

# 1 ChaProEV: Generating Charging Profiles for Electric 2 Vehicles

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## Software

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## 7 Summary

8 ChaProEV is

## 9 Statement of need

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

## Conceptual innovations: Supporting optimisation models

### Basic elements

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

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

$$\underline{E}N_t^{\text{plugged}} N \alpha \leq e_t \leq \bar{E}N_t^{\text{plugged}} N \alpha \quad \forall t \quad (2)$$

$$0 \leq p_t^{G2V} \leq \bar{P}_t^{G2V} N_t^{\text{plugged}} N \alpha \quad \forall t \quad (3)$$

$$0 \leq p_t^{V2G} \leq \bar{P}_t^{V2G} N_t^{\text{plugged}} N \alpha \quad \forall t \quad (4)$$

19 where  $t$  is the time index and parameter  $\Delta$  (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  $p_t^{G2V}/p_t^{V2G}$  (kW) are the power consumed/provided by the EVs from/to the grid. Parameters  $\eta^{G2V}/\eta^{V2G}$  (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  $\alpha$  (p.u.) is the share of controllable EVs providing demand response to the system.

25 Section ?? defines the remaining parameters (profiles).

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

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

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

### 30 Further modelling

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

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

42 The state of charge of EVs in [Equation 1](#) is now replaced by the separated plugged [Equation 6](#)  
 43 and unplugged [Equation 7](#) state of charges. Additionally, [Equation 2](#) is replaced by [Equation 8](#)  
 44 and [Equation 9](#).

$$e_t^{\text{plugged}} = e_{t-1}^{\text{plugged}} + \eta^{\text{G2V}} p_t^{\text{G2V}} \Delta - \frac{p_t^{\text{V2G}}}{\eta^{\text{V2G}}} \Delta + N_{t-1}^{\text{plugging}} N \alpha e_{t-1}^{\text{unplugged}} - N_{t-1}^{\text{unplugging}} N \alpha e_{t-1}^{\text{plugged}} \quad \forall t \quad (6)$$

$$e_t^{\text{unplugged}} = e_{t-1}^{\text{unplugged}} - E_{t-1}^{\text{drive}} \Delta N \alpha - N_{t-1}^{\text{plugging}} N \alpha e_{t-1}^{\text{unplugged}} + N_{t-1}^{\text{unplugging}} N \alpha e_{t-1}^{\text{plugged}} \quad \forall t \quad (7)$$

$$\underline{E}N_t^{\text{plugged}} N \alpha \leq e_t^{\text{plugged}} \leq \bar{E}N_t^{\text{plugged}} N \alpha \quad \forall t \quad (8)$$

$$\underline{E}N_t^{\text{unplugged}} N \alpha \leq e_t^{\text{unplugged}} \leq \bar{E}N_t^{\text{unplugged}} N \alpha \quad \forall t \quad (9)$$

### 45 Software innovations

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

- 48 1. *Demand for next leg (kWh) (from network)*: The charge that the vehicles leaving in the  
 49 next time step need to pull from the network for the leg they are about to undertake,  
 50 corrected by the charger efficiency.
- 51 2. *Demand for next leg (kWh) (to vehicles)*: The part of the above that vehicles get.  
 52 ( $E_t^{\text{drive}}$  in [Equation \(1\)](#))
- 53 3. *Connected vehicles*: The share of vehicles that are connected to a charger ( $N_t^{\text{plugged}}$  in  
 54 [Equation \(2\)](#))
- 55 4. *Charging Power from Network (kW)*: Maximum power that connected vehicles can  
 56 potentially draw from the network. ( $\bar{P}_t^{\text{G2V}}$  in [Equation \(1\)](#))
- 57 5. *Charging Power to Vehicles (kW)*: Maximum power that can potentially go to vehicles  
 58 go to vehicles (i.e. the same as above with a charger efficiency correction).
- 59 6. *Vehicle Discharge Power (kW)*: The amount of power connected vehicles can discharge  
 60 to the network.
- 61 7. *Discharge Power to Network (kW)*: How much of that discharged power can go to the  
 62 network. ( $\bar{P}_t^{\text{V2G}}$  in [Equation \(1\)](#))

- 63        8. *Effective charging efficiency:* Ratio between charging power going to the vehicle and  
 64        power coming from the network. This can vary in time, as the location of the charging  
 65        vehicles (and thus the efficiency of the involved chargers) changes as they move around.  
 66        ( $\eta^{G2V}$  in Equation (1))
- 67        9. *Effective discharging efficiency:* Same as above, but for discharging (it is the power going  
 68        out of the vehicles divided by the power going into the network). ( $\eta^{V2G}$  in Equation (1))
- 69        ChaProEV also provides charging sessions (in case they are not obtained from energy system  
 70        models). This provides another description of the system that could be used for models and  
 71        analyses that focus on charging sessions rather than profiles (which are aggregates of such  
 72        sessions). Sessions include (in addition the elements that a profile gets):
- 73        1. *Location:* Where the session takes place
- 74        2. *Start time:* At which moment the vehicles in the session can start charging (i.e. when  
 75        they arrive).
- 76        3. *End time:* At which moment the vehicles in the session must stop charging (i.e. when  
 77        they leave).
- 78        4. *Demand for incoming leg (kWh) (to vehicle):* How much the incoming vehicles have  
 79        spent on the leg arriving to the session.
- 80        5. *Maximal Possible Charge to Vehicles (kWh):* How much the vehicles could charge if they  
 81        used the available power during their whole session.
- 82        6. *Charge to Vehicles (kWh):* How much of the vehicles actually charge during the session.  
 83        This is based on the charging strategy of the vehicles and can be used to derive a  
 84        charging profile.
- 85        7. *Charge from Network (kWh):* The same as above, but corrected for charging efficiency  
 86        (i.e. how much the network provides)

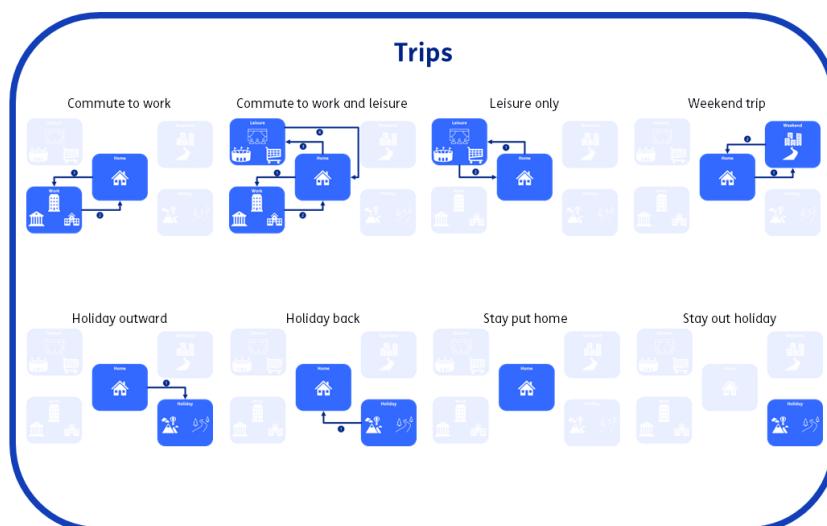


Figure 1: trips

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