EU-ZEVAM: European Zero-Emission Vehicle Adoption Model

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Integrating transport simulation and fleet survival analysis to forecast Europe's electric vehicle transition

Summary

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Vehicle adoption models are essential tools for a wide range of stakeholders. Governments and policymakers use them to assess the alignment of existing policies with long-term decarbonization targets, guide infrastructure development, and evaluate the achievability of climate objectives (Ellingsen, Singh, and Strømman 2016; Gómez Vilchez and Jochem 2020). Meanwhile, original equipment manufacturers (OEMs) and industry players rely on these models to forecast future production demand, identify investment needs, and align their strategies with anticipated market shifts (BloombergNEF 2021).

The core objective of vehicle adoption models is to simulate how the vehicle fleet will evolve under different policy, market, and technological scenarios. These models help to identify the key drivers of vehicle electrification and support decision-making by offering insight into long-term fleet composition trends (Maybury, Corcoran, and Cipcigan 2022; Kumar and Alok 2020).

However, many existing vehicle adoption models lack a strong theoretical foundation, leading to reduced transparency and reproducibility. This modeling flexibility can introduce inconsistencies across studies and hinder comparability. In contrast, approaches grounded in econometric theory offer greater methodological transparency and empirical robustness but typically require large, high-quality datasets (Jochem et al. 2018).

To address these limitations, we introduce `EU-ZEVAM`, a fully open-source

framework that combines the outcome of a bottom-up transportation model—specifically, an agent-based model (ABM)—with a cohort model (Möring-Martínez et al. 2025). The ABM simulates individual vehicle adoption decisions across heterogeneous agents in the population using the transportation model Vector21 (Institute of Vehicle Concepts (DLR) 2023) at an EU-level (Möring-Martínez, Senzeybek, and Jochem 2024), while the cohort component incorporates cumulative survival probability curves to represent the longevity and phase-out of vehicles within national fleets (Held et al. 2021). This hybrid architecture enables a dynamic and disaggregated representation of fleet evolution over time, capturing both behavioral and technical aspects of the transition.

`EU-ZEVAM` features a user-friendly interface for estimating electric vehicle stock adoption rates across EU countries through 2050. It uses new vehicle registration data under the STATS scenario from (Möring-Martínez, Senzeybek, and Jochem 2024), though it remains flexible to alternative input scenarios or transportation models. Survival rates are computed empirically following the methodology in (Held et al. 2021), with default values provided for the base year 2021 (Möring-Martínez et al. 2025). While updates to these rates are possible, they require considerable data collection and processing effort. A summary of the modelling framework can be found in the graphical abstract (cf. Figure 1).

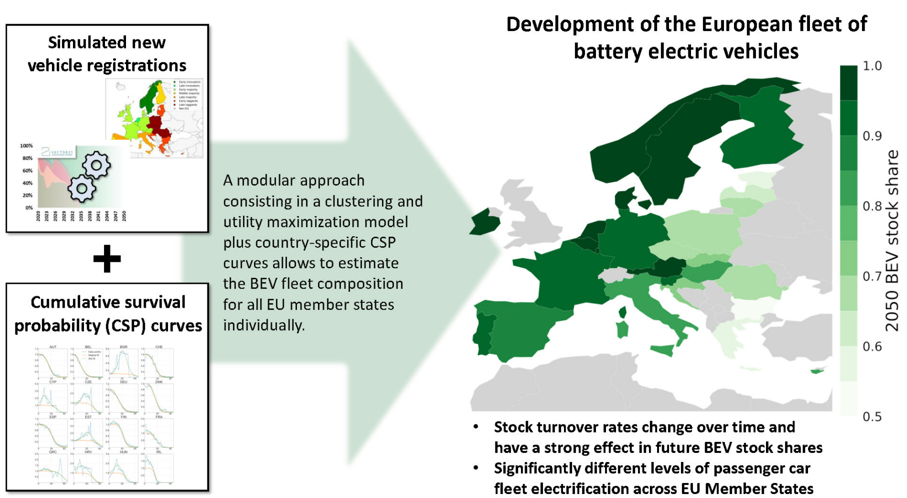

Figure 1: Graphical abstract of the electric vehicle adoption model for European Union countries. The framework combines a transportation model for estimating electric vehicle new registrations (Möring-Martínez, Senzeybek, and Jochem 2024) with a country-based cohort model (Held et al. 2021). Figure extracted from (Möring-Martínez et al. 2025), licensed under CC BY 4.0.

The model outputs national electric vehicle stock projections under various assumptions, and includes two validation steps and several sensitivity analyses to assess the impact of survival rates. By integrating empirical data with a flexible modeling structure, `EU-ZEVAM` offers a transparent and extensible platform for analyzing electric vehicle adoption in line with climate and mobility goals.

Statement of need

Numerous electric vehicle adoption models have been developed (Kumar and Alok 2020), varying in geographic focus, explanatory variables, modeling approaches, and data sources (Maybury, Corcoran, and Cipcigan 2022). Yet most remain not transparent, hard to reproduce and difficult to adapt (Jochem et al. 2018), and—so far as we are aware—no fully open-source implementation is publicly available.

We address this gap by introducing a transparent, EU-wide electric vehicle adoption modelling framework, whose methodological foundation is supported by a peer-reviewed article (Möring-Martínez et al. 2025). The code is openly available and can be coupled either with the transport-demand outputs from (Möring-Martínez, Senzeybek, and Jochem 2024), also included here, or with any alternative transportation model. The framework:

- estimates electric vehicle adoption rates using empirical survival rates
- supports sensitivity analyses on fleet-turnover assumptions and possible scenarios
- allows users to define alternative EV-registration trajectories to assess their impact on the vehicle fleet.

By providing open-source code and a modular structure, `EU-ZEVAM` facilitates reproducibility, transparency, and flexible exploration of policy scenarios.

Zero-emission vehicle adoption is a key objective of the European Union. To this end, the EU has implemented binding CO_2 emission standards that manufacturers must meet to avoid financial penalties (European Commision 2022). In addition, individual EU Member States support the deployment of zero-emission vehicles through varying national policies, including tax incentives, infrastructure development, and other supportive measures (Neshat, Kaya, and Ghaboulian Zare 2023).

Despite these EU-wide targets, most vehicle adoption models remain country-specific (Maybury, Corcoran, and Cipcigan 2022). Among the limited number of EU-wide models, several rely on strong simplifying assumptions—for example, applying Germany's vehicle survival rates uniformly across all countries (Ntziachristos et al. 2008). However, multi-country analyses of future fleet compositions require country-specific survival modeling due to significant differences in used vehicle import and export dynamics (Held et al. 2021).

Furthermore, several studies have highlighted the lack of comprehensive datasets needed to compute country-specific cumulative survival probabilities. To address this, we present a country-level modeling framework using updated cumulative survival rates up to the year 2021. This builds upon earlier work by (Held et al. 2021) for 2016 and (Oguchi and Fuse 2015) for 2008.

By adopting a country-level approach, EU-ZEVAM enables the estimation of electric vehicle adoption rates at both national and EU-wide levels (cf. Figure 2). It supports evaluation of whether fleet electrification and decarbonization targets are on track, while facilitating cross-country coordination and compliance planning. This is particularly relevant because scrappage schemes can accelerate fleet renewal (Marin and Zoboli 2020; Svoboda, Fanta, and Mošovský 2023), while insufficient infrastructure or incentives may slow it down—leading to increased demand for second-hand internal combustion engine vehicles (Maybury, Corcoran, and Cipcigan 2022).

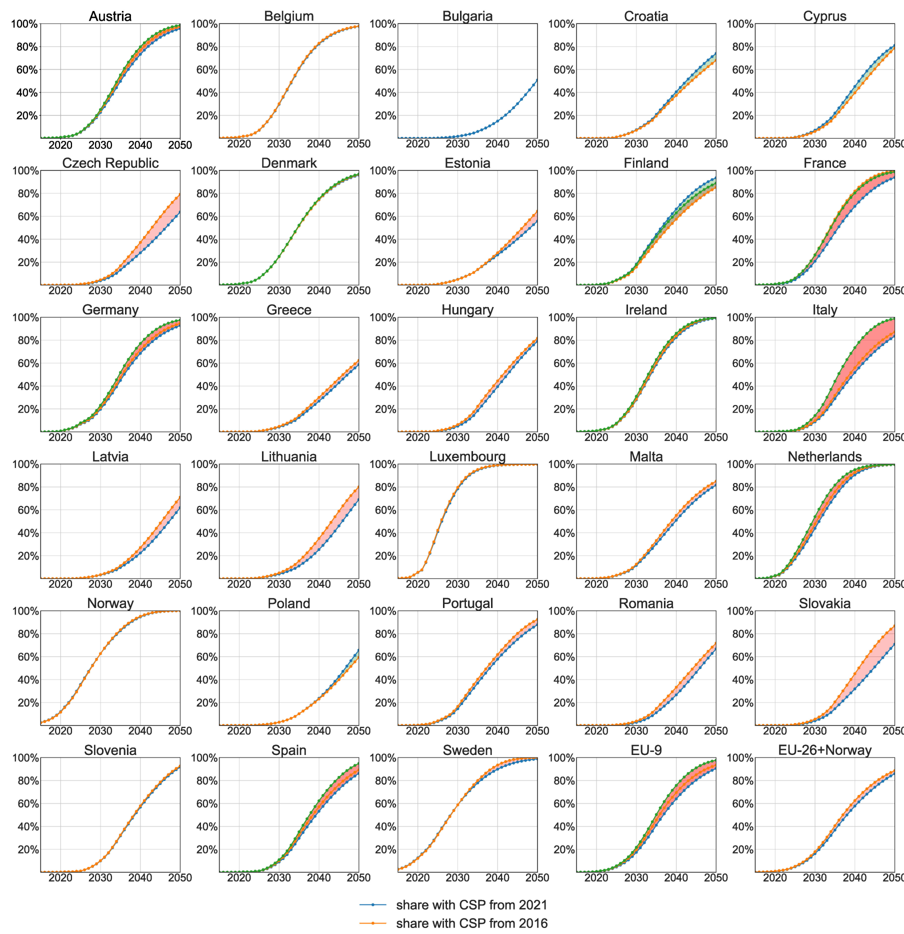

Figure 2: Battery electric passenger car fleet shares estimated using country-level empirical cumulative survival rate probability curves for all EU-27 countries and Norway. The sensitivity analysis varies the survival rates from 2008 and

2016 to illustrate how changes in vehicle lifespan assumptions affect fleet share projections. Figure extracted from (Möring-Martínez et al. 2025), licensed under CC BY 4.0.

Mathematics

Single dollars ($) are required for inline mathematics e.g. $f(x) = e^{\pi/x}$

Double dollars make self-standing equations:

$$\Theta(x) = \left\{\begin{array}{l} 0\text{ if } x < 0\cr 1\text{ else} \end{array}\right.$$

You can also use plain LaTeXfor equations

$$\hat f(\omega) = \int_{-\infty}^{\infty} f(x) e^{i\omega x} dx \tag{1}$$

and refer to Equation 1 from text.

Citations

Citations to entries in paper.bib should be in rMarkdown format.

If you want to cite a software repository URL (e.g. something on GitHub without a preferred citation) then you can do it with the example BibTeX entry below for.

For a quick reference, the following citation commands can be used: - `@author:2001 ->` "Author et al. (2001)" - `[@author:2001] ->` "(Author et al., 2001)" - `[@author1:2001; @author2:2001] ->` "(Author1 et al., 2001; Author2 et al., 2002)"

Figures

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