*33rd Electric Vehicle Symposium (EVS33)*
*Portland, Oregon, June 14 - 17, 2020*

# ADAM & EV: Developing an Adoption Dynamics Analysis Model for Electric Vehicles

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**Summary**

This work describes the development of an agent-based simulation that is an Adoption Dynamics Analysis Model for Electric Vehicles (ADAM & EV). ADAM & EV supports stakeholders in understanding the electric mobility landscape and the possible effects on policies. The model takes a consumer perspective by focusing in-depth on the consumer decision making process following the Theory of Planned Behaviour. In this work, we discuss the structure and interface of the model, and shortly discuss a few initial outcomes such as the consequence that stimulating BEVs increases emissions in the short-term when taking into account manufacturing emissions.

*Keywords: electric vehicles, 2nd hand market, EV uptake model, agent-based simulation*

## 1 Introduction

While the transition to electric mobility seems inevitable, most national and local markets are still in their early stages. In these markets, the attitude and behaviour of consumers towards different modes of electric transport largely determine their uptake. Of course, other factors, such as the availability of electric transport options, their pricing and convenience have an important role as well. These are some of the key factors shaping the (electric) mobility ecosystem. In order to shape and steer this ecosystem, policy makers put in place policy programmes that touch upon these different factors [1], [2] and ultimately aim to reduce the impact of the mobility system on climate change and quality of living.

In earlier work, we looked more closely at how it can be determined whether these subsidies and incentives are effective and “where” they influence the electric mobility landscape [3]. This work is a continuation of that research, as we aim to enrich the insights of the relational model presented in that work by capturing it in an executable simulation model. We do this by employing a user-centred perspective to research consumer behaviour in the electric passenger vehicle market.

### 1.1 Research Context

Our research is situated in the context of the proEME project [4]. The goal of the proEME project is to further accelerate the transition to electric mobility. ProEME does this by providing stakeholders in the electric mobility ecosystem with the right information, tools and guidance to ensure that electric mobility can build upon the foothold it has already established by now. ADAM & EV (Adoption Dynamics Analysis Model for

Electric Vehicles) is an essential part of this effort. It should allow stakeholders to have a holistic view on the electric mobility market through an explanation of both the role of as well as the relation between the various elements within the electric mobility ecosystem.

## 1.2 Research Question & Goal

The (electric) mobility system is a socio-technical system that is influenced by and dependent on many factors. Central in this system is the end-user - the consumer, particularly considering our focus on electric passenger vehicles. Due to the aim of making electric mobility mainstream, a very heterogeneous group of actors needs to be considered. Policies or market developments affect these people very differently due to the widely varying contexts in which they find themselves. In this work, it is our goal to create a foundation that allows exploration of in-depth insight in the effects of system wide changes to individual actors. It should also support understanding the effects of the responses of actors towards other actors and the overall system. Therefore, we define our research question as follows:

- What is an applicable simulation model structure and process to support stakeholders, such as policy makers, to better understand and steer the transition towards electric mobility?

We aim to realize this by developing a simulation model that explores specific stakeholder relevant scenarios. We hypothesize that improving insight in these dynamic relationships for policy makers and other stakeholders will ultimately improve the effectiveness of policies and market regulations, as well as improve the effectiveness of the actions of other actors.

## 1.3 Outline

This work is structured as follows. Section 2 discusses the background of this research by exploring existing electric vehicle adoption models and evaluating them on their purpose and goals. We also highlight existing research in the consumer decision making process, as well as emphasize why it is essential to develop the ADAM & EV model. In Section 3, we expand on the goals and purpose of ADAM & EV, as well as the requirements that we posed that shaped the development of ADAM & EV. Section 4 details the methodology and process that was followed to develop ADAM & EV and discusses the resulting structure and set-up of the model. Section 5 discusses both several initial outcomes and necessary validation steps. Finally, section 6 presents a short outlook on expected future results and activities with the model.

# 2 Background

This section describes the background of the proposed ADAM & EV model by discussing existing electric vehicle adoption models and their characteristics, as well as an in-depth discussion of modelling consumer behaviour. It concludes by arguing the need for a model like ADAM & EV.

## 2.1 Electric vehicle adoption models

In this research, we focus on the electric passenger vehicle market. Predicting and understanding uptake of EVs (electric vehicles) has been a topic of intensive research for at least the last two decades [5]. These models consider and classify different types of electric vehicles, be it PEVs (plug-in electric vehicles), PHEVs (plug-in hybrid electric vehicles), FEVs (full electric vehicles) or BEVs (battery electric vehicles). Within this research we look exclusively at BEVs versus their ICE counterparts, and where we mention EVs, we thus refer to BEVs.

In [6]–[8] several key attributes for an EV uptake model are identified, namely (1) behaviour realism, (2) vehicle supply and (3) policy representation. In [5], it is highlighted that "to determine the important policies" has become a more frequent goal of EV uptake models in recent years (since 2014). In this work, we would like to expand the analysis done in [5] by coupling this to a focus towards the specific type of simulation model. Below, several simulation model types are presented that are widely recognized (for example in [9], [10]) including some examples. In [10], also a hybrid type of model is proposed that combines principles from agent-based and system dynamics models.

- System Dynamics Models – (PTTMAM [11], [12], SERAPIS [13])

  - Approach to understand the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, etc.
- Agent-Based Models – (SparkCity [14], Silvia/Krause [15])
  - Simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assess their effects on the system as a whole
- Equilibrium Models – (MoMo – IEA [16], REPAC [6])
  - Mainly used in economics, to describe the economy by aggregating the behaviour of individuals and firms
- Other model types
  - Discrete Event Simulation Models
  - Network Models

## 2.2 Consumer decision making process

In order to appropriately model EV uptake from a consumer perspective, it is necessary to understand and formalize the consumer decision making process. Various types of models and theories can be applied. In other work by the authors [17], we elaborate our choice for using the Theory of Planned Behaviour (TPB) [18] in more detail but we will expand on this briefly here as well.

The Theory of Planned Behaviour is one of the most well-known decision making (and behaviour) theories. Structuring the decision making process according to the TPB will result in three high level constructs that we are able to vary across scenarios. These constructs are:

- *Attitude*; The intrinsic attitude of an individual towards the subject of the decision, which is, in this case, the EV (and to an ICE as well). This attitude can of course be influenced by external factors.
- *Subjective Norms*; The perceived attitude and opinions of the society and groups in which the individual resides. This could be the overall “EV-climate” in a country, direct family, co-workers or the influence of a car dealer or commercials.
- *Perceived Behavioural Control*; The manner in which an individual perceives that he is able to execute the behaviour. For an EV this relates to financial matters (e.g., TCO, Purchasing Price), but also to whether an EV range meets an individual’s mobility needs or the ease of charging an EV.

## 2.3 The Modelling Approach

In order to achieve our goal of creating understanding of the electric mobility system, we intend to involve the relevant stakeholders at an early stage through a flexible and participatory modelling approach. This means that stakeholders are involved in the modelling process by sharing experiences, giving input and evaluating the model and can influence its outcomes in an iterative process. Earlier work by the first author has shown that early involvement and representation of different views in the simulation exploration can support this understanding and facilitate multidisciplinary design discussions [19]. In the development of ADAM & EV, we focus on incorporating a modelling approach as described in [20] by Voinov et al. Voinov et al. also highlight two main goals of (participatory) modelling, being (1) *“to increase and share knowledge and understanding of a system and its dynamics under various conditions”* and (2) *“to identify and clarify the impacts of solutions to a given problem, usually related to supporting decision making, policy, regulation or management”*. Finally, Voinov et al., discuss various modelling processes and give several recommendations. One of these is *“keep it flexible and focus on the process rather than the product”* which has implications for how the model is set-up and developed. Another recommendation is *“Accept a different kind of uncertainty – be certain about uncertainty”.* These recommendations are also reflected in [21], [22]. We feel that when modelling socio-technical systems, uncertainty is inherent and it is an illusion to expect exact predictions from simulation models that can stand the test of time in ever changing environments. The goal should thus be to increase understanding of the system, to empower stakeholders to make more informed decisions under various conditions. The recommendations given here are the two key foundations for ADAM & EV, being (1) to focus on the process and the system itself and (2) to be open about uncertainties in the model.

# 3 ADAM & EV: Goals & Choices

This section details the rationale for developing ADAM & EV, by reviewing existing EV uptake models and outlining the goals and requirements for the model.

## 3.1 Comparison of EV uptake models

An extensive review of various EV models is presented in [3] by Gnann et al. Here, 40 models are reviewed on various characteristics. One of the elements of the analysis, is a review of whether 18 specific factors are covered by the model. Examples of these factors are purchase price, energy prices and battery cost.

In Table 1 we present our own in-detail analysis that covers 6 models that were not included in the analysis of Gnann et al. [5] and an expanded list of factors. The list of factors is based on the relational model we presented in earlier work in [23] and is further discussed in section 3.4. Our list includes several holistic factors to emphasize a review of systemic approaches. These are for example whether models incorporate the overall car market developments, the 2nd hand car market and whether other types of mobility are considered. For each reviewed model, we indicate whether a topic was included with in-depth modelling and analysis, whether the topic is only discussed superficially, or, not modelled at all.

## 3.2 The need for an EV uptake model with an in-depth consumer behaviour focus

In the various EV uptake models presented in Table 1 and in [5], most of the factors modelled do not relate to consumer behaviour and beliefs directly. Rather, these are indirect links, for example modelling the effects of the amount of chargers available in a country and comparing it with sales figures does not give concrete insight into how consumers respond to the presence of charging infrastructure. Therefore, we argue that the effects of changes in the systems towards consumers should be modelled more explicitly. To underline this, we emphasized this relation in Figure 1, which is an adapted visualization of earlier work in [3]. It emphasizes that different focus areas (combination of factors) should be linked to the focus area *soft factors* (consumer behaviour) which ultimately determines EV uptake.

Table 1: Comparison of covered subjects in EV uptake models

| | **Models** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Systems Dynamics** | | **Equilibrium** | | **Agent-Based** | | |
| **Subject** | SERAPIS [13] | PTT-MAM [11], [12] | MoMo (IEA) [16] | REPAC [6] | Silvia / Krause [15] | Spark City [14] | ADAM & EV *this work* |
| Vehicle Fleet Development | ++ | ++ | ++ | ++ | ++ | ++ | + |
| Incentives / Policy Scenarios | ++ | ++ | + | ++ | ++ | ++ | ++ |
| EV Total cost of Ownership | - | ++ | - | ++ | - | ++ | ++ |
| Consumer Demographics | - | ++ | - | ++ | - | + | ++ |
| Consumer Behaviour | + | + | - | ++ | + | + | ++ |
| Mobility Behaviour | + | + | ++ | + | ++ | ++ | + |
| Charging Infrastructure | - | ++ | - | - | + | ++ | *+ |
| Geography (Spatial) | - | - | - | - | ++ | ++ | + |
| Energy Market | + | ++ | ++ | - | - | ++ | + |
| Non-Car Transport | - | - | ++ | - | - | - | - |
| Sustainability Impact | + | ++ | ++ | - | - | - | + |
| Vehicle Type Variety | + | ++ | - | ++ | - | + | - |
| Vehicle Supply & Stock | - | ++ | - | ++ | - | - | + |
| EV Tech/Market Development | + | ++ | - | - | - | + | + |
| 2nd Hand Market | - | - | - | - | - | - | ++ |
| Business/Leasing Car Market | - | - | - | - | - | - | *++ |
| ++ signifies detailed modelling of the topic, + signifies superficial modelling, - signifies that subject is not included<br>*+ / * ++ Envisioned in future versions | | | | | | | |

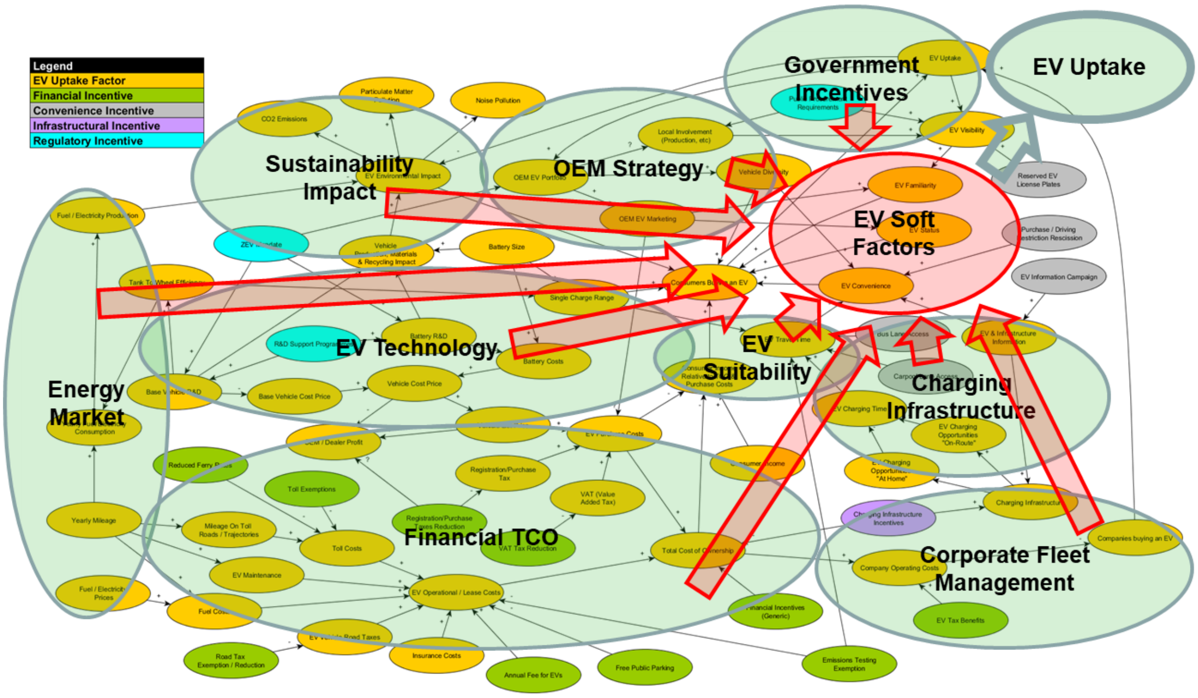


Figure 1: Relational Model of different Focus Areas determining EV Uptake – the visualization shows that effects of the different focus areas should be analysed against their impact on EV soft factors (i.e., consumer attitude and behaviour) as the ultimate determinant of EV uptake. Adapted from [3].

### 3.3 The choice for an Agent-Based Model

In this section we will outline why we chose for a consumer behaviour focused agent-based model. In order to understand the effect of market developments and the changing mobility landscape on individual consumers, modelling at an aggregated level does not offer the required insight. For example, in order to understand how various consumers in different situations experience a zero emission zone policy for a city centre, detailed, disaggregated modelling is needed. And, if policy makers understand how various consumers in 2030 are affected by such a policy, we expect that this will increase the likelihood that such a policy can be implemented successfully. For example, the scenario for a low-income consumer who lives in the city suburb but commutes to the city centre daily can be envisioned much more concretely. The model can then give meaning and support discussion on how the (simulated) world looks like for this person and what his or her capabilities and possibilities are.

In [9], Hoekstra et al. advocate the use of agent-based models to model complex adaptive sociotechnical systems. They state *"A review of modelling techniques shows that equilibrium models are unsuitable and that system dynamics and discrete event simulation are too limited. The agent-based approach is found to be uniquely suited for the complex adaptive sociotechnical systems that must be modelled"*. In [1], an in-depth analysis using panel regression has been executed to analyse the impact of incentives. However, the authors state: "*Our model does not capture country specific shocks to EV adoption that are not time-invariant (e.g. advertising incentives or model-specific releases). Further studies may thus be warranted both on supply side regulations as well as more time dependent country specific shocks*". We translate this as that there is a need for models that allow for time specific events to which the entities in the model then react, and ultimately the behaviour of individuals and the state of the overall system can be analysed.

### 3.4 Goals & Scope of ADAM & EV

In Table 1 we have also indicated which subjects will be covered by ADAM & EV to achieve specific goals. This section discusses each of these subjects in more detail and also compares them to the list of criteria used to assess various models in [5]. This overview is presented in Table 2. In general, it was chosen to add as much complexity as needed to achieve the goals of ADAM & EV, but to avoid detailed modelling where possible.

Table 2: Detailed rationale of covered subjects in ADAM & EV

| Subject | Criteria in [5] | Explanation |
|---|---|---|
| **Vehicle Fleet Development** | Average Vehicle Life, Purchase Price | (+) Various scenarios for growth (or decline) of the fleet, as well as price developments can be seen as global developments that must be present as a background to which more detailed situations can be explored. |
| **Incentives / Policy Scenarios** | Policies | (++) The goal is to visualize various future scenario's for national and or local policy makers. Thus, the effect of a wide range of applicable policy measures should be implemented. |
| **Total Cost of Ownership (TCO)** | Purchase Price, Operating Costs, Payback Period, | (++) Both depreciation (influenced by purchase price) and operational costs should be detailed in order to model the financial implications for consumers to give reason for their (financial) decision making. |
| **Consumer Demographics** | n/a | (++) In order to understand various situations for consumers, the modelled population should be very specific with respect to income, age, job situation and other demographics where needed. |
| **Consumer Behaviour** | Social interaction, Risk Aversion, Attitude to PEVs | (++) One of the main goals is to describe consumer behaviour. Therefore, attitude towards EV and ICEs, perceived social norms, reactions to global and local events and similar factors are very important to model. |
| **Mobility Behaviour** | Mileage | (+) In order to assess EV suitability or operational costs, mobility behaviour of a consumer needs to be quantified to at least a basic level. |
| **Charging Infrastructure** | Charging Infrastructure | (*+) Charging infrastructure can be influential for EV uptake. For now, this factor is not explored explicitly in ADAM & EV, but this is likely to change in future versions as reported in section 5. |
| **Geography (Spatial)** | n/a | (+) By modelling spatial relations or classifications, it is possible to simulate physical interactions. Currently we model consumers in a living environment, mainly to facilitate future developments that might use this. |
| **Energy Market** | Energy Prices | (+) Similar to vehicle fleet development, but in a more constrained manner, mainly energy price developments are modelled to assess future mobility operational costs. |
| **Non-Car Transport** | n/a | (-) To explore certain mobility futures, the development of the modal split between different transport options, including shared ones could be modelled. We have chosen not to focus ADAM & EV on this subject. |
| **Sustainability Impact** | Emissions | (+) The impact of emissions (both manufacturing and driving emissions) is modelled to enable comparison of various scenarios on this key outcome. |
| **Vehicle Type Variety** | BEV Range | (-) Next to overall vehicle fleet development, the variety of types within different fuel types and/or classes, with associated BEV ranges, can be modelled. We have chosen to abstract from this. |
| **Vehicle Supply & Stock** | Availability of PEVs | (+) The supply side of vehicle uptake can severely limit uptake and influence pricing. As it is not a main focus, we model this limited. |
| **EV Tech/Market Development** | Battery Cost & Technology / Technology Cost | (+) Again similar to vehicle fleet development, we model EV technology development such that we can explore behaviour against various future development scenarios. |
| **2nd Hand Market** | n/a | (++) One of the key goals of ADAM & EV is to understand the effect of policies and incentives on every actor in the passenger car market. This requires extensive modelling of the (dynamics in) 2nd hand market as well, which up till now has not been addressed well in existing EV uptake models. It also allows exploration of subsidies for 2nd hand vehicles. |
| **Business/Leasing Car Market** | Company cars | (++*) In many countries, leasing constitutes a large share of new vehicle sales. In this version of ADAM & EV we did not yet include this, but it is a key focus for upcoming developments and is discussed in section 5. |
| Before each explanation, the scope of modelling in ADAM & EV is indicated, equivalent to Table 1 (++ / + / - ) | | |

# 4 ADAM & EV

This section describes the development of the ADAM & EV model. The model is developed in Anylogic [24]. AnyLogic was chosen because it offers a visually attractive agent-based modelling environment that can be even extended with other modelling paradigms such as System Dynamics. Furthermore, the model can be shared online very easily through the "Anylogic Cloud" and can be accessed in a browser without the need to install additional software, thus enabling easy access for all stakeholders.

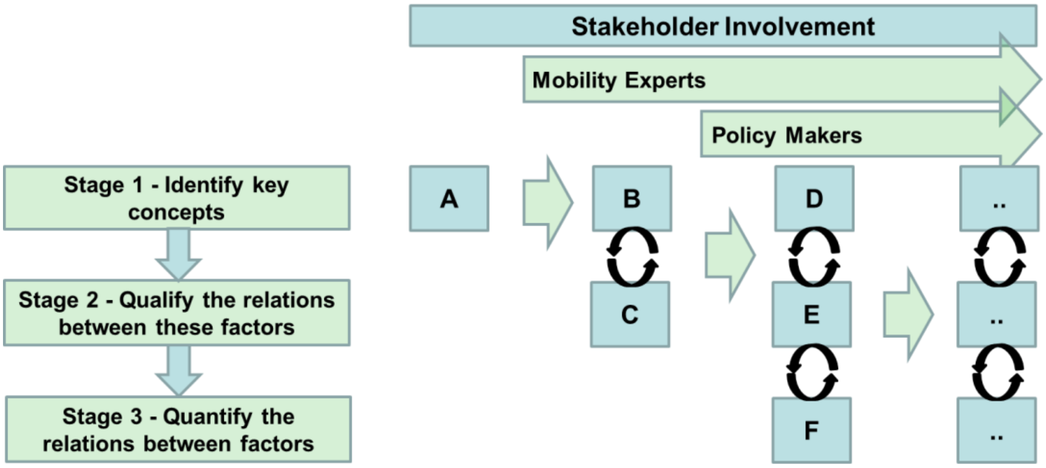


Figure 2: Development process of ADAM & EV following a three staged, iterative, expanding process.

## 4.1 Development Process

In the development of ADAM & EV, we follow a three staged iterative process, based on the participatory process described in [25]. The process involves the following stages: (1) identification of key concepts, (2) qualifying the relations between these components in manner of their directionality, sign (positive or negative influence) and importance and (3) quantifying the relations between factors with more exact formulas.

This process is visualized in Figure 2. The figure shows the three main stages on the left side. The right side of the diagram illustrates that we initially developed a baseline of key concepts with still limited user involvement (step A). This baseline was verified with mobility experts in our project consortium [4] (step B) and subsequently expanded to qualify relations between the identified factors (step C). Some of the results from step A to C are described in [3]. Afterwards, we reached out to policy makers to verify the identified concepts and relations (steps D to F). ADAM & EV is currently in this development phase. The next step is to quantify the relations and validate the model fully. Afterwards more iterations can be executed over the three steps together with involved stakeholders. As a note, we opted to refrain from immediately involving policy makers in phase 1, executing step D before step C, due to two main reasons. The first is that, this way, we gradually expanded the complexity of the model with the number of involved stakeholders. Second, although in a participatory process early involvement of as many stakeholders is advised, we felt that in order to convince policy makers to involve themselves with ADAM & EV, there was a need to present more expansive results than only the outcomes of Stage 1.

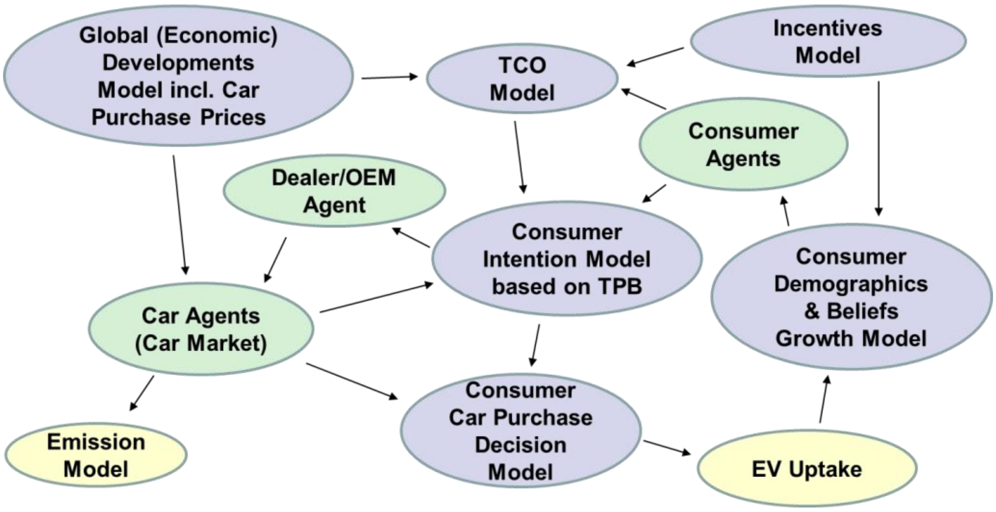


Figure 3: Structure of the ADAM & EV simulation model. Purple circles represent actual models, green circles the agents in the model and the main outcomes, EV uptake and Emissions are depicted in yellow.

## 4.2 Structure of the Simulation Model

The structure of the simulation model is presented in Figure 3 and all main agents and models of ADAM & EV are described shortly in Table 3. The model structure can be explained in a number of ways, but in this work we chose to emphasize the key modelled areas as well as the relation between them. Figure 3 shows the main agents within ADAM & EV, which are consumers, cars, and a single agent representing the supply side of the car market, the dealer/OEMs. Other actors are modelled as global functions and events. As visualized, the model contains one main reinforcing feedback loop – that is the fact that EV uptake influences consumer beliefs. Next to the explanations in Table 3, it is important to highlight shortly what happens at model initialization and at runtime. At the start of the model, consumers agents are instantiated and their preferences are determined. Based on this, a number of car agents is introduced in the model. Then, consumers are allowed to assign a car to themselves. The model is currently configured to start in 2020 and runs until 2050. We feel that a 30 year period is an adequate period to explore the relations within ADAM & EV. All agents and parameters are updated each month, and thus consumers asses their situation again each month. Some statistics and economic developments are only updated yearly.

Table 3: Detailed explanation of components of the ADAM & EV simulation model

| Component | Explanation |
|---|---|
| **Consumer Agent** | Consumer Agents are modelled in high detail. Amongst others they have an age, gender, income, mobility pattern and a specific living area. They also have a (fixed) car holding period. Consumers get born, age, die and also frequently change mobility pattern. Consumers have a state transition diagram with respect to car ownership. Notable algorithms are mentioned below. |
| **Car Agent** | Car Agents are modelled in moderate detail. The model currently only includes two car types based on a VW Golf, a petrol and a BEV variant. Cars have an age, and get disposed when their lifetime ends. They furthermore have a fuel/energy efficiency and given a mileage, can calculate their operational cost including depreciation. |
| **Dealer/OEM Agent** | The dealer/OEM agent is modelled very superficially. Mainly, this agent assesses the current demand of cars by consumers, compares this with available vehicle stock and then introduces new vehicles in the model based on this demand. |
| **Global (Economic) Developments** | At the top level, ADAM & EV models global economic developments. One of the main aspects of this is a fixed scenario for car price developments. For example, currently a scenario with price parity between ICEs and BEVs in 2030 is implemented. Other factors are fuel and energy cost developments. Also, the population size is roughly kept at the same level. |
| **Incentive Model** | ADAM & EV has implemented several (financial) incentives that can be configured in height and active duration with a start year and end year. A zero emission zone for the city centre that currently affects consumers living in the city centre is also included. Consumers only consider incentives that are in place. They do not (yet) look ahead or react to announcements of incentives. |
| **TCO Model** | The TCO model in ADAM & EV includes depreciation, incentives and operational costs (including energy cost based on a user's mobility pattern). The operational costs and depreciation are based on previous research of the authors presented in [26]. |
| **Consumer Demographics & Beliefs Growth Model** | Currently a basic beliefs' growth model is implemented. Consumers have a BEV attitude which is currently a randomly assigned score between 0 and 1. ICE attitude is the inverse of this number. The BEV attitude grows gradually over time. Societal attitude is the average over all consumers. Future developments foresee the more explicit modelling of influences on these beliefs. |
| **Consumer Intention Model based on TPB** | The intention model consists of a weighing of three factors: the personal attitude, the societal attitude and behavioural control. The first two factors are modelled as described under the beliefs growth model. Behaviour control is modelled based on a purchase price fit, a TCO fit and a basic variable (between 0 and 1) representing other factors under behavioural control. The fits are determined for each consumer by looking at which portion of available cars fit their financial requirements. The basic variable increases over time for BEVs, signifying BEV range and charging infrastructure developments. For ICEs this factor is 1, unless a zero emission zone is active, then it becomes 0. This ultimately results in a positive intent if the resulting score is > 0.5. |
| **Consumer Car Purchase Decision Model** | Once a consumer has positive intention and takes actual action (based on mobility and current car situation), the consumer will look for a car. Currently this is implemented by considering all non-owned cars in the model that fit a consumer's criteria in powertrain type, purchase cost and TCO. Currently, from the available cars, the cheapest car with respect to purchase cost is selected. |
| **EV Uptake** | ADAM & EV tracks sales figures and displays them in various manners. Both the monitored demand by the dealer/OEM agent as well as the actual sales are compared in the visualizations. |
| **Emissions Model** | For each time step of the model, emissions are modelled of owned cars, based on the mobility patterns of their owners. At the point of introduction of new cars, manufacturing emissions are also registered. The emissions values are based on [27]. |

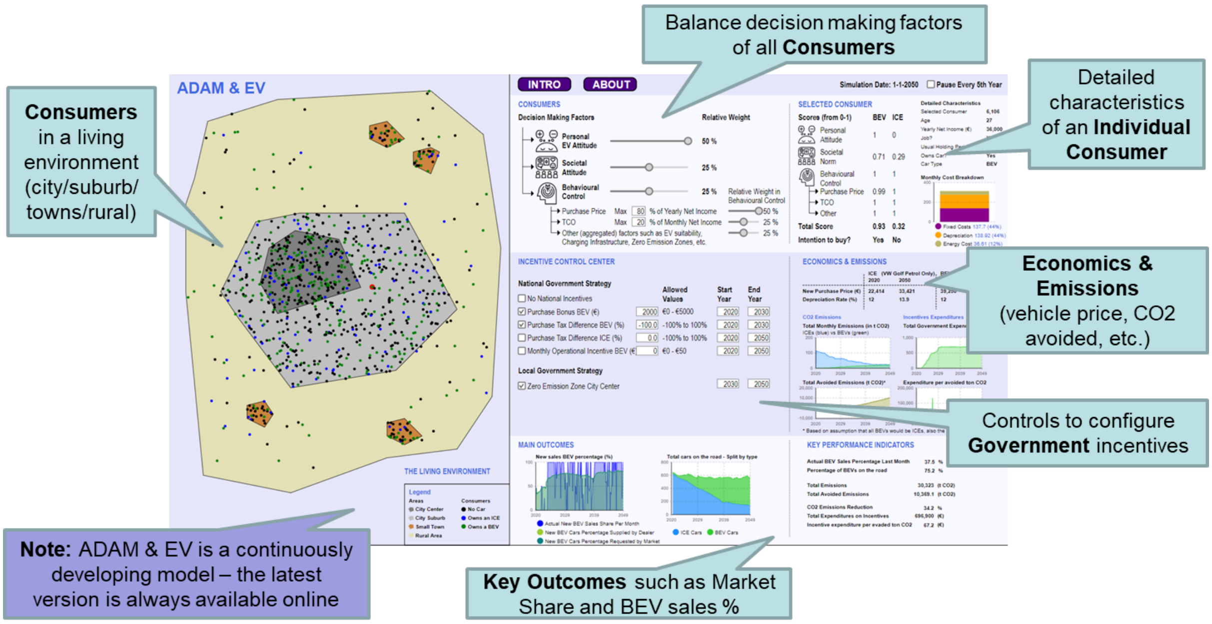


Figure 4: The simulation interface of ADAM & EV in its current state of development – for the most recent version of the model, visit [www.bit.ly/adamev](www.bit.ly/adamev)

## 4.3 Simulation Interface

The current development state of the visualization and interactions with the simulation model is shown in Figure 4. The interface covers, on the left side, the consumer agents in a living environment, in which each of the consumer agents can be selected for additional details on that individual consumer, shown on the right side. The right side also features controls to balance the decision making factors of consumers in the model, on a global level. Scores of this decision making process are visualized for the individually selected consumer. A more detailed picture of these aspects is shown in Figure 5. Here, it can be seen that the three main decision making factors can be balanced by adjusting sliders. For behavioural control, the three sub-elements, purchase price, TCO and other factors can also be balanced and maximums for purchase and TCO expenditures can be set based on a consumers' income. For now, no option is offered to vary these criteria across consumer groups, although it could be a relevant setting for future scenario exploration. The model does currently include an income distribution, so not all consumers reason from the same values.

In the middle of the right side in Figure 4, an "incentives control centre" has been created, where a user can enable and configure incentives with a value (for financial incentives), start year and end year. To its right, an overview of outcomes of economics is shown. The bottom right side lists various key outcomes such as EV uptake, the composition of the car fleet in the model and several key performance indicators.

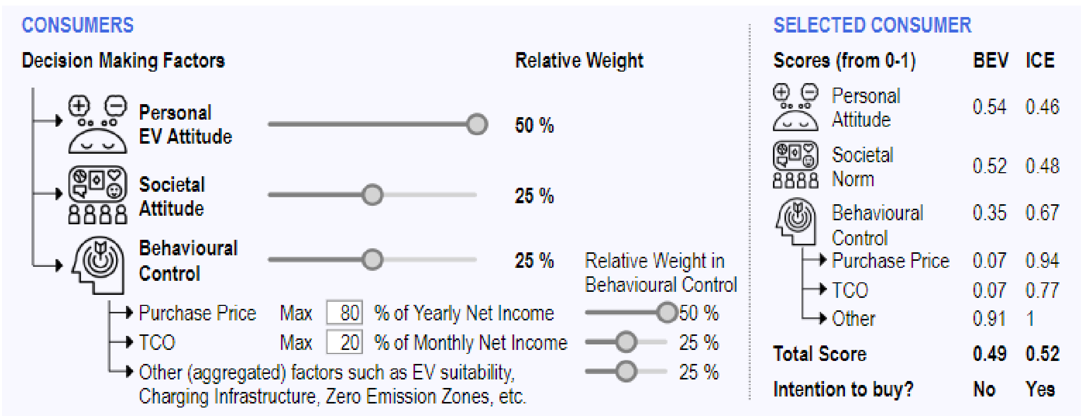


Figure 5: Detail of the simulation interface showing controls that allow variation of the balance between the decision making process of consumers

# 5 Initial Outcomes & Discussion

This section will provide a reflection on the proposed process, structure of the model and ongoing developments, and discuss several initial outcomes of ADAM & EV. In this work, we have introduced ADAM & EV in the context of already existing EV uptake models. We argue that there is a need for consumer behaviour focused simulation models to give policy makers more insight in the effect of various policy scenarios. In order to strengthen this insight, a flexible modelling process is proposed.

With respect to the proposed process, we have experienced a continuous need to balance between stakeholder involvement and modelled complexity. This stems from the fact that the more complexity that is added to the model, the harder it is to involve stakeholders without overwhelming them. However, we also stated earlier in section 4.1 that we experienced an internal drive to present something finished and somewhat complex, i.e. worthwhile, to stakeholders. Nonetheless, the group of mobility experts supporting us in the development of the model has been involved from an early stage and provided valuable feedback in the scope and set-up of the model.

The scope of the model has evolved continuously and will continue to evolve as we explore different scenario's with various stakeholders. From experiences with the model and discussions with mobility experts we identified the need to include business and private lease in the model. In the current situation, these car "purchase" channels are not available and the behaviour concerning uptake of electric vehicles seems to be missing this key relation to take off properly. Another example is the fact that when speaking with local (city) policy makers, modelling of relations regarding the charging infrastructure was a key behaviour to explore with the model. In this case, we discussed to utilize the spatial set-up of our model and link the geographical location of consumers to socio-economic data, including for example type of housing and with that access to charging infrastructure. This way, the model is used to create valuable insights for, in this case local, policy makers.

We have several examples of the initial outcomes that highlight the capabilities of the model. First, it was observed that, somewhat surprisingly, the graph that tracks total emissions savings is sometimes negative during model runs. Of course this is not entirely surprising as emission savings tend to be negative in the first few years due to the fact that manufacturing emissions, which are higher for BEVs, are attributed directly to the produced emissions. However, visualizing it this way was still an eye-opener for the involved stakeholders (and modeller). Second, currently a fleet of cars is instantiated at the beginning of a simulation run. The extent to which this fleet matches the requirements of consumers is an influential factor. In some model runs, particularly those where only financial factors were considered in decision making there was a sizeable stock of ICE cars which led to consumers ignoring possible new BEVs. This is of course more a modelling issue, but it also signifies the (hindering) role that remaining ICE stock can have on EV uptake.

# 6 Outlook

In future work we will report on continued development and use of the model. Some of the first new subjects to be included are the business market and charging infrastructure. Furthermore, we will work together with the involved stakeholders to validate the behaviour and outcomes of the modelled system. Ultimately, this should help us to answer our overall research question, which is: How can stakeholders be supported to understand and steer the design, realization and use of electric mobility systems?

# Acknowledgments

The proEME project has received funding from the ERA NET COFUND Electric Mobility Europe (EMEurope). Participating project partners are Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center), Chalmers University of Technology from Sweden, Copenhagen Electric from Denmark, FIER Automotive from the Netherlands, Hungarian Electromobility Association, Metropolregion Hannover Braunschweig Göttingen Wolfsburg from Germany, National Academy of Sciences of Belarus Center for System Analysis and Strategic Research, Robert Bosch GmbH from Germany, VTT Technical Research Centre of Finland and the University of Twente from the Netherlands.

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