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System architecture modelling framework applied to the integration of electric vehicles in the grid

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Abstract. A structured approach for the design of a model architecture is presented. From a simplified representation of the current situation, the aim is to implement regulations and test solutions in order to reach future climate targets. The challenge is to combine model accuracy to minimise uncertainty of the results on one side, and ease of implementation / plausibility of scenarios on the other side, which often decreases as systems complexify. A stage-wise model expansion is suggested to balance these two criteria. This approach is applied to the case of increased grid integration of electric vehicles (EVs) in Denmark.

Keywords: modelling architecture, stage-wise approach, EV grid integration.

1 Introduction

The combination of electric vehicles (EVs) and smart grids is increasingly considered as a promising solution to solve both the decarbonisation of the transportation sector and the increasing grid power variability due to the uptake of renewable energies.

Indeed, EV batteries for passenger cars can have a storage capacity of up to 100kWh [1] , which represents approximately a 10-fold of the daily consumption of an average household in Denmark [2] , and this storage capacity keeps increasing.

However, this large battery storage capacity also presents some challenges, as it puts a lot more stress on the existing grid infrastructure, particularly on the distribution level [3], quickly leading to grid overloads or voltage and frequency deviations.

In recent years, many academic research efforts focused on proposing innovative market frameworks to minimise the additional grid infrastructure costs of integrating EVs. While first models have been from a top-down coordinated control approach [4], [5], the increasing use of simulations and particularly agent-based modelling (ABM) simulations have recently encouraged market-regulated bottom-up approaches [6], [7].

A major flaw of the models presented in the previous paragraph, along with many other models, is the lack of consideration for the plausibility of the proposed scenarios, with focus staying on the accuracy of results and their effectiveness at achieving the desired climate goals. This work therefore proposes the setup of an architectural framework to ensure innovative solutions are tested in scenarios with minimised implementation risk / high plausibility. The approach is inspired by the business ecosystem modelling framework proposed in [8], which proposes a three-part methodology: architecture development, analysis of influential factors and simulation of proposed changes.

While the methodology is applied to the EV-grid integration case, the aim is to develop a method to test regulations and market mechanisms in the energy sector overall.

To present this work, this paper will first present the stage-wise approach of the model setup, before illustrating it with the specific case of electric vehicles. A final section links the proposed model architecture to an agent-based modelling simulation.

2 Method: the stage-wise architecture

The modelling framework will first focus on a minimum viable ecosystem (MVE), where the main stakeholders at the level of interest are identified and their main interactions are defined. Interactions are separated into different types, which for now are categorised as product, data, information, regulatory and monetary flows. These different flow types relate to the interoperability layers defined in the Smart Grid Architecture Model Framework in [9], developed in an effort to standardise Smart Grid design at a European level. The more flow types a model contains, the more layers it covers in the framework, and therefore the more holistic the modelling approach becomes.

The outcome of this base-case scenario is compared to the fixed objectives within a certain timeframe. For Denmark, this would be a 70% reduction in carbon-equivalent emissions from 1990 to 2030 [10]. A sensitivity analysis on the model parameters is done to identify the key drivers within the system. Due to the limited amount of interactions in the base case, this reduces the number of parameters to a small amount.

In the next stage, the model is expanded to include more actors which are less directly involved but allow to model interactions in more detail. This allows to test whether the difference between the MVE results and the fixed objectives is simply due to modelling inaccuracy or not.

As a next step, a regulation agent is added to the model, to represent regulation updates from the government and regulatory authorities. The regulation agent is connected in priority to agents from the MVE, especially those with critical parameters identified in the first step. This ensures that impactful measures are focused on highly engaged stakeholders, which are more likely to react. The regulations should also prioritise individual agents over populations, as the latter have inevitable variability and are more likely to introduce uncertainty to the outcome of the regulations.

The next step introduces the different solutions to test within the constraints set by the regulation agent. The regulation agent therefore acts as a filter, quickly disqualifying any solution not fitting the constraints or yielding poor results within the given constraints. If different solutions are tested simultaneously, they should each focus on different parts of the system and avoid interacting with each other, as this increases the uncertainty of their output and reduces the likelihood of being implemented.

3 The architecture for EV grid integration

The stage-wise approach is illustrated in Fig. 1 for the EV integration case.

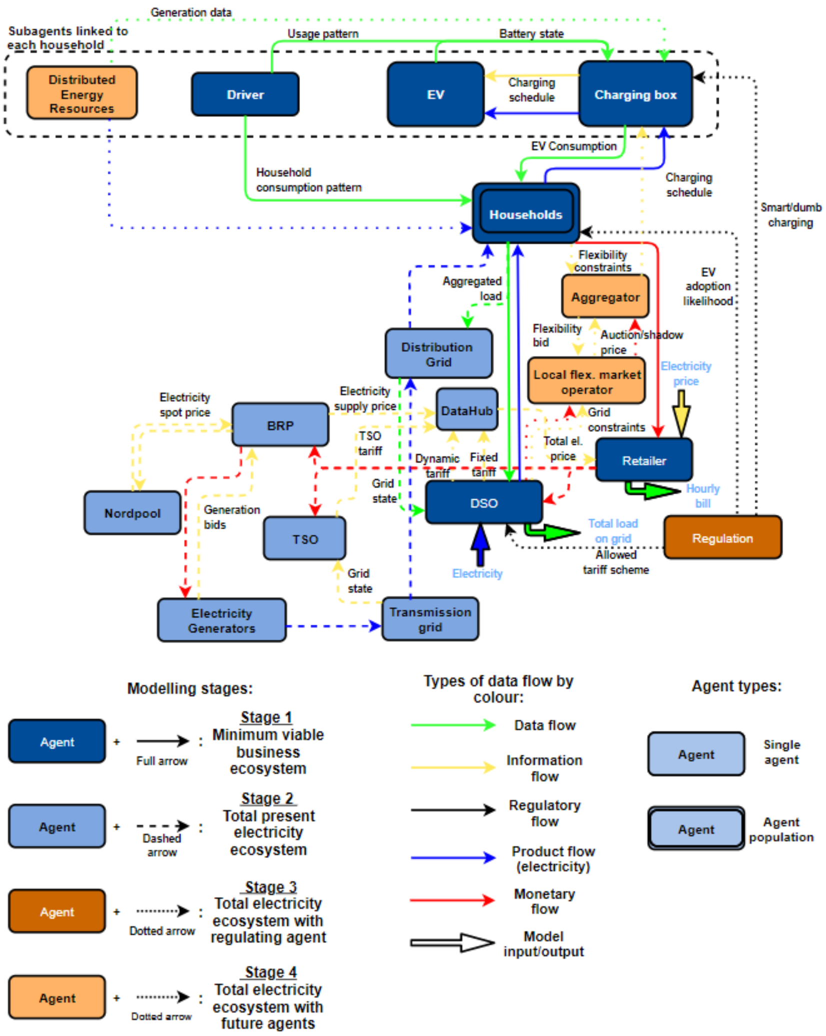

Fig. 1. Model architecture for EV integration case

In the MVE (dark blue actors with full arrows), most drawn-out flows are data flows. This basic ecosystem mainly relies on actors communicating the output of their actions, without taking the action of other actors into account. As more stakeholders are added, more information is exchanged. Information flows occur as stakeholders' actions become more dependent on others' behavior and more data processing is needed. Examples are charging scheduling, day-ahead price tariffs, forecasts…

The regulations implemented in stage 3 only focus on the MVE agents. In stage 4, two solutions are shown: the addition of distributed energy resources and the introduction of a flexibility market. Each solution acts on different parts of the system: the first focuses mainly on data and electricity flows; the latter focuses more on information and financial flows. This avoids too much interactions between the proposed solutions.

4 Future work

This model will be implemented using ABM simulations in AnyLogic. Once the first and second stage implementation and validation, the regulations proposed in the third stage need to be based on a thorough literature review of Denmark's regulation history. The market mechanisms and solutions tested in stage four should undergo a first screening process based on plausibility and accuracy criteria before being added in AnyLogic. Scenarios will be run in increasing complexity order and decreasing plausibility order.

5 Conclusion

The adequate system integration of a proposed solution follows a four-step approach: identification of stakeholders with highest invested interest and influence, grouped into an MVE; extension of the ecosystem to peripheral players to enrich the type of agent interactions; introduction of a regulation agent focusing in priority on the MVE for high-plausibility and low uncertainty regulations; testing of proposed solutions in the model, while avoiding the overlap of solutions in the ecosystem.

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