Forecasting energy use flows of air routes under aviation electrification

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AVIATION ELECTRIFICATION AS A SMART GRID CHALLENGE

Aircraft have transformed global mobility by enabling rapid movement of people and intensifying economic, cultural, and social exchange worldwide. Yet aviation is also contributing a growing share of global greenhouse gas emissions, especially carbon dioxide, with recent emissions growth exceeding that of rail, road, and shipping. According to the International Energy Agency, aviation emissions recovered to nearly 800 Mt after the pandemic, about 95% of the pre-pandemic level, and were projected to exceed their 2019 level in 2025. In this context, aviation electrification is increasingly viewed as an important pathway for decarbonization under international climate initiatives such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). In practice, however, electricity enters aviation in two distinct ways. The first is the electrification of ground operations, for example, through fixed or mobile ground power units that replace onboard auxiliary power units for parked aircraft. This transition is already advancing and can reduce fuel burn, emissions, and noise. The second, and more disruptive, form is electricity used for aircraft propulsion. It is this latter case that creates a new planning challenge for airports and power systems, because electric-aircraft charging must be coordinated with flight schedules, stand allocation, and turnaround windows rather than treated as a smooth aggregate load.[1,2]

Unlike conventional refueling, charging battery-electric aircraft is constrained by both time and location. Aircraft arriving within the same schedule bank may require charging during overlapping turnaround periods, creating short-duration but high-power demand spikes. Airports may therefore evolve from fuel-distribution nodes into concentrated electrical load hubs, with implications for feeder capacity, transformer loading, on-site storage, and airport–grid coordination. Aviation electrification is not simply a matter of replacing jet fuel with electricity. It introduces a spatiotemporal planning problem for airport energy systems and surrounding distribution networks.

This Commentary places that problem within the broader aviation energy transition, which also includes hydrogen and synthetic-fuel pathways, but focuses specifically on airport-grid-coupled charging demand from battery-electric aircraft. These alternative pathways remain important for decarbonization, yet they do not map directly onto the same airport-side charging problem and therefore should not be treated as equivalent cases in the framework developed here.

A key limitation of the existing literature is that electricity demand is usually estimated at fleet, airport, or system levels. Such aggregate views are useful, but they do not capture where and when charging demand will actually emerge. Early electrification is more likely to appear on short-haul, repeatedly operated routes served by aircraft with feasible range and turnaround characteristics.[3] The relevant planning question is therefore not only how much electricity aviation may consume, but which routes will electrify first, when charging concurrency will occur, and where local network stress will concentrate. We argue that a missing intermediate forecasting layer is needed between fleet-wide scenarios and airport-level planning: route-level, time-resolved prediction of electrified air- route demand. This planning layer is especially relevant to airport authorities and operators, while necessarily requiring coordination with utilities, grid operators, and airlines.[4,5]

ENERGY USE OF REPLACING FUELS WITH ELECTRIC AIRCRAFT FLEETS

Although long-run aviation decarbonization may involve multiple energy pathways, the planning object considered here is battery-electric aircraft and the airport-side charging demand they create. We therefore focus on electricity drawn directly from the grid during aircraft turnaround, rather than upstream electricity used for hydrogen production or synthetic-fuel manufacture. The distinction matters because these pathways imply different infrastructure chains and different relationships with airport power systems.

Fleet replacement under electrification is not a one-time choice, but a long-horizon transition involving multiple stakeholders. Airlines must weigh aircraft acquisition costs, battery replacement cycles, operating economics, emissions targets, and exposure to electricity and fuel-price volatility. Airports face decisions on charger deployment, stand electrification, storage installation, and electrical-capacity expansion, all under uncertainty about the pace and pattern of adoption. Utilities and grid operators must assess feeder, transformer, and wider network impacts, while regulators shape the transition through policy, incentives, and market design. These decisions are interdependent, but the most immediate technical challenge for airport infrastructure planning is to anticipate where and when charging demand will arise.

From this perspective, airport authorities and operators are the natural lead planners of airport- side charging infrastructure, working in coordination with distribution utilities, grid operators, and airlines. What they need is not only a projection of total electricity use, but also the temporal and spatial structure of that demand. The same annual electricity consumption can imply very different infrastructure requirements depending on whether charging is concentrated on a few repeatedly operated short-haul routes with overlapping turnaround windows, or spread more evenly across routes and times of day.

This is why route-level, time-resolved forecasting may serve as a useful intermediate planning layer between fleet-wide scenarios and airport-level demand estimation. Its purpose is not to claim a validated operational standard, but to define a forecasting object that is directly relevant to charger siting, storage deployment, substation phasing, and airport–grid coordination. In this formulation, the task is to predict which technically feasible routes are likely to electrify over a planning horizon and how much charging demand each active route will induce at specific airports and times. The value of this approach remains an empirical question and should be tested in future scenario-based studies. Even so, much of the required information, including schedules, route distances, aircraft suitability, turnaround times, and local power-system conditions, is already available or increasingly accessible in practice.

SPATIOTEMPORAL ENERGY FLOWS FORECASTING ALONG AIR ROUTES

Existing airport-level assessments are useful for estimating broad electricity needs, but they generally do not preserve the route identity, directionality, and schedule-specific timing needed to infer charger concurrency, stand-level conflicts, or feeder stress associated with repeated electric-aircraft rotations. Electrification will materialize through specific routes, aircraft assignments, and turnaround windows rather than through a smooth increase in aggregate airport demand. For this reason, the forecasting object most relevant to infrastructure planning is not simply total airport electricity consumption, but the spatiotemporal distribution of charging demand across electrified air routes.

We therefore propose representing future battery-electric aviation demand as a dynamic directed weighted network (Figure 1). In this representation, airports are nodes, origin–destination services are directed links, and route-associated charging demand is encoded as a time-varying edge weight. The forecasting problem then has two coupled dimensions: whether a route will be active under a given electrification scenario, and how much airport-side charging demand that route will generate. This formulation shifts the focus

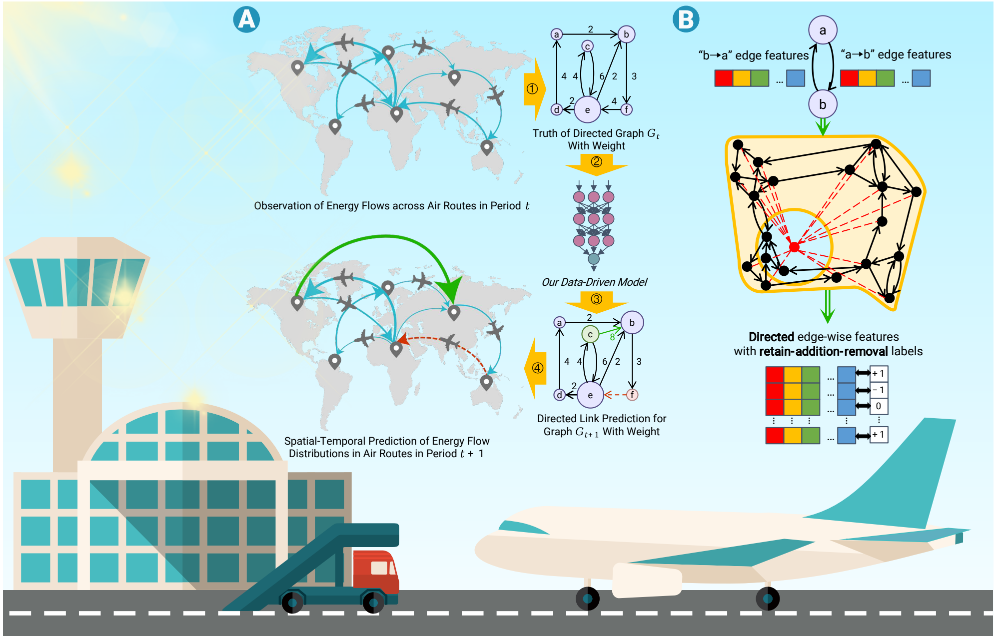

Figure 1. Route-levelforecastingframeworkforair-port-sidechargingdemand (A)Historicalbattery-electric aviation demand is represented as a sequence of directed weighted graphs, where airports are nodes, air routes are directed links, and route-level charging demand is the link weight. ①Observed route-level energy flows in period t are converted into graph Gt.②Directededge-wisefea-turesare constructed from temporal, structural, and operational information. ③Adata-drivenmodel jointly predicts route activation and link-level charging demand for period t+1. ④generating the forecasted spatiotemporal distribution of energy use across air routes. (B) The resulting forecast maps the spatiotemporal distribution of airport-side charging demand across electrified air routes.

from static aggregate estimation to the prediction of the evolving geometry of the airport charging network.

The contribution of this Commentary is not to claim that route-level forecasting has already been shown to improve planning outcomes in a particular market. Rather, it is to identify this route-level, time-resolved energy network as the missing intermediate planning layer between fleet-wide scenarios and airport-level electricity forecasts. That is the level at which practical planning questions arise: where chargers should be installed, how much stand-side electrical capacity is needed, whether storage is needed to buffer schedule-bank peaks, and when local grid reinforcement should be phased in. Demonstrating the decision value of this approach remains a task for future empirical studies under explicit technology and adoption scenarios.

A practical implementation can be built from data that are already routinely available or increasingly accessible in aviation planning. These include flight schedules, airport-pair traffic records, route distance, aircraft assignment data where available, scheduled turnaround times, stand utilization, airport charging readiness, and local power-system characteristics such as tariff windows and feeder capacity. Under a given battery-electric adoption scenario, these inputs can be used to define a feasible sub-network of candidate electrified routes, especially short-haul services consistent with aircraft range, charging power, and turnaround constraints.

Forecasting can then proceed at the directed-edge level. For each candidate airport pair, predictors can combine three broad classes of information: temporal route-history features, network-structural features, and operational electrification-related covariates. Temporal features may reflect recent persistence, growth, decline, seasonality, or volatility of a route and its associated energy use. Structural features can describe the route's role in the wider aviation network, such as hub connectivity, neighborhood relationships, or directional interaction patterns. Operational covariates can capture electrification feasibility, including route length, service frequency, aircraft suitability, turnaround conditions, and airport electrical readiness. Using these predictors, supervised learning or other fore- casting methods can be used to jointly estimate future link state and non-negative route-level charging demand.

The resulting forecast is a map of where electrified air-route energy demand is likely to emerge, persist, intensify, or recede over time. Such outputs may offer a more decision-relevant basis for infrastructure planning than annual airport-level demand alone. If repeated short-haul services on a small number of airport pairs are forecast to electrify early and to generate tightly clustered charging demand during morning or evening schedule banks, the likely bottleneck may lie in charger power, stand allocation, storage buffering, or upstream feeder capacity. By contrast, if route-level charging demand is more temporally dispersed, staged deployment or price-based load shifting may be more appropriate than immediate grid reinforcement. In both cases, similar annual electricity totals could correspond to very different operational and investment requirements.

This route-level forecasting framework is intended specifically for battery-electric aviation and airport-grid-coupled charging demand. It does not treat hydrogen-powered aircraft or synthetic-fuel pathways as equivalent cases, because their implications for energy systems occur through different infrastructure chains and are not represented directly by airport-side charging links. The framework is therefore modular: different technology assumptions, policy conditions, battery-performance tra- jectories, charging strategies, and fleet-replacement scenarios can be imposed without changing the underlying graph-based formulation.

Future work should evaluate this planning layer empirically in specific regional markets. Such studies could compare airport-level aggregate planning with route-level forecasting under alternative assumptions about battery range, charging power, fleet replacement pace, and schedule concentration, and then assess differences in predicted peak-load concentration, charger utilization, storage value, or upgrade timing. The main novelty here is therefore not simply methodological. It is to formalize the infrastructure-relevant forecasting target for aviation electrification: a route-level, time- resolved energy network whose topology and charging intensity must be predicted jointly. For airport authorities and operators, this framing may provide a more actionable bridge between uncertain electrification scenarios and concrete investment decisions, while also offering a structured interface for coordination with airlines, utilities, and grid operators.

REFERENCES

1. Schäfer A.W., Barrett S.R.H., Doyme K., et al. (2019). Technological, economic and environmental prospects of all-electric aircraft. *Nat. Energy* **4**:160–166. DOI:10.1038/s41560-018-0294-x
2. Hou B., Bose S., Marla L., et al. (2023). Impact of aviation electrification on airports: Flight scheduling and charging. *IEEE TITTS* **25**:2342–2354. DOI:10.1109/TITS.2023.3324310
3. Bergero C., Gosnell G., Gielen D., et al. (2023). Pathways to net-zero emissions from aviation. *Nat. Sustain.* **6**:404–414. DOI:10.1038/s41893-022-01046-9
4. Cui Z., Dong H., Wang K., et al. (2025). The structural evolution of the chinese aviation network during and after the pandemic: A machine learning-based approach. *Trans. Policy* **172**:103774. DOI:10.1016/j.tranpol.2025.103774
5. Lei W., Alves L.G. and Amaral L.A.N. (2022). Forecasting the evolution of fast-changing transportation networks using machine learning. *Nat. Commun.* **13**:4252. DOI:10.1038/s41467-022-31911-2

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DECLARATION OF INTERESTS

The authors declare no competing interests.