A BOTTOM-UP MODEL FOR QUANTIFYING DEMAND-SIDE FLEXIBILITY POTENTIAL FROM BATTERY-ELECTRIC LONG-HAUL TRUCKS

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Abstract

Motivation & Challenge

Meeting the EU's climate targets requires significant emission reductions in heavy-duty transport [1]. Electrifying long-haul trucks is a key pathway that simultaneously introduces a new source of demand-side flexibility for renewable-dominated electricity systems [2,3]. Battery-electric trucks (BETs) combine high electricity demand with regulated driving and rest-time patterns, making their charging behaviour relevant for short-term system balancing [4]. Existing research focuses mainly on depot charging, leaving en-route flexibility during statutory breaks insufficiently explored [5]. Given Austria's role as a major European transit corridor, quantifying this flexibility is essential for system adequacy and integrated mobility-energy planning.

Research Questions

This paper addresses three central questions:

- When is the technically available flexibility potential from operating battery electric trucks available on the routes?
- Where is this flexibility located, given the spatial patterns of truck traffic and road infrastructure?
- How resilient is this flexibility across seasons and infrastructure constraints, and how can it inform energy system planning?

Method

A bottom-up simulation quantifies en-route BET flexibility by combining synthetic 2030 freight flow data with Austrian traffic counts on a detailed node network. BET flows, departure times, and route progression follow observed traffic patterns and full legal driving and rest-time regulations, including the night-driving ban. Electricity demand is calculated from distance and seasonal consumption profiles, and batteries are recharged at each statutory break. For every node and time step, the model determines minimum required and maximum possible charging power, whose difference defines the flexibility potential. Two infrastructure scenarios are analyzed: a low case with capacity just sufficient for timely charging, and a high case with full technical charging power.

Results

The analysis shows that en-route BET charging provides substantial and systematically structured flexibility in 2030. Across all transit routes, the national flexibility potential reaches 420–585 MW, and more than 1.25 GW in the high-capacity scenario during mid-week nights. Temporal availability is dominated by overnight rest periods, while short daytime breaks result in smaller recurring peaks; weekend availability is significantly lower due to reduced traffic. Seasonal consumption differences affect the magnitude but not the overall pattern. Spatially, flexibility concentrates along Austria's major freight corridors and logistics hubs, reflecting the distribution of long-haul traffic and break locations (Figure 1). The resulting flexibility is predictable, corridor-bound, and relevant for short-term balancing and congestion management in systems with a high proportion of renewable energy sources.

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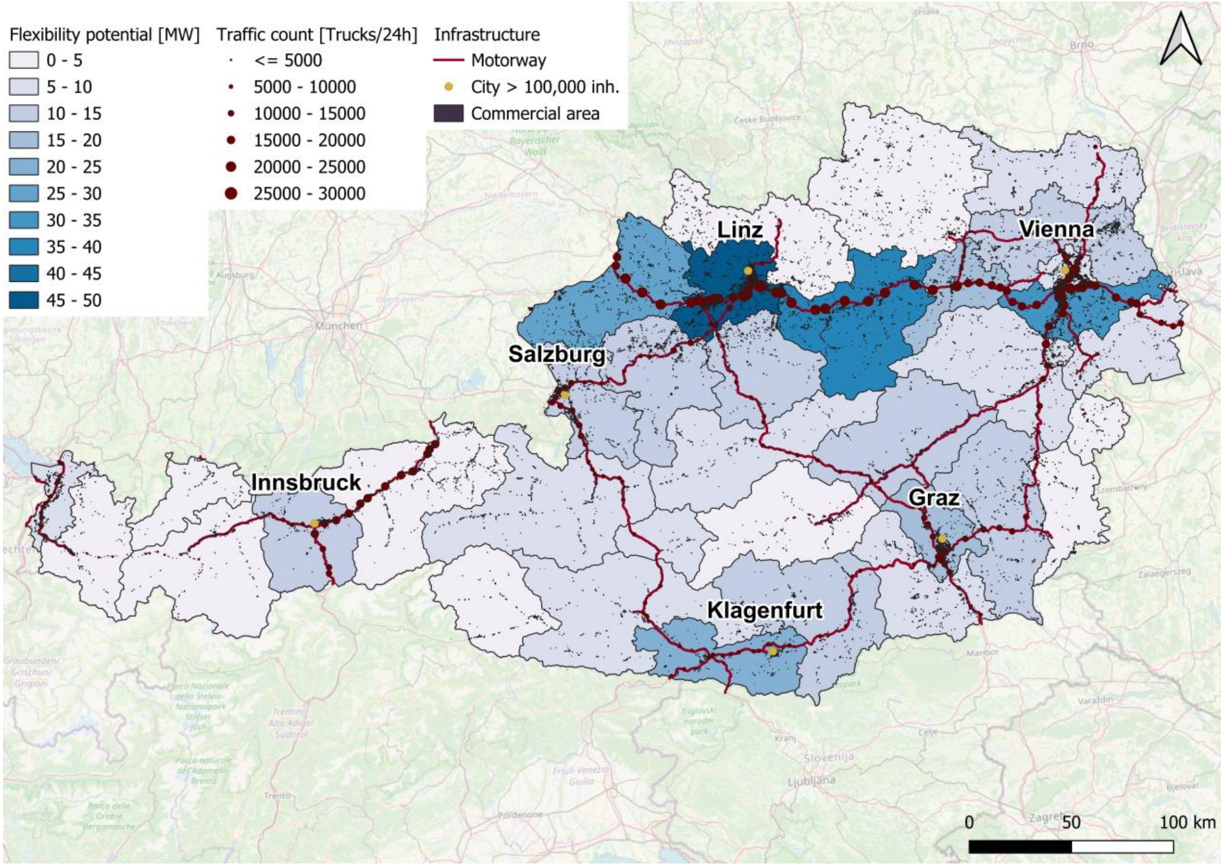

Figure 1: Flexibility potential for a 15-minute time step on an annual average

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