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Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech Division

Interim report dated 19.11.2021

PROBOUND

Promoting the energy transition by leveraging bounded rationality and appropriately redesigned policies

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Date: 19.11.2021

Location: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Bern
www.bfe.admin.ch

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SFOE contract number: SI/502172-01

Zusammenfassung

PROBOUND untersucht eine Reihe von Verhaltenseffekten aus dem Bereich der begrenzten Rationalität (BR) auf relevante energiebezogenen Entscheidungsprozessen im Bereich der individuellen Mobilität - einem Sektor, der aufgrund heterogener Entscheidungsfindung sehr anfällig für BR ist. Es untersucht diese Effekte mit Hilfe eines agenten-basierten Modelles der Schweizer Individualmobilität (BedDeM), erweitert um Kaufentscheidungen, sowie einem übergreifenden Modell des Schweizer Energiesystems (STEM). Dabei werden diese Modelle integriert, so dass eine Co-Simulation ermöglicht wird. Es bewertet die Auswirkungen mobilitätsbezogener BR auf die Ziele der Schweizer Energiepolitik aus der Gesamtenergiesystemperspektive. Es liefert Erkenntnisse für die Neugestaltung einer breiten Palette von Politikinstrumenten. Bis heute hat das Projekt Fortschritte bei der technischen Kopplung der Modelle (BedDeM und STEM), bei der Implementierung der Architektur für die Modellierung der Fahrzeugbeschaffung in BedDeM und der Verbrauchersegmentierung in relevante Bereiche und Interventionen, die für die Gestaltugn zukünftiger Massnahmen wichtig sein könnten, innerhalb STEM erreicht.

Résumé

PROBOUND examine un certain nombre d'effets comportementaux de la rationalité restreinte (BR) dans d'importants processus décisionnels liés à l'énergie dans la mobilité des personnes - un secteur qui est très vulnérable au BR en raison de la prise de décision hétérogène. Il les examine à l'aide d'un modèle (basé sur les agents) de mobilité individuelle suisse (BedDeM), élargi pour inclure les décisions d'achat, co-simulé avec un modèle global du système énergétique suisse (STEM). Il évalue les effets de la BR liée à la mobilité sur les objectifs suisses de transition énergétique du point de vue du système énergétique global. Il fournit des indications pour la refonte d'un large éventail d'instruments politiques. À ce jour, le projet a progressé dans l'interface technique entre les deux modèles, dans la mise en œuvre de l'architecture d'achat dans BedDeM et de segmentation des consommateurs dans STEM, dans une liste préliminaire de domaines et de lignes directrices qui pourraient être importantes pour la conception et la refonte des politiques.

Summary

PROBOUND investigates a set of Bounded Rationality (BR) types in key energy-related decision-making processes in personal mobility - a sector highly prone to BR, because of heterogeneous decision-making. It explores them by an agent-based model of the Swiss personal mobility (BedDeM), extended to include purchase decisions, co-simulated with an overarching model of the Swiss energy system. The Swiss TIMES Energy system Model (STEM) assesses impacts of mobility-related BR on the Swiss energy transition goals from the whole energy system perspective. It provides insights to re-design a broad range of policy instruments. Up to the current date, the project has progressed in 1) establishing interface between the two models, 2) implementation of the architecture for car purchase decision in BedDeM, 3) introduction of consumer segmentation and e-mobility charging stations in STEM, and 4) a preliminary list of areas and policies, which could be targeted for design and re-design.

Contents

Abbreviations

BedDeM	Behavioral-drive demand model, developed at HES-SO Valais/Wallis
BR	Bounded rationality
ESD	Energy service demands
MTMC	Mobility and Transport Microcensus
SHEDS	Swiss Household Energy Demand Survey
STEM	Swiss TIMES energy system model, developed at PSI
TIB	Triandis' Interpersonal Behavior model

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1 Introduction

1.1 Background information and current situation

Bounded rationality is a theoretical construct of many authors (e.g. H. Simon, D. Kahneman, A. Tverski, R. Thaler, D. Ariely) enjoying vast empirical support and being at the core of behavioral and evolutionary economics (Nelson & Winter, 1982; Nelson et al. 2019) as well as agent-based computational economics (Tesfatsion & Judd, 2006). The notion covers a number of different aspects in influencing decision-making, with the communality of deviating from the well-established notion of rational decision making. In the literature, a number of phenomena are grouped under BR, e.g. emotional and affective decision-making (Triandis, 1977; Litvine and Wüstenhagen, 2011), multi-stage decision-making process (Schrift et al. 2018), heuristic decision-making (Blasch et al. 2019), habits (Doyle et al., 2016), social norms (Litvine and Wüstenhagen, 2011), prospect theory, including loss aversion and endowment effect (Hoffmann & Thommes 2020), confirmation bias (Schrackmann M., & Oswald, 2013), mental accounting (Hahnel et al. 2019), etc. Many specific, even anecdotal, evidences of deviation from rationality are covered. However, their combined effects are never assessed quantitatively, particularly at a national level.

PROBOUND turns this large body of research into a novel direction by tight co-simulation of an agent-based simulation model (operating on individual decision-making of demand by considering emotions, habits, and social factors) and a cost optimization model of the whole Swiss energy system - with high level of technology/vehicle representation and a hard sector coupling of energy supply and demands.

PROBOUND has a clear country focus on Switzerland, utilizes well established micro-data sets, covers a large number of BR types, couples an agent-based model with a comprehensive model of overall Swiss energy system. It builds upon works in the domain of BR by the research team (Piana, Kannan, Schumann et al. 2019 and 2021; Nguyen & Schumann, 2019a and 2019b; Nguyen & Schumann, 2020).

1.2 Purpose of the project

PROBOUND aims to originally contribute to the national and international debate on new and better policy measures for the energy transition, leveraging BR for faster, deeper, and cost-effective transformation.

The scope of the project is defined by a sub-matrix of decisions (see Table 1) and different relevant instances of BR. These variables have been shortlisted in a pre-study covering more than ten BR instantiation and 13 sub-sectors for their potential to have a strong and positive effect on the transition, especially if properly addressed with suitable policies.

Table 1: Key categories of BR in mobility decision making

Bounded rationality type	Impacting on decisions
1. Sequential decision-making (e.g. need detection, search for information and alternatives, evaluation, experience, judgement, repurchase, communication) 2. Confirmation bias 3. Emotional decision making 4. Multiple criteria beyond cost (comfort, CO_2, social status, …) 5. Bandwagon effect 6. Habits formation	A. Vehicle purchase choice B. Purchase of innovative services C. Innovation diffusion

Though we focus on personal mobility sector, it is important to note that any budgetary constraint/reallocation at household spending will affect decision elsewhere in the energy system (e.g. choice of heating system or insulation), effect of which can be captured by STEM's systemic features.

1.3 Objectives

The goal of the proposal is threefold:

1. to identify specific BR types in personal mobility and assess their impacts on the system level in terms of emission reduction, energy consumption and overall costs for different policy interventions with and without consideration of BR
2. to improve current analytical power of existing models by enhancing them, and introduce a tighter integration by co-simulation. We will enhance and couple BedDeM (an agent-based model, focusing on decision-making at the household level, applying a decision-making scheme originating from psychology) and STEM (an optimization model of the whole Swiss energy system with full sector coupling)
3. to provide recommendations for the design of policies, so that BR effects are excplicitly considered and used to promote the policies' effectiveness.

We approach these goals with a particular orientation: to single out and leverage those specific BR types that have the potential of fostering, and not only hindering, the transition. Accordingly, the specific research questions this project aims to answers include, but are not limited to:

1. Which are the impacts of emotional and multi-criteria decision-making, confirmation bias, habit formation and bandwagon effects on the purchase of vehicles and mobility services, including innovative once, so as to influence their overall diffusion trajectories in society ?
2. What do these effects imply for the design of policy instruments, including their structure, degree of complexity, communication, timing, robustness and operational aspects ?

It is anticipated that extensive policy recommendation will be elaborated, based on all quantitative and qualitative analyses.

2 Facility, procedures and methodology

We go beyond the state-of-art by taking advantage of having two established models available and of their complementary nature. STEM, the Swiss TIMES energy system model (STEM), developed at the PSI-EEG, is a technology rich, cost optimisation model of the Swiss whole energy system (Panos and Kannan, 2018) . The model optimises technology and fuel mix to meet the given energy service demands (ESD) based on competing energy pathways while fulfilling energy supply and environmental constraints. It sheds powerful insights on long term development of the Swiss energy system. The transport sector in STEM has an extensive type of vehicles with a combinations of different drivetrain and fuels options. For any emerging vehicles such as fuel cell and battery electric cars, an aggregate infrastructure is included for both private and public transportation.
BedDeM, the Behavior-driven Demand Model, developed at SILab (HES-SO VS), is an agent-based model of the Swiss population, embedding a psychologically realistic model of human decision-making (.Nguyen & Schumann, 2019a). With them, we will address particular BR instantiations of high importance in the mobility area.

2.1 Facility

In both locations (Sierre and Villigen) computing facilities are available for the elaboration and storage of the large amount of data (input, output) and the executed code.

2.2 Overall strategy and procedures

The general strategy is: to develop and extend the two models so that they can embed some aspects of bounded rationality; to couple the models so that they alternatively participate in simulating of a relatively long time period, both contributing to its results; to set a list of particularly relevant policies aimed at fostering the energy transition in mobility that leverage BR; to produce alternative design for each policies that can be tested in models; to run the simulations and obtain their outcomes in a comparable way; to assess model results for providing policy insights and recommendations.

This strategy contains some temporal loops, in the sense that elements for a first list of policies helps modifying the models so that they are not deprived of variables through which the policies can be simulated. In general, data exchange is independent from model development but specific instances of coordinated modification may occur.

In procedural terms, both teams have systematic interaction at general and model level.

In the remaining sections of this section, a basic description of the two models and of their coupling approach is explained.

2.3 BedDeM basic description

BedDeM is an agent-based simulation platform. In its implementation to mobility, it contains several thousands of agents (simulated people) who take decisions, based on individualized state-data, choice parameters and history. Within each agent a decision-making process is the culminating part of a broader setting, in which perception of market and of other agents play an important role. As an effort to produce a comprehensive agent architecture that can utilize qualitative data to capture consumer behavior, a few years ago we decided to implement Triandis' Interpersonal Behavior (TIB) (Triandis, 1977) in our platform, Behavior Demand Model (BedDeM), by using the Repast library for agent-based modelling. TIB is chosen due to its expressibility as a theory for human behavior and ability to calculate expected utility with its tri-level form (see Figure 3 below), in a way that is compatible with a bounded rationality perspective.
BedDeM's first application was in the domain of mobility, whose main purpose is to generate daily mobility demands at the individual household level based on their modal choices for daily trips. We utilized the Swiss Household Energy Demand Survey (SHEDS) and the Mobility and Transport Microcensus (BFS, ARE, 2017) to parametrize the household profiles, build and calibrate a synthetic population (Nguyen, K. and Schumann, R., 2019a). A weekly schedule is also derived for each agent from MTMC to provide a way to calculate all relative attributes for a trip (including purpose, distance, execution time). The agent's main purpose is to select a mode of transportation (including rail, car, bus, tram, biking, walking, others) to perform a task on its schedule. This model has been used to explore the importance of different determinants (Nguyen, K. and Schumann, R., 2019b) and charging pattern for electric vehicles (Nguyen, K. and Schumann, R., 2020).

In PROBOUND we extend the model to also cover purchase of a resource, such as the vehicle, again using the Triandis' model as frame. In such extension we implement several additional bounded rational components. Thus, BedDeM now covers, both purchase of mobility resources, as well as their usage, in two intertwined decision-making schemes, each based on an implementation of the TIB model.

Once implemented these developments allow for the quantification of the BR impacts by systematically test all possible combinations of absence / presence of the components in TIB's theory, one will get the absolute and differential results at agent and aggregate level. This testing mechanism is further discussed in Section 3.1.

This innovative and comprehensive implementation of BR will be referred to the decisions of Table 1 (second column). Diffusion pathways will be micro-founded, possibly leading to S-shaped curves but potentially also other outcomes (e.g., aborted diffusion).

As for the calibration of the model, the current version has already been calibrated to aggregate and disaggregate statistics of the Swiss mobility systems. In particular, it is able to reproduce the large majority of trips contained in Mobility Microcensus 2015 (BFS, ARE, 2017), carried out by the real agents to which artificial agents have been matched to.

2.4 STEM basic description

The Swiss TIMES Energy system Model (STEM) is a technology rich, cost optimization model of the Swiss whole energy system (Panos and Kannan, 2018; Panos et al., 2021). The model optimizes technology and fuel mix to meet the given energy service demands based on competing energy pathways while fulfilling energy supply and environmental constraints. It sheds powerful insights on long term development of the Swiss energy system. The transport sector in STEM has an extensive type of vehicles with a combination of different drivetrains and fuels. For any emerging vehicles such as fuel cell and battery electric cars, an aggregate infrastructure is included for both private and public transportation. Within this project, the personal mobility sector is further developed (see Section 3) to assess the potential impact of bounded rationality to be quantified with the BedDeM model.

2.5 Repartition of tasks and coupling methods

STEM is used to provide the overarching context, the energy supply factors, marginal energy price and tax schemes. Whereas in JA Mobility (Piana, Kannan, Schumann and others, 2020), the purchase of vehicles was implicitly assumed as derived from a fleet optimally chosen in STEM, in PROBOUND such decisions are decentralised to agents (thus performed in BedDeM), in tight co-simulation with STEM, as these decisions will influence the overall energy system. Policy implementation will be in BedDeM, in STEM or in both depending on the policy.

Application and integration of two models of different underlying methodologies (simulation vs optimisation) is always challenging. In this task, we establish an interface to extract and exchange input/output parameters of BedDeM and STEM. We have already established a basic template for exchanging common data parameters, which was possible within the Joint Activity on the Evolution of Mobility of the SCCER Mobility and CREST. Based on these experiences and knowhow, we will follow a number of steps implementing the interfacing between the two models. The framework developed in this task is made of two components: *data* and *automation of co-simulation*. Both need to be specified, implemented and tested.

Deepening the description of the work plan and timeline, we now describe each sub-step:

1. Specification of the data exchange
2. Implementation of the data exchange
3. Testing of the data exchange
4. Automation of coupling of the models

5. Testing of the automation

1) Specification of the data exchange

Based on previous work, we already have mapped relevant parts of the input parameters and began to soft-link the models in an iterative manner. For example, car purchase decision from STEM has been used in BedDeM to understand their usage (driving) by consumer. This interface needs to be extended and adopted in a way that decisions which are made in one system and are relevant for the other system, get exchanged. For example, BedDeM simulates car purchase, and the resulting fleet needs to be communicated to STEM, evaluating overall consequences. Similarly, BedDeM informs STEM related to some non-cost driven decision variables which can be used for the proposed multi-criteria optimization in STEM. The data exchange based on the updated interleaved model execution should allow deeper mobility-related insights that reflect the dynamics within the transport sector, while taking into account the impacts on- and from- the overall Swiss energy system.

2) Implementation of the data exchange

Based on a overall specification, the data exchange functionality implements data import and export for both systems. Additionally, a data exchange platform, e.g. a version control system like a git platform needs to be established, as it was done for the JA Mobility. Thus, a git installation is already used and PROBOUND will evolve it for further collaboration.

3) Testing of the data exchange

The implementation needs to be tested a) with respect to its functional correctness, i.e. that data exchange actually happens according to the specifications, and b) with respect to plausibility of model results, so as to validate that all relevant data is exchanged, and model assumptions are harmonized.

4) Automation of coupling of the models

At this project aims for a tighter integration of two models, by enabling them to co-simulate a joint analysis requires a larger number of model-runs, data exchange between the models, updating of the internal representation, and a partial re-run of the models. To enable this, the steps mentioned above needs to be automated (or at least semi-automated) to keep the workload of the researchers reasonable. Without automation such an integration is inefficient for large scale experiments. Each of the aforementioned steps can be automated by scripts. Furthermore, using the event-notification system of a version control system, like git, enables to start these scripts automatically, in the moment new input data is available.

5) Testing of the automation

Before the automation can be used for experiments, it needs to be tested for functionality and correctness, including some test-cases where outcomes can be double-checked.

3 Activities and results

After the signature of the contract, the kick-off meeting with SFOE took place on the 11.02.2021. The work-plan for the year was then announced. The first Advisory Board meeting took place on the 19.04.2021, the second one on the 03.11.2021. During the first year of the project, the model development and coupling have progressed. The specific aspects of these developments are described in the following sub-sections.

3.1 BedDeM developments

In this model, we added a new decision-making procedure for car selection, which will run intertwined with the mobility demand decision. BedDeM's team has developed and coded the mechanisms of all the components shown in Figure 1. In each simulated decision cycle, an agent will perform the following cycle: First, its *Perception* component observes the market state, which will create number of available car models. In addition, with information from Opinion Channels of Neighbors, Media and Dealers and history of ownership, it filters, sorts and create a number of shortlisted options, including not purchasing. If certain criteria are archived (e.g. number of new models, changes in the household, mileages of current car …), the *Decision-making* component get triggered. It compares different determinants (e.g. attitude, social factors, emotion, habit) to evaluate the list of options in term of a utility value. An option is selected based on the provided utility, either by choosing the best (deterministic agent) or using a probability (probabilistic agent). The *Communication* component then output this action to the current market and updates the *Memory* state of the agent. It also informs the Opinion channels for future reference by neighbors.

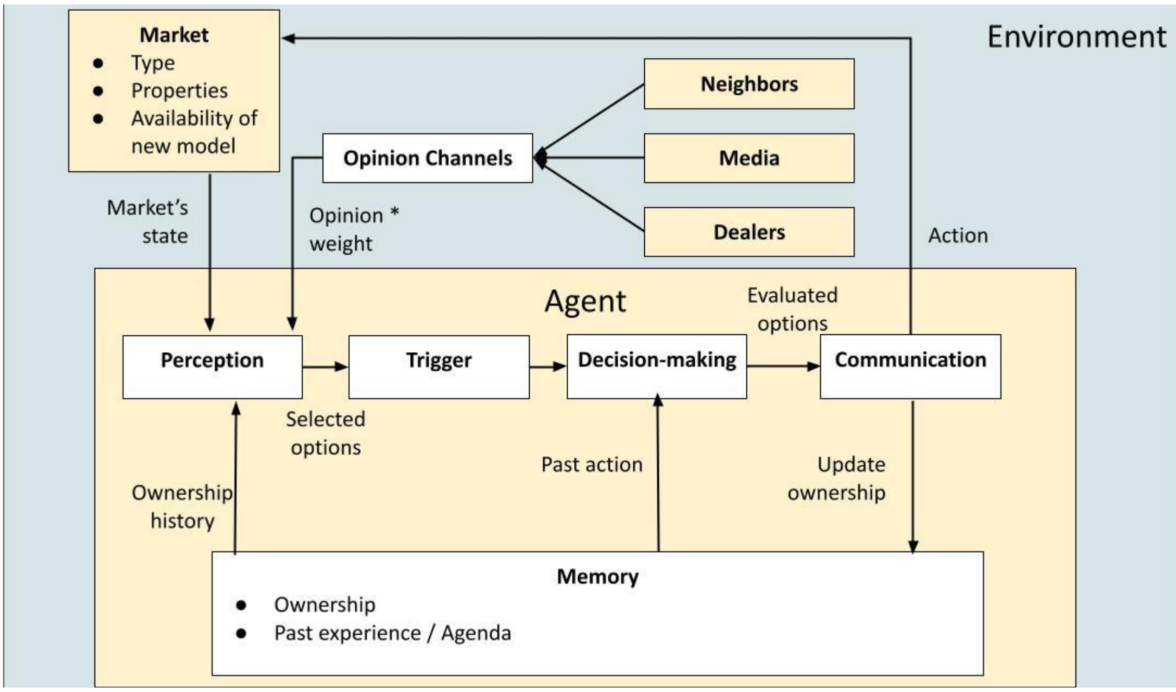

Figure 1. BedDeM's agent model for PROBOUND

We further expand the Perception components in Figure 2. Information To capture the discussed bounded rationalities, the following references are included:

1. Engine (electric, gasoline, hydrogen, hybrid)
2. Energy labels (A+/A, B, C, D, E)
3. Price (a certain threshold depending on yearly income)
4. New models in the perceived market
5. Brands
6. Recommendation from Opinion channels
7. Similar models form what currently owned

These criteria are used to filter all perceived options to create several lists. They are then sorted, multiplied with certain weights (depending on agent's profile) and merged to form a list of selected options for decision-making.
Their filtering thresholds and weights are currently calibrated according to a number of agent's profiles, which is created similarly to previous Join Activities project.

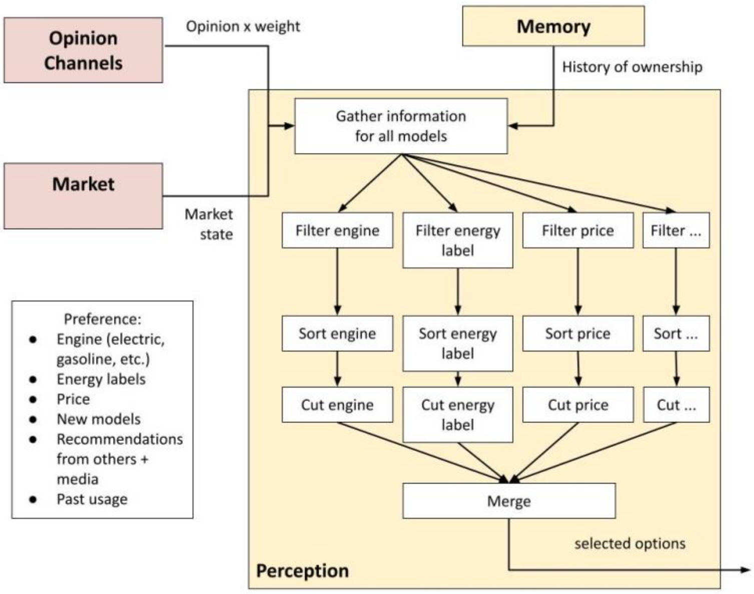

Figure 2. Perception component of BedDeM's agent

If the purchasing process is triggered, the Decision-making component will compute the utilities for all selected options. It follows the TIB's tri-level, which can be seen in Figure 3. The value of a determinant in first level is derived directly as observed from Perception component. Several properties of an alternative are considered here, including charging points availability, price, label, reference from others, social status, brand, emotion and past usage. The utility of each determinant in 2^{nd}, 3^{rd} level is equal to the combination of connected determinants at previous level multiplied with their weights. The agent used to final values (at Behavior output) to compute the best option to act. It should be noted that options also include *not purchase anything*. Similarly, to the Perception component, the weights of determinants here are calibrated according to the number of agent's profiles.

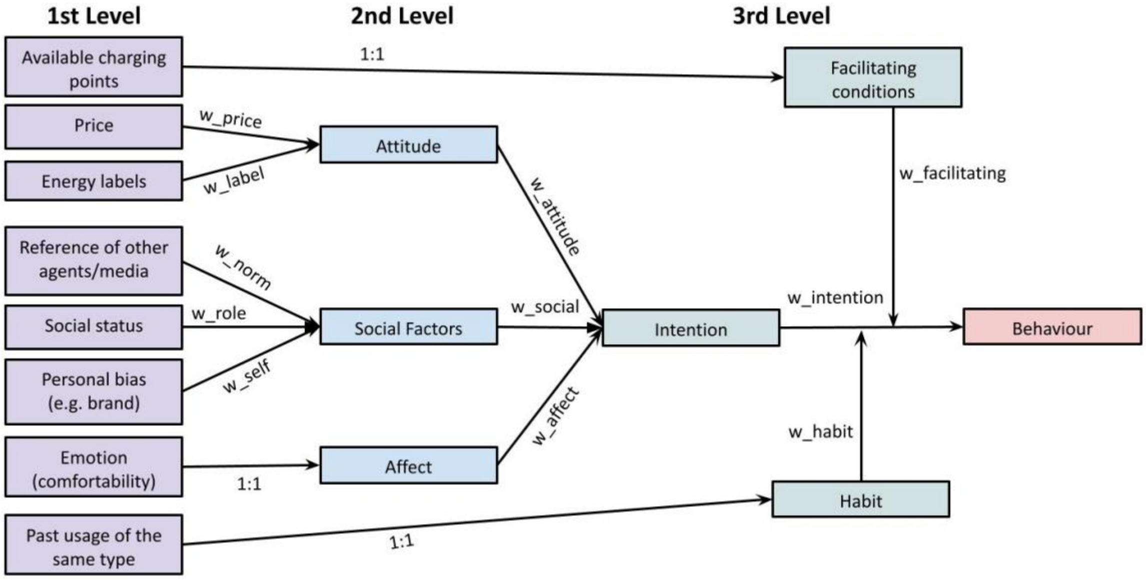

Figure 3. Decision-making component of BedDeM's agent

Using this architecture, we address the bounded rationalities as follow:

T1. (Sequential decision-making): When triggered, an agent gathers information about the alternatives within its preference (including car price, other agents/media opinions, its history of ownership, etc.). It filters and sorts this list using criteria in reference. These selected options are evaluated alternative(s) in decision-making component. If a purchase is made, the agent removes current ownership and communicates this action to the market.
T2. (Confirmation bias): We implement several filters in Perception component, e.g. engine, brand, energy label, price... The agent selects only models within these references to sort and merge into a single list of options for decision-making.
T3. (Emotional decision-making): It is captured in the weight of *Emotion* determinant in Decision-making component (see Figure 3). In scenario setting, it can be increased to highlight the effect of emotion in car purchasing.
T4. (Multiple criteria): These criteria are implemented in multiple determinants of Decision-making component (see Figure 3). For example, comfortability is emphasized in *emotion*, social status is connected to *social factor.*
T5. (Bandwagon effect): An agent accumulates neighbors, dealers and media's opinions in Perception phase (at 3 levels: good/bad/so-so). This will be feed into perception for a specific car model, which can be used in social factors box in decision-making. The agent can also use it for filtering its options and communicate its decisions to the same neighboring networks.
T6. (Habits formation): Past mobility experience that can affect the agent's evaluation, e.g. good experience with current car. It is captured in the *Habit* determinant in Decision-making component.

3.2 STEM developments

A stand-alone passenger transport model, which has the same structure as the STEM transport module (see chapter 2), has been developed. This standalone model is used to test novel methods that can be incorporated in STEM at a later point. Within the scope of this project the following two aspects specific to the personal mobility are implemented:

1. An enhanced mobility consumer segmentation to reflect consumer heterogeneity with distinguished daily trip distances
2. Extensive development of electric charging infrastructure for cars

Firstly, the homogeneous representation of the Swiss population by one "mean representative decision agent" (McCollum et al., 2016) in STEM was replaced with a set of twelve consumer segments (household income, annual driving distance, etc.) before the start of the PROBOUND project. The primary aim of the consumer segments is to reflect heterogeneity in household mobility consumers and their decision variables (Piana, Kannan, Schumann et al., 2020). However, these twelve consumer segments revealed some limitations in representing key aspects to address e-mobility. For instance, criteria based on annual driving distance have a low relevance for potential electric charging behavior. Besides, the STEM model was limited in exploring endogenous modal choice as the consumer segments were based on car ownership per se, instead of households. Within the PROBOUND project, some of these limitations are addressed by a different configuration of the consumer segments. This new segmentation is based on the following mobility-relevant socio-economic and socio-demographic parameters, inspired by Venturini et al. (2018). Figure 4 elucidates the overarching consumer segments.

1. Access to public transport with household agglomeration (good/limited)
2. Household income level (high/low)
3. Household ownership type (tenant/homeowner)
4. Daily trip distance (short/medium/long)

The four criteria were heuristically selected and enable us to include relevant aspects on modelling transformation of the personal mobility sector. The access for a private home electric charging station is based on the household ownership type. Modal-shift options can be modelled based on the accessibility to public transport connectivity at the place of living. The household income criterium enables us to consider capital budget for investing in expensive cars and/or use alternative mobility options, such as public transport. In addressing bottlenecks in e-mobility infrastructure, four different trip types have been introduced that distinguish the driving demands of each consumer segment. Based on the 2015 Swiss mobility survey (BFS, ARE,2017), we distinguish short-distance trips (<10km), medium-distance trips (10-80km) and long-distance trips (>80km). For the latter, we distinguish between long-distance trips where the starting point and the destination are both in a high agglomeration area and where one of such points is at a place that does not belong to any agglomeration or is in an area with low agglomeration. The trip distance mainly influences which transport modes are available. Besides, we can assess the need for rapid public charging infrastructure to cover long-distance trips with Battery Electric Vehicles (BEVs) to reflect a certain range anxiety of the consumers. Further, with the new consumer segments, the mobility sector is fully re-calibrated to 2020 vehicle stocks, annual driven-vehicle-km (vkm) and passenger-km (pkm), and fuel consumption (BFS, ARE, 2017; Kemmler et al., 2017; BfS, 2019; BfS, 2021). While the consumer segments are implemented in the model, we acknowledge that, at the current point, not all defining aspects of the segments have an impact on the simulations. For instance, the model is not yet considering the household income for its decision-making process. However, the implemented core structure of the model allows such aspects to be implemented when they prove being suitable for the overall model framework.

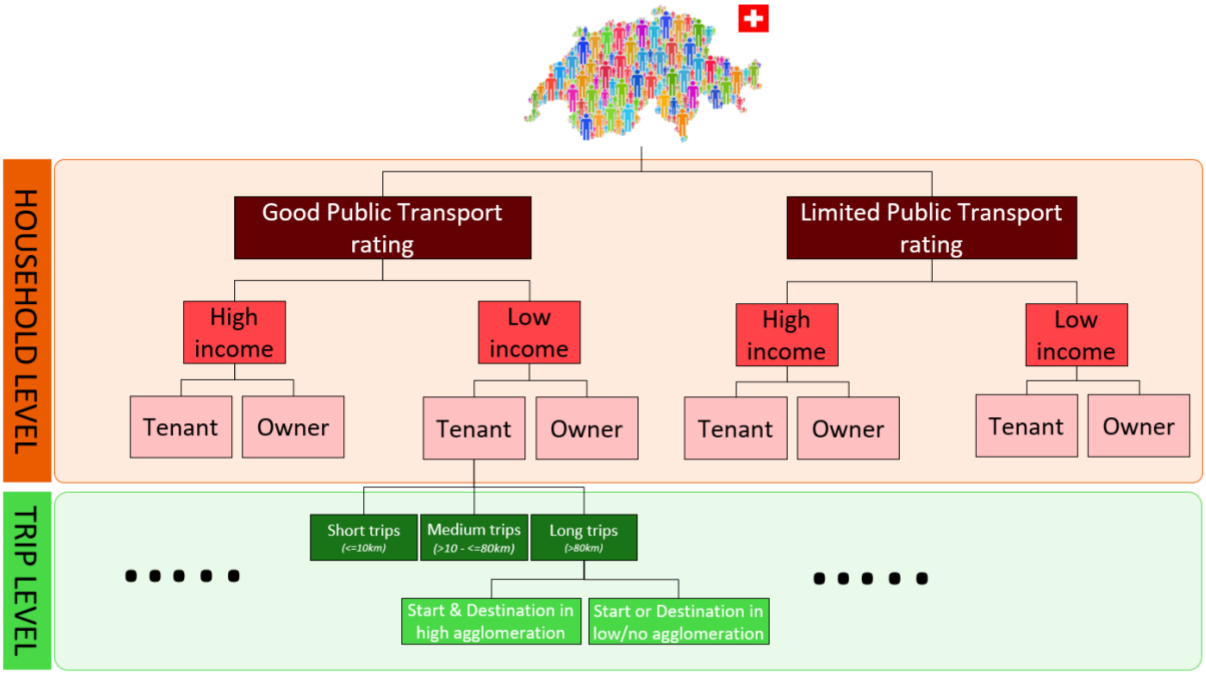

Figure 4: Hierarchy of the consumer segments by household types and trip types implemented in the standalone car passenger transport model

Several plots in Figure 5 provide an orientation and basic data for the consumer segments based on the Swiss Microcensus (BFS, ARE, 2017). Plots A, B and C compare the relative share of household types from each aspect of the consumer segmentation and their related relative share of trip distances in several transport modes. This provides insights on the impacts from the consumer segment selection aspects for a relative over- or under-proportional use of cars and the most important public transport modes. It becomes apparent that almost half of the Swiss households are tenants, who may rely on public charging infrastructure (Bundesversammlung, 2021). Plot D visualizes share of trip distances, by pkm in all modes and vkm in cars. The long-distance trips in cars provide an indication for the need for rapid/fast public charging stations for BEVs. Plot E shows the hourly car driving patterns of one day for each consumer segment. Such hourly profiles facilitate defining the availability of vehicle for charging. The hourly profiles are implemented for each trip type and consumer segment. Plot F presents the distribution of trip distances for the key transport modes in Switzerland.

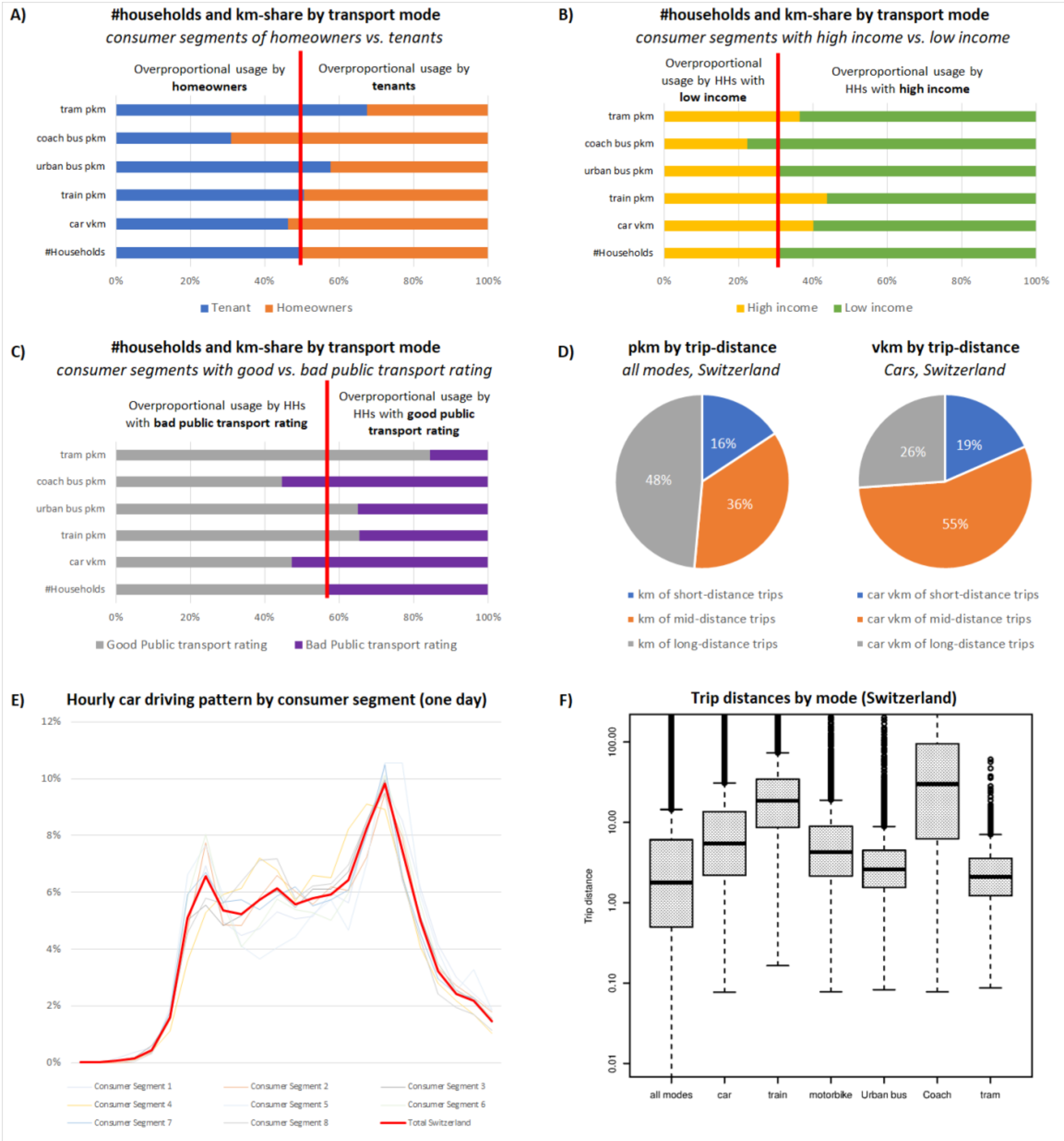

Figure 5: Basis for the consumer segments based on Microcensus (BfS/ARE, 2017)

Secondly, the electric charging infrastructure for cars has been further developed. Instead of one generic charging station in the previous version of STEM, three types of charging stations are modelled, *viz.*, home charging stations (6.6 kW), commercial public charging stations (22 kW), and rapid/fast public charging stations (150 kW). For each charging station, techno-economic parameters are updated, e.g., investment costs are based on Nicholas (2019); operating and maintenance (O&M) costs are based on ElectroSuisse (2015) and annual utilization rates are determined from PwC (2021). For each type of charging station, we have implemented the hourly usage patterns to reflect at what timings consumers charge their cars at the individual charging stations). The homeownership of consumers serves as a proxy for their parking spot ownership, which impacts the accessibility to installing home charging stations. Since tenants in Switzerland currently have few individual rights to install home charging stations, we assume tenants have only access to public charging stations (Element Energy, 2019 and

Celli et al., 2014). On the other hand, homeowners have access to their own private and public charging stations (PwC, 2021). Further, based on the daily trip distance, a certain level of range anxiety is proxied. For example, when BEVs are driven for long-distance trips, the battery needs to be fully recharged at rapid public charging stations. A schematic overview of the charging infrastructure is provided in Figure 6. Additional enhancements for linking the charging infrastructure to the various consumer segments and trip types are still ongoing in order to reflect more realistic use cases of charging infrastructure and its related fleet penetration of BEVs.

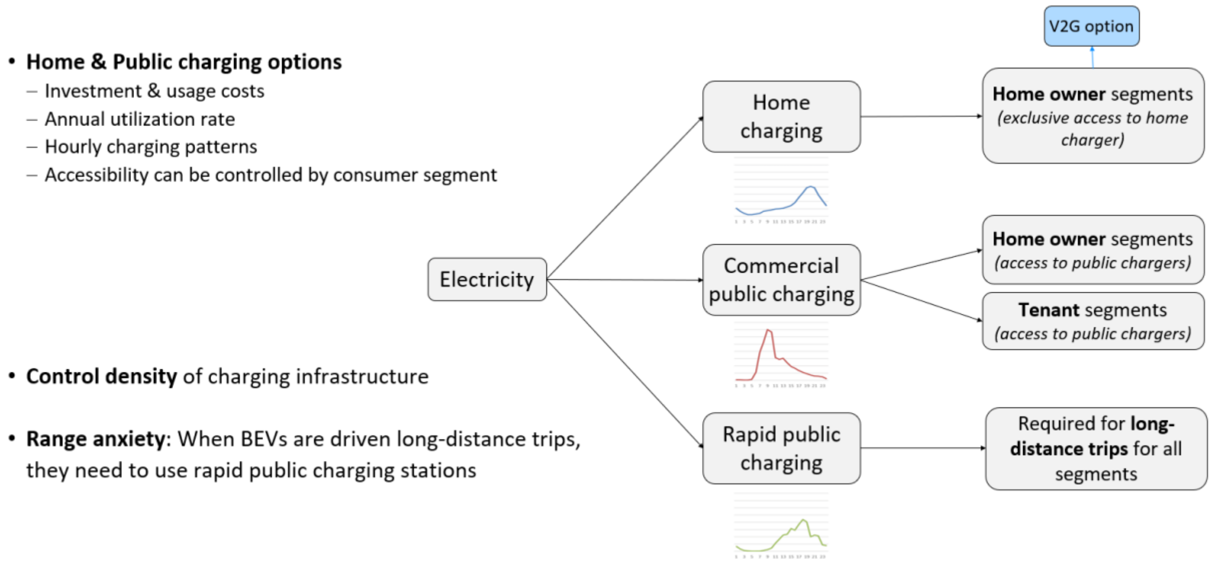

Figure 6: Schematic overview of electric charging infrastructure for passenger cars

Overall, the interaction of the individual categories in this enhanced version of the model has the purpose of being better suited for addressing relevant research questions regarding the build-up and usage of electric charging infrastructure, the investment and usage of electric vehicles, as well as modal choice. With the new model structure, i.e., revised consumer segmentation and enhanced electric charging infrastructure, we could also implement car investment decisions and driving patterns from the BedDeM model and thereby assess the energy system wide impacts of bounded rationality in personal mobility.

3.3 Development of model linkage interface

The steps 1-3 described in Section 2.5 have been implemented. In particular, a data exchange template has been established to facilitate data exchange between the STEM and BedDeM. It currently consists of data formats, units and an explanatory note on origins of data and the purpose/logic. A GIT repository has also been set up to allow automation exchanged, mainly through CSV files.

At the energy system level, STEM sends an update of energy and carbon prices for the years of 2015, 2020, 2030 and 2050. It also provides a starting fleets and segmentation of household in 2015. In BedDeM side, yearly updates are provided. As previous project, they include mobility demand (in term of vehicle kilometers) per trip and per STEM's segmentation (see section 3.2). With the new decision-making cycle, BedDeM aims to generate an updated set of car fleets, i.e., newly purchased and scrapped cars).

One iteration of coupling involves: STEM sending initial files for 2015. BedDeM processes this information and runs until 2020. STEM then calculates and returns the new set of data for BedDeM in 2020. The cycle continues until STEM finishing its analysis in 2050.

The two groups have performed two iteration tests (Step 4 from Section 2.5) in each period of 2015, 2020, 2030, 2040 and 2050. Their purpose is providing a sanity check of the data generated by the two models and allowing two teams to review their newly developed modules.

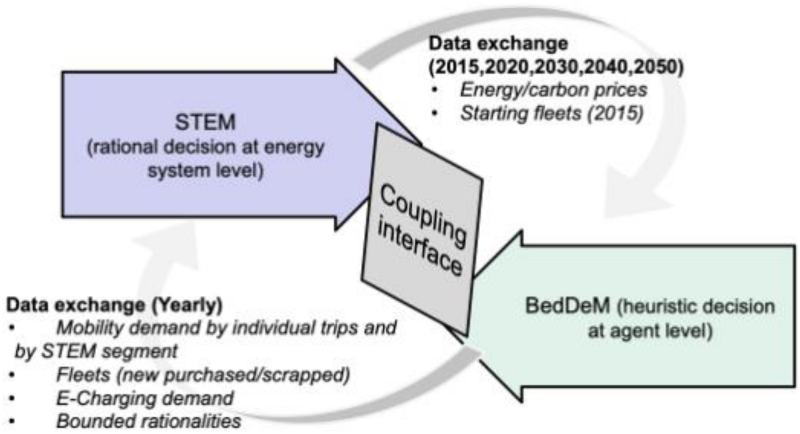

Figure 7: Overview of data exchanges for tight co-simulation of the two models

As for automation of exchanges (Step 4), currently, the communication for triggering exchange is mainly via email alert and subsequent manual order to carry out the computations. Data flow has been incorporated with GIT's functions. A full automation is envisaged for the next coupling stage, if required by the number of scenarios under consideration.

3.4 Synthesis of activities: milestones and deliverables

Until now, two milestones have been achieved: the instantiation of purchase decisions in BedDeM and the testing of data interface. Qualifying elements of the deliverable D1 (The evolution of economic models towards co-simulations) have been presented at the meeting with SFOE on the 21.09.2021. Deliverable D2 (Bounded rationality and its implications on the Swiss mobility system) is in preparation.

4 Evaluation of results to date

As anticipated in the initial project planning, larger parts of the work done in the first year of the project has been focused on deeper model integration, and model refinements, as it has been mainly outlined in the previous sections. As such, the amount of tangible results from the project is at the time of writing this report still limited.
However, the work on model enhancements, as well as model integration has been good progressed and is within the anticipated timeline and have been detailed above. It is foreseen that most of the

model enhancements will be finished by the end of the year, and calibration and extensive testing will follow afterwards.

In parallel to these technical developments the team has prepared the evaluation of policies by collecting and classifying policy interventions in regard of the different types of BR they take advantage of. In particular, the purchase of electric vehicles is subject to many opinions and uncertainties, providing a large potential for the application of policies oriented by bounded rationality. Information, visibility, experience shaping, price changes and other areas for policy interventions have been explored.
In this line of activities also the interactions with SFOE and the Advisory Board have allowed to streamline a number of possible evolutions of the project, with a clear priority given to the exploration of policies that can provide relatively quick results in areas where there is high societal innovation. Among others, it has been recommended for to the project team to broaden the scope of private mobility, to not focus to strongly on the perturbation rates of EVs, and instead to consider that the field of mobility is wider, and aspects like further promotion of means of public transport and forms of slow mobility, needs to be considered. The project team admitted that the option of “not buying” a vehicle is and will be always a valuable option of the decision making process, as it will also have different effects on the Swiss energy sector. It is envisaged that after this section is given due consideration, lessons for other parts of the mobility system (and also the overall energy system) can be highlighted.

Currently the process of analyzing options for different policy measures still continues and further selection of policy measures and remaining detailing them, in collaboration with SFOE and the advisory board is anticipated to happen in the next months.

5 Next steps

In the next phase, the convergence between technical and policy-oriented analysis will be advanced by the identification of the alternative designs, a system of simulations providing insights as for their differential effectiveness. This, together with qualitative factors, including a tentative assessment of feasibility, will lead to the final recommendations.

6 National and international cooperation

Although the project has a clear national and international value, the current year was rather devoted to internal developments, reserving to the next year – and possibly even beyond – its full exploitation in this direction.

7 Communication

External projection of the project must follow its results and so it would have been too early for communication activities.

8 Publications

The project has not funded publications this year. Two PhD are in preparation.

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