ChaProEV: Generating Charging Profiles for Electric Vehicles

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Summary

ChaProEV is

Statement of need

Battery-electric vehicles (BEVs) as the fleets of EVS are poised to grow sharply in the future and have a strong impact on the electric grid (Smit et al., 2022; Wilde et al., 2022), and on energy systemns in general. –>

It is therefore important that models that seek the optimisation of energy systems properly (Stralen et al., 2021) (*TIMES-Europe*, n.d.) ((Brown et al., 2018))

(Özdemir et al., 2020) (Tejada-Arango et al., 2023) (LNEG et al., 2020) (Helistö et al., 2024)

- Profiles are good and useful, but optimisation modes might also need soem underlying parameters to do optimisation computations as well
- Provide optimisation models with the boundary conditions they need
- ChaProEV povides the necessary parameters (as explemplified in COMPETES, Mopo/Ines, etc.) in a clear and accessible way, with the also allowing a clear way to modify them without touching code (Sijm et al., 2022)

tailored to supply optimisation models (list, but also actual implementations) throug the model below by explicitely supplying the necessary parameters EV parameters for optimisation models and providing an option to change some stiry parameters creating new scenarios

Conceptual innovations: Supporting optimisation models

Basic elements

A commonly used aggregated EV formulation is (Morales-España et al., 2022):

$$e_t = e_{t-1} + \eta^{\mathrm{G2V}} p_t^{\mathrm{G2V}} \Delta - \frac{p_t^{\mathrm{V2G}}}{\eta^{\mathrm{V2G}}} \Delta - E_t^{\mathrm{drive}} \Delta N \alpha \quad \forall t \tag{1}$$

$$\underline{E} N_t^{\mathrm{plugged}} N \alpha \leq e_t \leq \bar{E} N_t^{\mathrm{plugged}} N \alpha \qquad \forall t \tag{2}$$

$$0 \leq p_t^{\mathrm{G2V}} \leq \bar{P}_t^{\mathrm{G2V}} N_t^{\mathrm{plugged}} N \alpha \qquad \forall t \tag{3}$$

$$0 \leq p_t^{\mathrm{V2G}} \leq \bar{P}_t^{\mathrm{V2G}} N_t^{\mathrm{plugged}} N \alpha \qquad \forall t \tag{4}$$

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where t is the time index and parameter Δ (h) is the duration of the time step. Variable e_t (kWh) tracks the total state of charge of the plugged EVs to the grid. Variables $p_t^{\mathrm{G2V}}/p_t^{\mathrm{V2G}}$ (kW) are the power consumed/provided by the EVs from/to the grid. Parameters $\eta^{\mathrm{G2V}}/\eta^{\mathrm{V2G}}$ (p.u.) are the charging/discharging efficiencies; $\underline{E}/\bar{E}$ (kWh) are the minimum/maximum storage capacity per vehicle; N is the total number of EVs; and α (p.u.) is the share of controllable EVs providing demand response to the system.

Equation 1-Equation 4 model the demand response provided by controllable EVs through p_t^{G2V} and p_t^{V2G}. The total EV demand d_t^{Tot} (kW), including the non-controllable load, is defined as

$$d_t^{\mathrm{Tot}} = D_t^0 N(1-\alpha) + p_t^{\mathrm{G2V}} - p_t^{\mathrm{V2G}} \qquad \forall t \tag{5}$$

where D_t^0 is the reference (non-demand response) profile given by ChaProEV (see Section **??**), and α is the proportion of vehicles that are optimally providing demand response.

Further modelling

The formulation Equation 1-Equation 4 has several shortcomings because there is no clear distinction between plugged and unplugged EVs. For example, suppose that plugged EVs were fully charged and the unplugged EVs were near to being empty, equation Equation 1 allows that unplugged EVs could be charging while they should be unavailable to the system. (Momber et al., 2014) shows this and more detailed cases where the traditional EV aggregated formulation fails.

To overcome the above shortcomings, (Momber et al., 2014) proposed a more rigorous formulation, in which inventories for plugged/unplugged EVs are clearly distinguished from each other. This formulation ensures that only EVs plugged to the grid are charged/discharged from the electric system. It also guarantees that unplugged EVs cannot further charge while driving.

The state of charge of EVs in Equation 1 is now replaced by the separated plugged Equation 6 and unplugged Equation 7 state of charges. Additionally, Equation 2 is replaced by Equation 8 and Equation 9.

$$\begin{aligned}
e_t^{\mathrm{plugged}} &= e_{t-1}^{\mathrm{plugged}} + \eta^{\mathrm{G2V}} p_t^{\mathrm{G2V}} \Delta - \frac{p_t^{\mathrm{V2G}}}{\eta^{\mathrm{V2G}}}\Delta \\
&\quad + N_{t-1}^{\mathrm{plugging}} N\alpha e_{t-1}^{\mathrm{unplugged}} - N_{t-1}^{\mathrm{unplugging}} N\alpha e_{t-1}^{\mathrm{plugged}} \qquad \forall t \qquad (6) \\
e_t^{\mathrm{unplugged}} &= e_{t-1}^{\mathrm{unplugged}} - E_{t-1}^{\mathrm{drive}} \Delta N\alpha \\
&\quad - N_{t-1}^{\mathrm{plugging}} N\alpha e_{t-1}^{\mathrm{unplugged}} + N_{t-1}^{\mathrm{unplugging}} N\alpha e_{t-1}^{\mathrm{plugged}} \qquad \forall t \qquad (7)
\end{aligned}$$

$$\underline{E} N_t^{\mathrm{plugged}} N\alpha \le e_t^{\mathrm{plugged}} \le \bar{E} N_t^{\mathrm{plugged}} N\alpha \qquad \forall t \tag{8}$$

$$\underline{E} N_t^{\mathrm{unplugged}} N\alpha \le e_t^{\mathrm{unplugged}} \le \bar{E} N_t^{\mathrm{unplugged}} N\alpha \qquad \forall t \tag{9}$$

Software innovations

No code parameters and profiles modification (explain what kind of modifications are possible) Scenarios

1. *Demand for next leg (kWh) (from network):* The charge that the vehicles leaving in the next time step need to pull from the network for the leg they are about to undertake, corrected by the charger efficiency.
2. *Demand for next leg (kWh) (to vehicles):* The part of the above that vehicles get. (E_t^{drive} in Equation (1))
3. *Connected vehicles:* The share of vehicles that are connected to a charger (N_t^{plugged} in Equation (2))

4. *Charging Power from Network (kW):* Maximum power that connected vehicles can potentially draw from the network. ($\bar{P}_t^{\mathrm{G2V}}$ in Equation (1))
5. *Charging Power to Vehicles (kW):* Maximum power that can potentially go to vehicles go to vehicles (i.e. the same as above with a charger efficiency correction).
6. *Vehicle Discharge Power (kW):* The amount of power connected vehicles can discharge to the network.
7. *Discharge Power to Network (kW):* How much of that discharged power can go to the network. ($\bar{P}_t^{\mathrm{V2G}}$ in Equation (1))
8. *Effective charging efficiency:* Ratio between charging power going to the vehicle and power coming from the network. This can vary in time, as the location of the charging vehicles (and thus the efficiency of the involved chargers) changes as they move around. (η^{G2V} in Equation (1))
9. *Effective discharging efficiency:* Same as above, but for discharging (it is the power going out of the vehicles divided by the power going into the network). (η^{V2G} in Equation (1))

ChaProEV also provides charging sessions (in case they are not obtained from energy system models). This provides another description of the system that could be used for models and analyses that focus on charging sessions rather than profiles (which are aggregates of such sessions). Sessions include (in addition the elements that a profile gets):

1. *Location:* Where the session takes place
2. *Start time:* At which moment the vehicles in the session can start charging (i.e. when they arrive).
3. *End time:* At which moment the vehicles in the session must stop charging (i.e. when they leave).
4. *Demand for incoming leg (kWh) (to vehicle):* How much the incoming vehicles have spent on the leg arriving to the session.
5. *Maximal Possible Charge to Vehicles (kWh):* How much the vehicles could charge if they used the available power during their whole session.
6. *Charge to Vehicles (kWh):* How much of the vehicles actually charge during the session. This is based on the charging strategy of the vehicles and can be used to derive a charging profile.
7. *Charge from Network (kWh):* The same as above, but corrected for charging efficiency (i.e. how much the network provides)

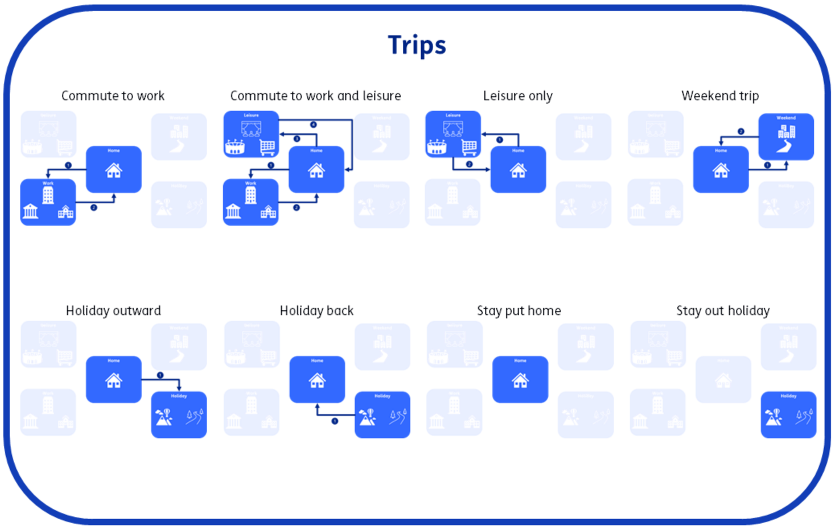

Figure 1: trips

Figure 1

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TIMES-europe: An integrated energy system model for analyzing europe's energy and climate challenges, volume = 30, pages = 1-19, url = https://link.springer.com/article/10.1007/s10666-024-09976-8, doi = 10.1007/s10666-024-09976-8, abstract = This paper introduces TIMES-Europe, a novel integrated multi-sectoral energy system optimization model for Europe based on the TIMES generator. We describe its main specifications and assumptions as well as its underlying methodology, and summarize the type of policy questions that it can help answering. TIMES-Europe can be used to analyze policy instruments designed for implementing the EU Green Deal and Fit-for-55 program, and to create strategic energy decarbonization and climate change mitigation insights for Europe against the backdrop of its interactions and relations with neighboring countries. Thanks to its technology richness across all main sectors—including power production, transport, industry and the commercial, agricultural and residential sectors—it allows for performing in-depth studies on the role of a large range of low-carbon options in the energy transition of all European countries, both jointly and individually. Three characteristics render TIMES-Europe particularly valuable: (1) it covers the entire European energy system and its main greenhouse gas emissions, (2) it includes all EU member states individually as well as a large set of countries in the EU's vicinity, and (3) it can be used to generate high-level strategic insights as well as detailed recommendations for both national and EU policies. TIMES-Europe is especially suitable for analyzing system integration, which makes it an ideal tool for assessing the implementation of the energy transition and the establishment of a low-carbon economy. We present several research and scenario examples, and characterize opportunities for future energy and climate policy analysis. Publisher = Springer Nature, author = Luxembourg, Stefan L. and Salim, Steven M. and Smekens, Koen and Dalla Longa, Francesco and van der Zwann, Bob, keywords = Energy transition · Europe · Energy security · Renewable energy · Sector integration, year = 2024, mont = jul, day = 18. (n.d.).

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