharem
Loa area	Bicknell, Loa, Lyman, Torrey
Manila area	Manila
Marysvale area	Marysvale
Milford area	Milford, Minersville
Moab area	Castle Valley, Moab
Monticello area	Monticello
Morgan area	Coalville, Henefer, Morgan
Orderville area	Alton, Glendale, Orderville
Panguitch area	Hatch, Panguitch
Price area	Castle Dale, Clawson, Cleveland, Elmo, Ferron, Helper, Huntington, Orangeville, Price, Wellington
Randolph area	Randolph, Woodruff
Roosevelt area	Ballard, Myton, Roosevelt
Santaquin area	Annabella, Aurora, Centerfield, Central Valley, Elsinore, Ephraim, Fairview, Fayette, Fountain Green, Glenwood, Gunnison, Joseph, Levan, Manti, Mayfield, Mona, Monroe, Moroni, Mount Pleasant, Nephi, Redmond, Richfield, Rocky Ridge, Salina, Santaquin, Santaquin, Sigurd, Spring City, Sterling, Wales
Scipio area	Scipio
Scofield area	Scofield
Snowville area	Snowville
St. George area	Apple Valley, Hildale, Hurricane, Ivins, La Verkin, Leeds, Rockville, Santa Clara, Springdale, St. George, Toquerville, Virgin, Washington
Tabiona area	Tabiona
Tooele area	Erda, Grantsville, Lake Point, Magna City, Rush Valley, Stockton, Tooele
Tropic area	Bryce Canyon City, Cannonville, Henrieville, Tropic
Vernal area	Naples, Vernal
Vernon area	Vernon
Wendover area	Wendover