CO-SIMULATING ELECTRIC GRID AND AGENT-BASED EV TRAFFIC/CHARGING USING HAMBURG AS AN EXAMPLE

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Introduction

The transition to sustainable energy systems is a cornerstone of global climate policy, with e-mobility serving as a critical pillar for decarbonizing transport. Cities like Hamburg have set ambitious targets for climate neutrality. However, this electrification wave introduces a significant new class of load on power distribution grids, which were largely designed without foreseeing such high, localized, and coincident demand. Uncoordinated charging, where users plug in their vehicles upon arrival (typically when they arrive in the morning at work or during evening residential peaks), threatens to overwhelm local energy distribution grid assets [1].

Traditional grid planning methods often rely on static load profiles, failing to capture the dynamic, stochastic, and behavioural nature of human mobility and charging decisions. Conversely, transportation models simulate mobility patterns in detail but are "grid-unaware," ignoring the physical constraints of the power network. This gap creates a critical blind spot for infrastructure planning.

To bridge this gap, this paper proposes a novel co-simulation framework that dynamically links an agent-based mobility model (BEAM – Behaviour, Energy, Autonomy and Mobility) [2] with a distribution grid simulator (pandapower) [3]. The framework is managed by HELICS (Hierarchical Engine for Large-scale Infrastructure Co-Simulation) [4], a standard for large-scale co-simulation. The contribution is twofold:

1) The development and validation of this modular BEAM-pandapower-HELICS architecture for coupled mobility-grid analysis;
2) Its application to a realistic, large-scale case study of Hamburg to quantify grid stress under future EV scenario.

This study is part of a broader simulation analysis that examines the impact of various scenarios on metropolitan areas. While the path towards zero carbon emission cities is not yet clear, in addition to the scenario in which all existing cars are electrified,

Methodology

Co-Simulation Architecture

- Agent-Based E-Mobility Simulation: Beam is an agent-based simulation tool that models the complete activity patterns and travel choices. For this each agent is endowed with a household, a workplace and a set of activities. Agents make decisions regarding mode choice (e.g. car (EV), public transport, bike) and for EV users, charging choice (when, where, and for how long to charge)
- Power Distribution Grid Simulation: pandapower is a comprehensive, open-source distribution system simulator capable of detailed power flow analysis, including quasi-static time-series simulations. It models the physical components of the grid, such as lines, transformers, and loads.
- Co-Simulation Framework: HELICS acts as the message broker and time-synchronization manager, ensuring both simulators advance in lock-step. It facilitates the data exchange that creates the cyber-physical link:
  - Time Step t: BEAM simulates agent movement and charging decisions. It calculates the charging load at all active stations and "publishes" this data (load_kW, location_ID) to HELICS.

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- Data Exchange: HELICS delivers this load data to the corresponding "subscriptions" in pandapower.
- Grid Simulation: pandapower adds this EV load to its baseline non-EV load for time t and solves the power flow. It calculates the resulting grid state (voltages, transformer loads).
- Feedback Loop (for Smart Charging): pandapower publishes grid state data (e.g. voltage, price signal) back to HELICS. HELICS delivers this data to BEAM.
- Time Step t+1: BEAM agents receive the grid signal, which influences their charging decisions (e.g., an agent may delay charging if the price is high or voltage is low), thus completing the feedback loop.

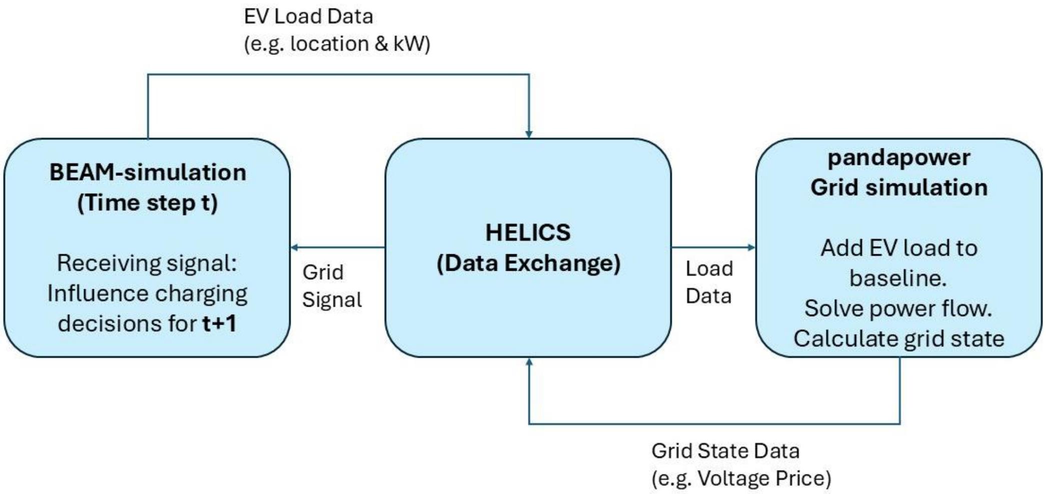

Figure 1: Flow chart co-simulation

Case Study

The study applies this framework to the city of Hamburg. The city itself has around 1.89 million inhabitants and when including the surrounding areas the metropolitan area involves nearly 5,5 million people [5]. The city of Hamburg has just decided to follow the referendum to make the city climate neutral by 2040 [6], which is 5 years earlier than the federal government wants Germany to by climate neutral. The focus of the authors is on a representative urban district with residential.

Data	Input	Output

BEAM	• Hamburg road network (from OpenStreetMap) [7]
	• a synthetic population representative of the city
	  ○ O-D-Matrix (from cell phone data) [8]
	  ○ Modal split [9]
	• locations and specifications of public and private charging infrastructure
		• At each time step (e.g., 1 minute), BEAM publishes the power demand for each EV currently charging

pandapower	• A model of a representative Hamburg distribution grid • Grid load through the day	• At each time step, after solving the power flow, pandapower publishes the grid state, such as the voltage at each charging point

Scenarios: In this study three key scenarios are analysed:

1. Base scenario: The model split in Hamburg reflects the current situation of the city.

2. EV scenario: The model split in Hamburg stays the same, but all combustion engine cars are replaced by EVs
3. Reduced EV scenario: Additionally, to the EV scenario, cars are reduced by 50%.

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