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venco.py: A Python model to represent the charging flexibility and vehicle-to-grid potential of electric vehicles in energy system models

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Summary

The bottom-up simulation model venco.py provides boundary conditions for load shifting and vehicle-to-grid (V2G) potential of electric vehicles (EV) based on mobility demand data and techno-economic assumptions. The tool enables the modelling of the energy demand and flexibility potential of EV fleets within the context of energy systems analysis. It supports the modelling of EV charging for both controlled, i.e. load shifting and V2G, and uncontrolled charging strategies. The model allows the configuration of assumptions regarding the charging infrastructure, the technical characteristics of the vehicle fleet, and the plugging behaviour, enabling the analysis of a wide variety of scenarios. The main modelling outputs include battery drain profiles, charging and discharging capacity profiles, minimum and maximum battery energy levels, and uncontrolled charging profiles both at single vehicle and at fleet level. The first four outputs can serve as constraining boundaries in other models, helping to determine optimal charging strategies for the vehicles and representing EV demand endogenously. In contrast, the uncontrolled charging profile simulates a scenario where charging is uncontrolled and vehicles begin charging as soon as a charging opportunity becomes available. The model's versatile and generic output profiles can help address a wide range of research questions across multiple modelling domains, including energy system optimisation models (Brown et al., 2018; Howells et al., 2011; Wetzel et al., 2024) and agent-based electricity market models (Schimeczek et al., 2023).

Statement of need

Estimating the electricity demand, load shifting potential, or V2G capacity of EV fleets is valuable across a wide range of research fields and industry applications. Whether it is to analyse future grid ancillary service demands, evaluate the profitability of aggregators managing EV fleets, calculate the additional electricity demand from increased EV adoption, or assess the demand-side flexibility EVs could offer to the energy system, these insights play a critical role.

Within the field of energy systems analysis, two primary approaches to modelling EVs can be identified: data-driven approaches and bottom-up simulations. Data-driven approaches rely on empirically measured data, such as onboard state-of-charge measurements or data collected at charging stations, which are then scaled to represent a fleet in line with the modelling scope (Märtz et al., 2022). In contrast, bottom-up simulation models derive the flexibility and load profiles of EV fleets by making assumptions about the charging controllability and the technical parameters of vehicles (Gaete-Morales et al., 2021). These models typically use mobility pattern data as their foundation, sourced either from National Travel Surveys

(NTSs) or transport research modelling results. Several tools to calculate EV fleet profiles have been recently published, including emobpy (Gaete-Morales et al., 2021), RAMP-mobility (Mangipinto et al., 2022), OMOD (Strobel & Pruckner, 2023), SimBEV (Mehr & Eskandarian, 2025), and MobiFlex (Märtz et al., 2022). Similarly, venco.py was developed to provide demand and flexibility potential assessments for future EV fleets.

While venco.py primarily focuses on plug-in battery electric vehicles, it introduces several key novelties compared to existing models. First, it has the capability to model different vehicle and transport segments, including passenger and commercial transport, expanding its application scope. Second, it uniquely captures plugging behaviours, which are often overlooked in other models, and can simulate both explicit and implicit charging strategies, incorporating exogenous and endogenous approaches. In the case of implicit charging strategies, the model generates boundary profiles that can be used as inputs in other models, without directly modelling the resulting load. Explicit charging strategies, on the other hand, involve selecting a specific strategy within the model itself, which is then simulated to produce the charging load as an output. Third, it features ready-to-use interfaces for integrating data from multiple existing NTSs across European countries. Another unique feature of venco.py is its ability to perform analyses at a finer granularity, such as for specific vehicle segments (e.g., small, medium, and large passenger cars, or vans and heavy-duty trucks for commercial transport), socio-economic groups, or at spatial resolutions beyond the national level. Since NTSs encompass a broad range of data beyond mobility patterns, the tool enables the generation of EV profiles that can be linked to specific groups of EV users.

The venco.py model is fully developed in Python and is openly available on GitLab at https://gitlab.com/dlr-ve/esy/vencopy/vencopy.

Modelling approach

The venco.py model is designed to model heterogeneous vehicle fleets in a user-friendly and flexible manner. While the model has been applied to several National Travel Surveys (NTSs), including the German NTS for passenger ("Mobilität in Deutschland") (infas, DLR, IVT, infas 360, 2018) and commercial transport ("Mobilitätsstudie Kraftfahrzeugverkehr in Deutschland") (WVI, IVT, DLR, KBA, 2010), the English NTS ("National Travel Survey: England 2019") (Department for Transport, 2019), the Dutch NTS ("Documentatie onderzoek Onderweg in Nederland 2019 (ODiN2019)") (Centraal Bureau voor de Statistiek (CBS), Rijkswaterstaat (RWS-WVL), 2020), and the French NTS ("La mobilité locale et longue distance des Français - Enquête nationale sur la mobilité des personnes en 2019") (Le service des données et études statistiques, 2023), it is adaptable to any input data representing the mobility patterns of a fleet within the specified modelling scope, thanks to its flexible parsing approach. The model additionally features user-defined temporal and geographical resolutions, and it supports modelling at both the individual vehicle and fleet level.

The model is based on the main building blocks illustrated in Fig. 1, which correspond to the underlying class structure of the tool. Starting with a parsing interface for mobility datasets, the data undergoes cleaning and plausibility filtering, followed by consolidation to model internal variables. The individual trips on the survey day are then consolidated into person-specific travel diaries, which include multiple trips carried out by each vehicle throughout the day. Next, the charging infrastructure allocation takes place, using a charging infrastructure model that assumes charging stations are available when vehicles are parked. Since the model's analytical focus is at the regional level, the charging infrastructure availability is allocated either based on binary mappings related to the trip's purpose or according to probability distributions for charging availability. This approach allows for the distinction of different charging availability scenarios. Subsequently, demand and flexibility estimation is performed, based on techno-economic input assumptions primarily related to vehicle battery capacity and power consumption. After an iterative process, this produces the minimum and maximum battery constraints. The daily activities are then discretised from a table format into a time series format. The final step in the framework involves aggregating the individual vehicle profiles to the fleet level and creating annual profiles from the daily and weekly samples. Additionally, there is an option to normalise the profiles or scale them to a desired fleet size.

The model output is accompanied by automatic metadata generation that complies with the metadata requirements of the Open Energy Platform (OEP) (Booshehri et al., 2021; Hülk et al., 2024), ensuring alignment with the FAIR (Findable, Accessible, Interoperable, Reusable) principles (Wilkinson et al., 2016).

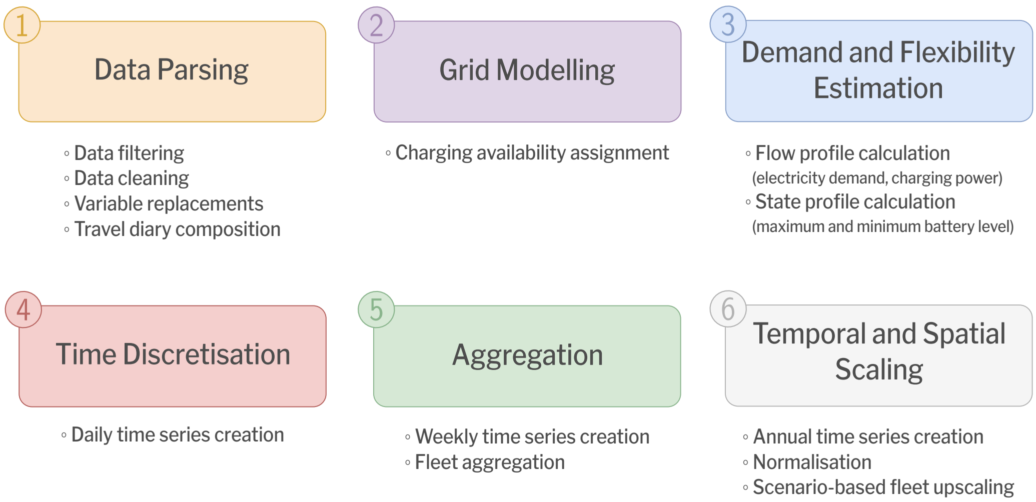

Figure 1: Structure of venco.py.

Projects and publications

Earlier versions of venco.py have been applied in various projects to address diverse research objectives. For example, in the EVer project (EVer project, 2018), the model was used to compare different modelling approaches for demand-side flexibility assets within the energy system optimisation model REMix (Wetzel et al., 2024). A more detailed assessment of the transport sector was conducted in the BEniVer (BENiVer project, 2018) and UrMoDigital (UrMoDigital project, 2019) projects, which analysed the roles of synthetic fuels, EVs, and innovative vehicle concepts, respectively. Additionally, venco.py was employed in the framework of the SEDOS project (SEDOS project, 2022), which aimed to develop an open-source national reference energy system dataset and create a reference model for three open-source frameworks (oemof (Krien et al., 2020), TIMES (IEA-ETSAP, 2016), and FINE (Groß et al., 2023)), with a specific focus on the German energy system. In the En4U project (En4U project, 2021), the model was used to generate representative load profiles based on the mobility patterns of different household clusters and residential time-varying tariffs. Moreover, in the EU DriVe2X project, venco.py is being employed to evaluate the impact of large-scale deployment of V2X technologies on the energy system as a whole (DriVe2X project, 2023).

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