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The project aims to research key technological components for the large-scale (>10.000-1M) coordination of light-duty electric vehicle (EV) charging and vehicle-to-grid for grid balancing and congestion management. The technological components comprise of:

(1) Development of a simulation framework for the development and evaluation of smart charging scheduling (including vehicle-to-grid), capable of simulating large volumes (>10.000-1M) of EVs and their interaction (charging/discharging power, money flow, information flow) with the energy markets (e.g. day-ahead) and the balancing markets (e.g. day-ahead, FCR, aFRR, imbalance market, …), with inclusion of constraints (maximum allowed ampacity), needs (required voltage profile with respect to the EN50160 grid standard[2]) and tariffs (e.g. time-of-use) of the distribution grid.

(2) Develop simulation models to determine the dynamic hosting capacity of the distribution grid for EV charging and discharging (including Vehicle-to-Grid, V2G), by accounting for local grid constraints—such as urban morphology (urban vs. rural), transformer capacity, and the presence of stochastic distributed grid exchangers (SDGEs). The models will assess the maximum injectable and extractable power on both LV and MV (up to 12 kV) grids, ensuring compliance with the voltage boundary conditions defined by the EN50160 grid standard.

(3) New generation forecasting (of EV arrival and connection patterns, driver charging needs), optimization, and control techniques (1 Artificial Intelligence (AI) based, 1 non-AI based, 1 hybrid) for large-scale coordination of charging and discharging (vehicle-to-grid) of light-duty EVs in a real-world grid balancing context (e.g. aFRR, FCR, imbalance, …).

(4) Model the business ecosystem of EV-enabled flexibility (with actors from both energy and mobility such as aggregators, FSPs, ESCOs, and CPOs interacting) as a quantified system dynamics model for the identification of business opportunities and evaluation of policy choices

(5) New generation privacy-friendly and security enhanced communication protocol to protect users against tracing attacks and compatible with the ISO15118 standard.

(6) Assess the technical (grid imbalance, baseload adaptations, flexibility merit order, …) and business implications (charger prices, flexibility prices, driver remuneration schemes, …) of using EVs on large scale (>10000-1M) to provide flexibility services and manage congestion under different scenarios by using the technological developments of (1)-(4).

The first simulation frameworks (1) will allow to assess the potential of using EVs for the existing grid balancing services (FCR, aFRR, imbalance market, ...) under realistic conditions (with specific constraints and principles of existing flexibility services) as well as evaluate the effect of changes to the constraints and principles of the existing flexibility services. It will allow to simulate large volumes (>10.000-1M) of light-duty EVs (i.e. passenger vehicles and vans), further in the project expressed as "EVs" with inclusion of the stochasticity of their charging behaviour. Particular attention will be given to understand how the acting with EVs on balancing services (transmission grid) affect or can be aligned congestion management needs (distribution grid). To that end, the impact of large-scale simultaneous use of EVs on low-voltage distribution grids, and consequently the upstream mid-voltage grid on the hosting capacity as a function of urban morphology will be studied and modelled (2). To coordinate the charging process for flexibility service for large volumes of EVs in a reliable and performant way requires new techniques for forecasting, optimization and management (3). The project will advance forecasting techniques and explore hybrid approaches (mathematical, metaheuristics, machine learning) for the large-scale coordination of EVs for flexibility services. At least 1 AI-based, 1 non-AI-based and 1 hybrid approach for optimized coordination will be investigated and benchmarked. The project further sets out to identify the business opportunities and business models for EV-enabled flexibility (4). To that end, research will be performed to quantify the interactions (dynamics) between the actors in a system dynamics model of the EV-enabled flexibility business ecosystem. This should also allow to investigate longer term horizon evolution (2030 and beyond) of the market under different scenarios (e.g. charger price erosion effects, tax policy choices, ...) and enable the identification of business opportunities. If EVs are to be assets in critical infrastructure (energy grids), then security and privacy are of utmost importance. The last technological component therefore focuses on developing an efficient privacy-friendly solution for the communication between the EV, the charger, and controlling actors (CPOs, ESCOs, FSPs, ...) as an upgrade of the current ISO15118[3] standard (5). Finally, the last scientific objective (6) is to use the simulation frameworks and models developed in (1)-(4) to assess the technical (grid imbalance, baseload adaptations, flexibility merit order, EN50160 voltage limitations, ...) and business implications (charger prices, flexibility prices, dynamic tariffs, ...) of using EVs to provide flexibility services under different scenarios and formulate recommendations towards industry and policy.