People-centric policies for decarbonization: Testing psycho-socio-economic approaches by an agent-based model of heterogeneous mobility demand*

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Abstract

Decarbonization has become a crucial issue for all countries in the world, which have varied targets and strategies to deal with it, especially after the Paris Agreement. Around one-fifth of global carbon-dioxide emissions is originated from the transportation sector. Policy changes and new regulations are planned to reduce such emissions e.g. by reducing the use of fossil-fuel private cars. For railways, supply-side policies involving large scale and long-term investment have dominated the debate. In this paper, we focus on people-centric policies that could be, in principle, faster and less expensive. To test the potential success of mobilizing demand for low carbon solutions, we have been developing an agent-based computational economics (ACE) model for many modal choices (including railway, bikes, private cars, etc.). It contains a large number of agents, with realistic operative parameters, environment, and infrastructure, reflecting in this study the Swiss system. In this paper, we focus on the railway system. A description of the Swiss world-class railway system is presented and the dynamics in the model, covering the demand for railway mobility as derived from psycho-social-economic approaches, are explored. Innovations in preferences, emotional attitudes and innovative swaps in non-technological resource shift the simulated use of the railway system. Carbon-dioxide direct emission levels are computed. Dynamic and heterogeneous demands of the agents are investigated along with several scenarios, some of them lead to significant decarbonization. We argue, after the simulation results, that railway demand increase can contribute to decarbonization strategies, including those possibly included in the next wave of Nationally Determined Contributions under the Paris Agreement. However, total decarbonization of the transport system will need to embrace further modes, such as e-vehicles and non-motorized transport.

Keywords: Multi-agent-based simulation, computational economics for policy-making, heterogeneous demand, demand-side policies, demand for innovative goods, diffusion of innovation, transport, climate change, decarbonization

JEL Codes: L92,Q54,Q41,Q55

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1 Introduction and operational definitions

In this paper we explore psycho-socio-economic approaches within an agent-based model to investigate whether heterogeneous demand for mobility can be shifted towards zero carbon modes (in particular, under certain conditions, the railway system) by help of people-centric policies. In their core, people-centric policies include every supported change in people decision-making processes and parameters, preferences, mental frames. They aim to change demand (and actually exchanged quantities) without changes in supply, neither in quantity or in quality. They are particularly suitable to impact collective transport, because in this sector, demand is often rationing the supply. For instance, in Switzerland, 67% of seats are empty in long distance trains and even more in regional trains. In the case at hand, people-centric policies aim to higher utilization of the existing carrying capacity. This can be achieved with no modification of timetable or of pricing structures and levels. The advantage for the railway operator would be then a higher revenue flows from passengers, possibly with an enlarged consensus in the population. As we shall see, people-centric policies can have a certain effect, which might be further enhanced by "soft" supply policies, including changes in pricing structures and alliances with other non-rail operators (e.g. bike-sharing schemes), without changes in the physical infrastructure.

To investigate the effectiveness of policies, we use an Agent-Based Modeling (ABM) approach. ABM is being used to inform decisions in many fields of practical importance e.g. [8, 10, 15]. In particular, we complement a Multi-Agent System (MAS) - a computational system consisting of multiple interacting intelligent agents within a dynamic environment - with a leading psychological theory of decision-making: the Triandis' Theory of Interpersonal Behavior (TIB) [45]. This modular and relatively extensive framework can offer a fair insight into the collective behaviors of individuals while shedding light to some real-life scenarios. As test case, Switzerland has been chosen, because of the availability of micro-data and a world-class railway system.

The immediate goal of the policies is to modify the level of use of a certain transport mode, while the overarching goal is the decarbonization of the sector. CO_2 emissions are core part of the overall greenhouse gases emissions (GHG). They are endangering the Earth climate system and its interaction with land, ocean, criosphere, which, in line with the UN Framework Convention on Climate Change, should be avoided. Decarbonization is the reduction of CO_2 in energy production and use (e.g. in transport), with total net decarbonization requiring that the residual emissions are compensated by negative emission techniques (currently not available within the transport system) [35, 17]. For a discussion of integrated policies pushing for co-evolution of demand, supply and regulation for the goal of total decarbonization see [30].

2 Related Works

Plenty of research aims to answer how to reduce emissions from the transportation (i.e. mobility) sector question by way of technological change approach [46, 23, 34, 39]. The main message of them is that total emissions from the transportation sector can be reduced in the long term by diffusion of new technologies e.g. e-vehicles. Schwaneen et al. investigate psycho-socio determinants e.g. habits that influence mobility behavior [40]. This research demonstrates that habits (frequency of past behaviors) are strong determinants for individual decisions. It mentions habit-breaking mechanisms to reduce car usage that leads to reducing emissions. It refers also to Triandis' model (TIB) as an explanation of interpersonal behavior that we use in our model. Kern and Rogge handle low carbon energy transitions as a whole (not only mobility) [19]. The main message of the paper is that if economic and technological steps can be supported by political, social and psychological aspects, the transition can be faster than expected. Sovacool presents an integrative framework of electric mobility transitions that contains four main components (motile pleasure, sociality, sociomaterial commensurability and habitutal momentum) which are synthesized from 15 decision making units of three different theories [41]. This framework contains both inter and intra-personal determinants which influence individual behavior. Some of the determinants are similar to Triandis' model that we followed in our model e.g. experience and habit, price value, social influence whilst some of them e.g. hedonic motivation are not. Chalabi et al. handle targeted and untargeted (spillovers) effects of behavior change of individuals by way of social networks [2]. They observe that change of a particular behavior (e.g. electricity usage) can influence other related behaviors e.g. travel behavior, what is called the untargeted effect. They also mention that family members and close friends influence each other more than other connections. This phenomenon called homophily can be reflected by social distances that we intend to include in our model when we implement social factors part of Triandis' model (one of our future work). The significant difference between this research and ours is that they perform an experiment with real individuals (volunteers) by way of interviews whilst we do with artificial agents. Our research, meanwhile, is in line with the emphasis on people-centric demand-driven policies such as those explored, based on an extensive multi-country empirical survey, in Moberg et al. 2018 [24]. Overall, there are no studies that use agent-based modeling as a methodology for investigating the affect of people-centric policies on decarbonization of the transportation sector. This piece of research aims to bridge this gap by experimenting with various people-centric policies with agent-based modeling.

3 The policy context

3.1 The Paris Agreement

The international Agreement on climate approved in Paris (2015) and entered into force on the 4$^{\text{th}}$ November 2016, ratified by Switzerland on 6$^{\text{th}}$ October 2017, commits parties to make ambitious commitments, regularly tracked and monitored, to collectively maintain the rise in average global temperature well below two degrees Celsius, with the aim of limiting to 1.5°. In particular, a first round of Nationally Determined Contributions (NDCs) has been submitted, mostly before and some after Paris[1]. There will be soon a second round of NDCs, following the IPCC Special Report on 1.5° impacts and pathways [17] and the Talanoa dialogue, whose technical part has begun in Jan 2018 and whose political part takes place in COP24 in Katowice (Poland). They will need to be characterized by significantly higher ambition, in line with long term goal of net zero emissions (a necessary, although not entirely sufficient, condition for the stabilization of temperatures) [35].

3.2 The state-of-art of the role of railway in official decarbonization trajectories under the Paris Agreement

For a transport system that is one of the most difficult industries to decarbonize [17], and that generates more than 20% of total emissions [51], many solutions have been proposed, from non-motorized transport to electric vehicles powered by zero-carbon sources[2]. The railway system may in principle play a very important role[3]. This possible role is largely due to the high degree of on-grid electrification, to the high efficiency of using metal "tracks", to the broad capacity (1000+ passengers per train) [37]. Indirect emissions depends on how the electricity is produced and distributed. Such advantages and even more as for safety and green economy have consistently been underlined and embedded in many policy-oriented documents by UIC [47, 48] and by the COP22 Global Climate Action [13].

This potential has been only in part actually utilized by policymakers in their climate commitments (NDCs). The word "railway" is used in such documents only by 15 countries, including India, Japan, Egypt, Ethiopia, Turkey, Switzerland, Bahrain, Tanzania, Mozambique, Argentina, Bolivia (source: our analysis and [22]). It should, however, be noted that many developed countries, including EU,

[1] http://www4.unfccc.int/ndcregistry/Pages/Home.aspx

[2] For scenarios for transport sector decarbonization of each country in the world compatible with 1.5° Threshold Peak Carbon Budget see [28].

[3] We do not consider here the role of railway in adaptation to climate change (UIC, 2017).

World region	Rail passenger traffic (in billion passenger kilometers
Asia / Oceania / Middle East	2195.0
Europe	463.5
Russia	124.5
America	27.5
Africa	23.0

Table 1: Rail passenger traffic [42]

US, South Korea did not make specific sectoral commitments but rather an economy-wide commitment (e.g. -40% for EU; -50% for Switzerland). From the textual analysis of the above-mentioned 15 NDCs, current commitments cover issues like “modal shift to railway”, “increased share of railways passenger transport”, “increased use of railway”, “energy consumption efficiency improvement of railways”, “improvement for Coaching Service Locomotives”, “installing solar power on (railway) land and roof tops of coaches”, “the renewal and improvement rail infrastructure and incorporation of technologies and services that contribute to the modernization and efficiency of the railway public transport system”, “electrification of railway lines and the transition to alternative current system in traction, improvement and expansion of the scope of intellectual transport management system”, “developing and implementing climate change compatible building/construction codes for ...railways, bridges”, “investments in air, railway, marine and road infrastructures”, and new lines (e.g. the GCC Railway project), including by “realizing high speed railway projects”.

The next wave of NDC could contain many more commitments towards zero carbon transportation, including non-motorized mobility and renewable-powered [7] electric vehicles and railway. This would occur in a global context characterized by a very uneven actual use of railway, as evidenced in Table 1.

3.3 The supply side debate on railways

As seen by the textual analysis of the NDCs, in the railway system, a major emphasis is placed on supply and technical issues. For instance the construction of new lines is the focus in many developing countries. This is not a low-hanging fruit. The cost per km is much higher than for road, and the immediate effects on the economy may be lower (which explains why many politicians fight for new roads in their electoral districts). Upgrading the existing road networks is financially de-coupled by new road vehicles (which mostly are purchased by businesses and households), while railway need to be furbished with further trains from the same (usually public) budget.

Conversely, Transit-Oriented Development (TOD) that attributes building rights in proportion to the distance to stations (with high density in the immediate proximity to station) is a way to structurally assure the financial sustainability of the infrastructure and of the service. At an extreme, the cost of the station is shifted to building companies getting building rights in the proximity, as it happened in Tiburtina Rome station and is common in Hong-Kong metro stations [21, 49].

However, even where density provides a distinctive advantage to collective transport, this is easily dissipated in rents. The monopoly position of many railway companies may lead to organizational disadvantages (higher employment than efficiency would dictate, rigidities in the deployment of people and technologies, etc). Railway companies usually work at a loss, compensated by state subsidies. In turn, cuts in public budget to rein in deficits may hinder further investments, especially if current subsidies are mainly used to pay for the workforce. In certain countries, well organized and powerful unions may focus on stability and wages instead of financial capability of company’s investment.

The technological advancement in this transport mode has been directed towards higher speed, which means higher energy consumption. The pervasive substitution of steel with aluminum and plastics, with new vehicle designs resulting in much lower weight and significant fuel consumption savings, that took place in automotive has yet to materialize in the railway production: "whilst in other sectors innovations in materials provide steady improvements, the majority of railway systems continued to be based on traditional materials" [32].

All this said, this paper and our model takes another path. We cover demand side policies, since we are interested to find out finding upon which conditions railway services have larger use, given the same infrastructure (lines, tunnels, etc.), the same train endowment and deployment (thus the same indirect GHG emissions).

In particular, the paper explores `people-centric` policies and `soft` supply policies:

- advertising, which is intervening in every stage of bounded rational decision making processes, well beyond mere information to cover emotional attitudes [29], which would be fostered by the implementation of an overall policy of free advertising for green goods and services [30];
- swaps in non-technological resources, including yearly free tickets and subscription in exchange for driving licenses;
- alliances with other operators, complementary to provide a door-to-door fast and effective solution to passengers.

In so doing, we provide an original point of view, since we could not find policy-oriented studies with models allowing for testing this people-centric perspective with disaggregated demand at agent level. In particular, we utilize empirical data from a specific country (Switzerland), in which the case for a railway contribution to decarbonization trajectories is particularly strong, since the electricity used by railway operators is mainly from hydro-power, in a context of very low CO2 intensity of the national electricity mix. Conversely, the study is not about reducing emissions within the railway system, but rather about what might be effective in modal shift. A distinctive advantage of utilizing an ABS for this purpose is that we specifically identify which mode is substituted e.g. by rail (at each trip level), without assuming symmetries (as it happens with multi-logit models) and we do not need aggregate and homogeneous elasticities to prices or to other parameters, fully recognizing the individual heterogeneity of agents.

4 Description of Swiss railway system

The Swiss rail network has high density despite rigors of geographical conditions (Swiss Alps cover 65% of Switzerland's total 41,285 square km of surface area). It is in a very good position in terms of utilization: with average 2.500 km traveled person per year [5]. Also, it is almost fully electrified. Around 74 railway companies operate in Switzerland [6]. The largest one is the Swiss Federal Railways (SBB in German)[4], which became a fully state owned limited company in 1991 and dominates the market. Companies other than SBB operate only in specific regional, urban and touristic areas - sometimes in cooperation with SBB - e.g. BLS[5]. Their services might be purchased via SBB mobile app, website or shops. So, there is no direct competition but cooperation among the companies.

In general, there are three main determinants that used to measure performance of railway networks:

- intensity of use,
- quality of service,
- safety.

[4] Official website: www.sbb.ch
[5] Official website: www.bls.ch

According to the 2017 European railway performance index, Swiss rail system remains the best of the all covered countries. This result is not new, since it was present also in previous years. Switzerland has the highest intensity of use ranking in the world [3]. Almost 20% of total travels are performed by railway (20.8 billion person-km in 2017). Optimized synchronization of Swiss railways boosts intensity of use. People who need an extra transportation mode in addition to train e.g. bus, funicular, etc., for rural destinations, do not wait long time in station due to synchronized timetables. Railway is very well-connected with bus companies e.g. CarPostal[6] that serve rural towns where no railway station exists [31]. In the same index [3], safety and quality of service were measured "good" and "very good" respectively. Around 89% of total trips were punctual in 2017 [36]. Since punctuality is a determinant of quality of service [3], this ratio affects quality of service positively. Conversely, other determinants e.g. speed of trains and average fare per km, affect quality of service negatively, since speed of Swiss trains is slightly lower and average fare per km is higher than neighbor countries e.g France, Germany.

Public cost in Switzerland (total amount of investments and subsidies) for railway is quite high compared with other countries [3]. The state aims to the increase of demand. According to statistics, person-km per railway has increased by 65% since 2000 while total person-km (all mobility modes) increased by 30% [5]. But it is mostly due to supply-side policies (e.g. opening new tunnels). Despite the demand growth, in long distance trains, 67% of seats are still empty whereas in regional trains this percentage goes up to 82% [37]. There is still a big room for the improvement of demand. People-centric novel approaches can play a role in this point without changing available excellent supply.

SBB offers specific travel-cards e.g. GA to boost intensity of use. GA travel-card (General-abonnement in German[7]) provides unlimited travel opportunity in Switzerland for one year including all transportation modes for free, in exchange of a substantial fixed fee. Around 10% of Swiss population have a GA. Half-fare travel-card (Halbtax in German) provides a 50% deduction for all public transportation trips, in exchange for a minor yearly fixed fee. 36% of Swiss population have half-fare card. Apart from these two major travel cards, there are point-to-point or modular travel-cards which provide unlimited travel among specified origins and destinations.

5 Methodology - Behavior-Driven Demand Model (BedDeM)

The goal of this piece of research is experimenting effect of people-centric policies on railway demand and consequently on emissions originated from the mobility sector. Agent-based modeling (ABM) is utilized as a methodology. It is considerably useful to reflect heterogeneous individual behaviors as well as environmental and demographic attributes. It functions like a melting pot where various disciplines (e.g. sociology, psychology, computer science) blend together as one. Thus, agent-based models can be used as artificial laboratories for in silico experiments of real-case studies. Through a calibrated and validated agent-based model, future scenarios/policies can be explored before implementation. As a case study, we are currently undertaking modeling heterogeneous mobility demand by an agent-based model called BedDeM (Behavior Driven Demand Model). In the next sub-sections, the model is explained detailedly.

5.1 General features

To have a tool for addressing these and other potential issues, we are developing a social simulation platform, built on the key theoretical tenets of multi-agent cognitive system, in which individual agent is capable of making psycho-socially sound decisions and takes into account both objective and subjective elements (e.g. weight for evaluation criteria of alternatives).

The core element of the platform is a agent based simulator, written in Java with RePast library [33], complemented by key concepts from Triandis' Theory of Interpersonal Behavior (TIB), described

[6] Official website: www.postauto.ch

[7] https://www.sbb.ch/en/travelcards-and-tickets.html

below at 5.4. This promotes communication with scientists from diverse research backgrounds (computer scientists, economists, psychologists etc.) about different scenarios of our model.

5.2 Mobility related features

The model allows for modal choices for mobility trips based on price and non-price signals, implementing approaches not only from economics but also from psychology and sociology. This platform has the ability of generating yearly data that can be interpreted at the granularity of an historical evolution of mobility, which largely hinges on aggregate kilometers traveled and emissions produced by mode, including possible decarbonization trajectories. In this study, by using real Swiss data about people and territories, the platform can produce statements about Switzerland transportation and the behaviors of its households. It currently generates individual and heterogeneous mobility demands of agents (i.e. with which mobility mode they perform their trips). These demands are accumulated to obtain macro-patterns (along with total kilometers) over which the model is calibrated [26].

BedDeM models individuals (i.e. demand side), not companies offering mobility services (nor intermediaries between purchaser and producer, nor financial institution supporting the investment needed by companies). Accordingly, description of the supply is simplified, as for what is necessary for the individuals to take their decisions. For instance, availability of bus is assumed in certain geographical area and the demand may choose to make certain distances by bus (which in turn assumes that the bus service is supplied). Our current model covers not only demand issues but also issues that assume properties of the supply (e.g. the price and the speed of a mode). BedDeM contains two main components, BedDeM configurator and a simple event-driven agent-based simulator. In the post-processing phase, the results gathered during the action of the simulator are analyzed. In the following sections, they are introduced briefly.

5.2.1 BedDeM Configurator

The role of BedDeM Configurator is obtaining input data from data sources and profiling the data if needed. Raw input data is processed and passed to the agent-based simulator as arguments that are used for the model building. This step is called pre-processing. Scenario attributes that outline various details of model e.g. agent attributes, time series, are determined in the pre-processing phase. All processed micro and macro data are provided to the simulator for describing the characteristic of model components and also for agent and environment creation.

5.2.2 The Agent-based Simulator

We have created a simple event-driven agent-based simulator using RePast framework for BedDeM. It consists of 3 main components: controller, agents, environment. From the input of the configurator, the controller generates a number of agents and their locations (the Swiss cantons). The controller then schedules the agents according to their list of activities (ordered by time) and starts the simulation. At the time of action, an agent takes a decision about which mode of transportation to use and sends this information to the environment to update the result.

As mentioned above, the decision-making occurring at the agent level is based on Triandis' Theory of Interpersonal Behavior (see 5.4). It makes use of both exogenous constraints (e.g. availability of modes, prices and time required) and an internal state of the agent (e.g. feelings about a mode, frequency of previous usage). The results of this process are probabilities, each of which can be interpreted as the likelihood of the agent chooses a particular transportation mode.

5.3 The empirical data used in the model

Two qualitative data sources, a census (Mobility and Transport Microcensus - MTMC [43]) and a survey (Swiss Household Energy Demand Survey - SHEDS [44]), were joined to obtain a final input data-set to model mobility demand [26]. The MTMC is mainly utilized to obtain socio-demographic attributes (e.g. age, income level, household size, canton, municipality type, education level, etc.) while the SHEDS is used for psycho-social values (e.g. environment friendliness, mobility preferences, habits, emotions, etc.) to map the decision-making mechanism of agents. A detailed description of how to map the survey data to the decision-making mechanism can be found in [26]. Thus, agents in the model represent the real respondents (i.e. from the data sources) by having all their attributes. Except for agent characteristics, the MTMC is utilized for the territorial structure of the country, including the differentiation of urban and non-urban areas according to a 9-item typology is reflected in the availability of different modes (e.g. not all areas have tram or railway stations).

5.4 Agent's decision-making mechanism

5.4.1 Towards human psychology

In psychology, there are different branches that offer explanation for people's actions, including the Five-Factor Model of *Personality* [10], *Behavior genetics* [12], *Social psychology* theories [16, 18, 20] etc. Since what we aim to simulate is the effectiveness of policies on society as a whole, social aspects leading to decision-making are our main focus in this study.

In rational-choice domain, many theories in schools of cognitive model have tried to describe this process, e.g. Ajzen and Fishbein's Theory of Reasoned Action (TRA) [9] and Ajzen's (1991) Theory of Planned Behavior (TPB) [1], etc. They state that the key determinant of behavior is an individual's intention to perform a specific act. There are several agent-based models which have attempted to incorporate these theories [38].

Harry Triandis [45, p. 8] went beyond these theorists in his tri-level TIB model (see Figure 1) by adding habits and the presence of facilitating conditions that either enable or hinder the performance of a particular behavior. He stated that interpersonal behavior is a multifaceted and complex phenomenon, due to the fact that in any interpersonal encounter, a person's action is determined by what that person perceives to be appropriate in that particular situation and by what others pressure them to do, the extent to which the individual enjoys or dislikes it. The entire social setting, including aspects of an individual's personality, has the power to influence and modify interpersonal relations. TIB includes all aspects of the TRA and TPB models as well as additional components that potentially add to its predictive power, namely habits, facilitating conditions and affect.

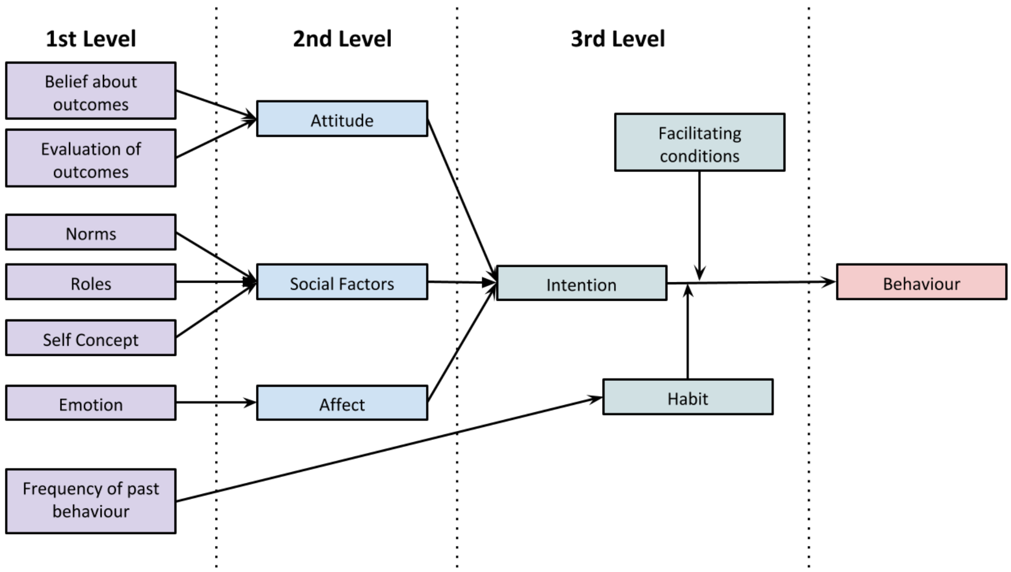

Figure 1: Triandis' model [45].

Although there is no concrete proof on which theory is more suited for the application of mobility domain, Triandis' theory is chosen for our study since it provides more comprehensive understanding as to what determines behavior and is useful in explaining complex human thought processes. This would be valuable when presenting our platform to other discipline's scientists as our set of default parameters will come from Triandis' model.

5.4.2 Agent decision-making architecture

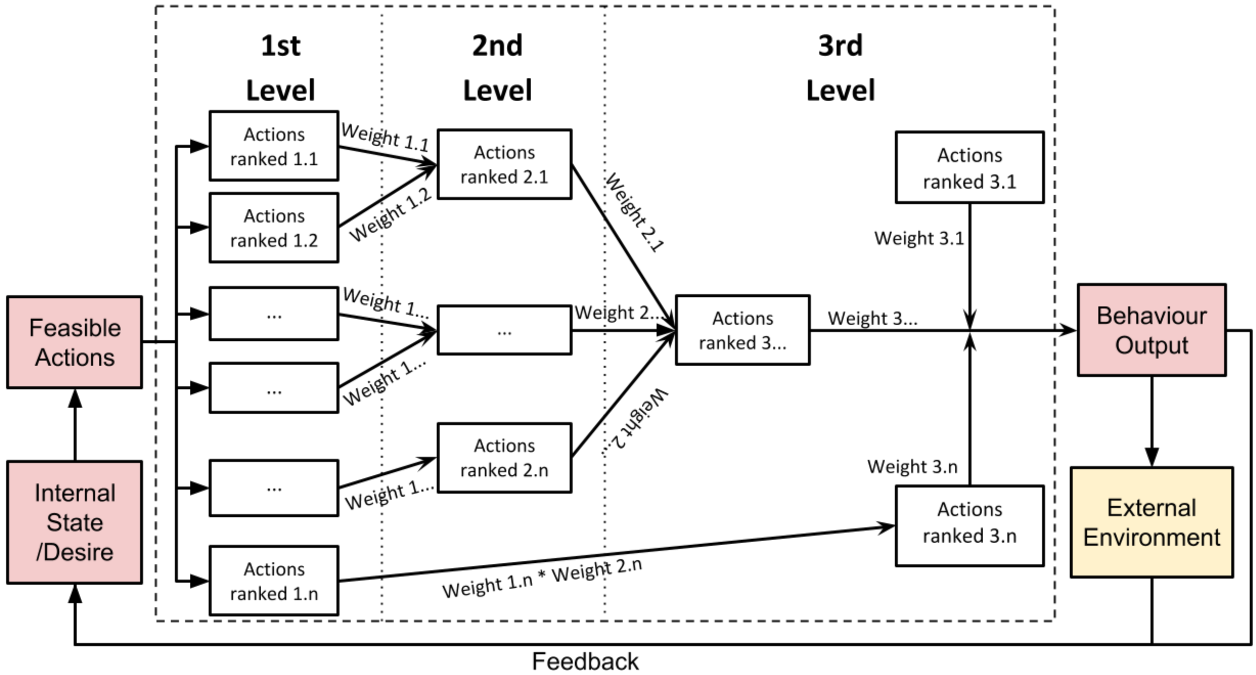

Figure 2: New agent architecture with mapping to Triandis' model.

Our agent decision-making architecture (see Figure. 2) is based on a combination of horizontal and one-pass vertical layered architectures [50, chap. 5.2]. An agent first selects an isolated decision-making task from the list that is sequentially executed. Its personal desire/goal is then combined with means provided by the external environment to generate a set of possible options. For all determinants (d), each option (opt) is given a referenced value which comes from comparing its property with other's ($R_d(opt)$). In the first level, this can be done using either a real numerical system (for determinants such as price or time) or ranking function (for determinants such as emotion). Both can be derived from empirical data (e.g. census/survey) or calibrated with expert's knowledge/stakeholder's assessment.

The results for these determinants are then normalised and multiplied with an associated weight (called w_d); the sum of which becomes the referenced value for the option in the next level (see Equation 1 below). The weight, in this case, represents the importance of a decision-making determinant compare to others at the same level and emphasises on the heterogeneity of individuals. It also allows the modeller to express a certain theory by cutting of determinants (by setting their values to 0) that are not relevant to a case study. The combination process then continues until it reaches the behaviour output list; the referenced value of which can be interpreted as the probabilities that an agent will perform that option. If the agent is assumed to be deterministic, it can pick the option that is correlated to best-evaluated value.

<table>
<tr><th>1st Level</th><th>2nd Level</th><th>3rd Level</th><th>Behavior Output</th></tr>
<tr><td>Evaluation - Price

w = 2
R(Numerical data - Swiss Francs per a 10 km trip - car price linked to the type of car, its consumption and the price of fuel) =
Walking (0), Train (2.0), Car (4.0)</td><td rowspan="2">Attitude

w = 4
R =
Walking (0/6*2 + 2/2.7*4 = 2.96),
Train (2/6*2 + 0.5/2.7*4 = 1.41),
Car (4/6*2 + 0.2/2.7*4 = 1.63)</td><td rowspan="6">Intention

w = 3
R =
Walking (2.96/6*4 + 2.83/9*3 + 3/6*3 = 4.42),
Train (1.41/6*4 + 3/9*3 + 1/6*3 = 2.44),
Car (1.63/6*4 + 3.17/9*3 + 2/6*3 = 3.14)</td><td rowspan="7">R =

Walking (4.42/10*3 + 2/6*2 = 1.99),
Train (2.44/10*3 + 3/6*2 = 1.73),
Car (3.14/10*3 + 1/6*2 = 1.28)</td></tr>
<tr><td>Evaluation - Time

w = 4
R(Numerical data - Hour) =
Car (0.2), Train (0.5), Walking (2)</td></tr>
<tr><td>Norm - Environmental Friendly

w = 2
R(Ranking) =
Walking(1), Train(2), Car(3)</td><td rowspan="3">Social Factors

w = 3
R =
Walking (1/6*2 + 1/6*3 + 3/6*4 = 2.83),
Train (2/6*2 + 2/6*3 + 2/6*4 = 3),
Car (3/6*2 + 3/6*3 + 1/6*4 = 3.17)</td></tr>
<tr><td>Role - Environmental Friendly

w = 3
R(Ranking) =
Walking(1), Train(2), Car(3)</td></tr>
<tr><td>Self-Concept - Environmental Friendly

w = 4
R(Ranking) =
Car(1), Train(2), Walking(3)</td></tr>
<tr><td>Emotion

w = 3
R(Ranking) =
Train(1), Car(2), Walking(3)</td><td>Affect

w = 3
R =
Train(1), Car(2), Walking(3)</td></tr>
<tr><td>Frequency of Past Behaviour

w = 2
R(Ranking) =
Car(1), Walking(2), Train(3)</td><td></td><td>Habit

w = 2
R =
Car(1), Walking(2), Train(3)</td></tr>
</table>

Table 2: Numerical example of an agent's decision-making

$$R_d(opt) = \sum_{c=1}^{C} (R_c(opt) / (\sum_{o=1}^{O} R_c(o)) * w_c) \tag{1}$$

where • $R_d(opt)$ is the reference value of an option (opt) at determinant d.
• C is the set of the children of d (i.e. determinants connects with d in the previous level).
• O is the set of all available options.
• w_c is the weight of child determinant c.

A numerical example of an agent making a decision to use a transportation mode can be seen in Table 2. For simplicity's sake, let's assume that there are 3 options available: walking, using car or taking train for a working trip of 10 kilometres distance. As the agent has automatically filter out all transportation modes that are unavailable, we are not considering the factor of facilitating conditions in this case. All determinants are organised into layers according to TIB (see Figure 1). As mention above, the reference values of the 1st level are obtained for statistical data source (e.g. evaluation - price, time) or personal preference (e.g. self-concept - environmental friendly). For 1-1 mapping, i.e. emotion - affect and frequency - habit, values are then copied directly to the next level. Equation 1 is then used to calculate reference values for the remaining determinants. From the final values at the output level, we can interpret that the agent's preference for this trip is Car (1.28), followed by Train (1.73), then Walking (1.99).

5.5 Agent specification

5.5.1 Calibration

As mentioned in Section 5.4.2, the decision-making architecture requires 2 elements to calculate the probabilities for a set of options: (1) how to specify a ranking order of the option according to a determinant ($R_d(opt)$) and (2) the weight of the determinant (w_d). For this purpose, we utilise the Swiss Household Energy Demand Survey (SHEDS) [44]. There are several questions that compared the criteria for mobility mode choices, which answer can be interpreted as the weights(w_i) for different psychological determinants in TIB. A typical example is "Please rate how important the following aspects are for choosing this mode of transportation (from 1 to 5) - •Choosing the cheapest option; •Travelling as fast as possible, etc.". A large number of similar questions can be categories into TIB determinants. However, as the first step into this experimental design, we decided on a mapping of a smaller set, which is presented in our recent paper [26]. We then parameterize the mobility profiles to build a synthetic population. This is accomplished by utilising another data source - the MTMC [43]; details of which can also be found on [26]. Individual demands that the model generates are accumulated to obtain macro-patterns (along with total kilometers) over which the model is calibrated [26]. They should be consistent with real (empirical) data sources. For instance, around 22% of trips in Switzerland are performed by train (yearly) [43]. It should be reflected in the macro-patterns that the model generates. Calibrated model generates macro patterns, which are in line with the empirical data. Detailed information about the calibration process can be found in our recent paper [26].

5.5.2 Structure of social interactions

BedDeM allows agents to interact and to learn (i.e. social learning) from each other. To activate this part in the decision making mechanism, a social network which conceptualize the social structure, is created. The network depicts the distributions of a population among different social positions in a multi-dimensional social space (i.e. latent space) that determines and affects agent's relations with one other. Basically, through socio-demographic features (e.g. income, age, location, etc.), agents are placed in a latent space (multi-dimensional social space), whereby interactions occur. Basically, agents with similar characteristics stay closer in the space, so-called homophily. To represent the latent space, a symmetric socio-matrix (see Fig. 3) is created that includes all pairwise distances/dissimilarities (social correlation). According to a question in the SHEDS survey that observes susceptibility to be influenced by various actors e.g. neighbors, heterogeneous thresholds are assigned to agents. These thresholds, which are normalized and scaled between 0-1 as pairwise distances, draws borders of social reach of agents. If the distance between agent A and B (in the socio-matrix) is less then these A's thresholds, a one-way relationship is constructed. Thus, the thresholds help to transform the socio-matrix to a sociogram that reflects networks of interpersonal relations (see Fig 3). The distances are transformed to dichotomous variables in the sociogram that illustrates the social network of agents.

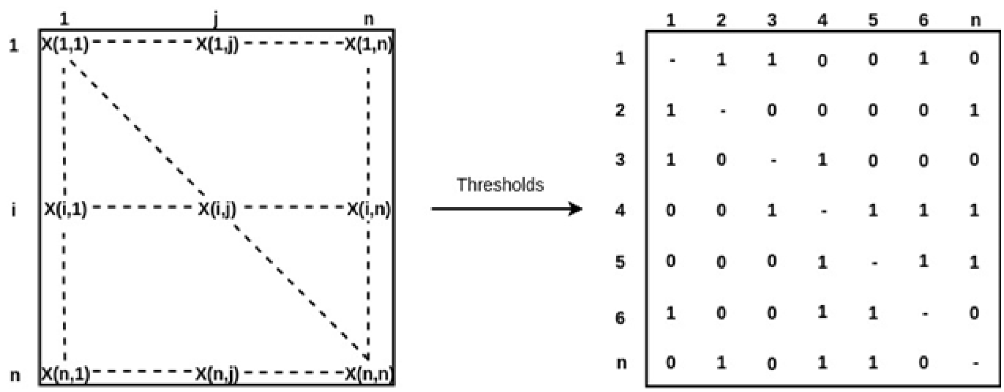

Figure 3: Usage of the thresholds to transform the socio-matrix to the sociogram [45].

When the decision-making take place, agents execute all steps of the TIB architecture as explained in the previous section. When execution comes to the social factors step, agents, first, control the created sociogram. They find the influencers in their social reach. In other words, they find the other agents (neighbors) who have a direct relationship with them. Then, they receive their neighbors' preferences (lists with ranked modes). Therefore, neighbors' (people like me) actions/preferences play a role in the decision-making with respect to its weight in the overall decision-making mechanism. Agents don't imitate directly such as direct copying the neighbors but consider their decisions. Therefore, other parts of the decision-making mechanism (e.g. emotions, evaluations) still involve the decision-making mechanism.

5.6 Current limitations of the model

The model is undergoing improvements over time. In the current implementation, the following limitations apply:

1. the years covered by the simulation are from 2018 to 2030, with the first year being calibrated to real data referring, however, to years 2015-2017 depending on the actual dataset used; this allows us to use the latest available data (even if not referring strictly to the same year) and avoid "nowcasting" [11];
2. fossil fuel vehicles are combined, with no internal distinctions across gasoline, diesel and gas (also we not not distinguish non-renewable from renewable sources, like biogas or biodiesel);
3. substitution of vehicle fleet is not implemented, so technical features and emission factors of vehicles do not evolve over time;
4. foreigners and cross-border workers are not included in the analysis;
5. freight is not included;
6. the territorial details of the model is the crossing value of canton and types of municipality (e.g. large agglomeration); however robust results with an acceptable level of confidence are produced only at the marginal values of either canton or types of municipality and, even more, for Switzerland as a whole;
7. the territorial detail of the model has not led to explore whether the specific increase of demand in a certain time in a certain location is compatible with current supply, in the context of the overall occupancy rate;
8. as for GHG emissions, we consider only CO_2 and not the other gases;
9. agents take their decisions in a deterministic way while we intent to have version with stochastic decision making;
10. in the experimental design, we do not perform sensitivity analysis.

6 Simulation and experiment design

As explained in the previous sections, despite high intensity of use and occupancy rate, around three-fourth of total seats of the Swiss railways are still empty. This piece of research investigates how the demand can be increased without any change on an already excellent supply side (e.g. no new infrastructure). Its main goal is implementing people-centric policies to boost demand. To this end, different scenarios are defined. Each scenario contains a novel policy, which aim to change certain individual attribute. The policies are implemented to the reference scenario, as described above, for a part (2018-2030) of a time-series which is set to the 2018-2050 interval[8]. Basically, policies are implemented until 2030 after which the effect of canceling policies is aimed to be observed. An important note about the use of the term "policy", for which we do not mean necessarily a government intervention: we define it as a widely distributed change in agents' parametres and features, whose effectiveness is directly computed within the model but whose origin is exogenous, conceptually linked to the action of non-modelled agents, such as companies, non-governmental organizations (NGOs), the academy, etc.

[8]The model is particularly flexible in terms of policy impulsed: it allows for the application of policy in different years, interruptions and combinations of the policies together

6.1 First policy - Increasing positive emotions towards railway usage

Empirical results show that emotions are important determinants for decision making [4]. Human mobility behavior is influenced by psychology. Attributes like monetary cost, speed, or availability of transportation do not sufficiently enough to depict mobility behavior [14]. Psychological attributes such as habits and emotions are relevant for modal-choice as well. In this policy, the goal is increasing positive emotions towards railway usage. TIB architecture followed by our model allows for their inclusion, as the only determinant of affection (second level). As we can see in Table 2, agents rank available mobility modes according to reference values. For emotions in the 1st level, the reference value reflects comfort of modes, which are time and cost for the evaluation part. Basically, each mobility mode in the model (e.g. private cars, railway, soft mobility modes, etc.) has a reference value for comfort. Thus, agents can rank available modes according to these values in emotions part of the decision making mechanism as explained in the example (see Table 2). Then in the next level, emotional rankings are merged with other determinants according to its weight (i.e. importance)(see Section 5.4.2). As explained before, weights of each determinant are mapped directly from the empirical data [26]. In this policy, we experiment how would be the consequences if 5% of the agents perceive railway more comfortable than other modes (i.e. positive emotions towards railway usage). To this end, reference value for comfort of these 5% of the agents is increased. Without any change in its weight that we map from the empirical data, we allow 5% of agents to perceive railway more comfortable. In overall decision making mechanism, importance of emotions (i.e. weights) stay steady as in the reference scenario. This allow us to experiment consequences of changes in emotional preferences (rankings) in the overall decision making mechanism.

6.2 Second policy - Increasing the importance of time in agent's evaluation

Besides psycho-socio determinants (e.g. emotions, habits), agents evaluate mobility modes based on the reference values from empirical data; price (i.e. cost) and time (i.e. duration, which is related to the speed of modes). This evaluation takes place in "evaluation about outcomes" part of the decision-making mechanism (i.e. TIB model). Agents rank available mobility modes based on their time and price (for a particular trip). Then, they are combined with other determinants according to heterogeneous weights that we map from the empirical data. For instance, one agent might prefer the fastest option (i.e. does not care the cost), while other one tries to keep a balance between them. In this policy, we experimented what would be the consequences if 5% of the agents increase the weight of time in the decision-making. Rankings (i.e. reference values; time and price) do not change as in the previous policy (i.e. speed and cost of modes stay steady). But importance of time in the overall decision making mechanism, which is its weight, is increased.

6.3 Third policy - Swapping driving licenses of older people (65+) with GA travelcards

Some studies have found a link between age and risk of accident [25]. Since neuro and tendon reflexes weaken by time, elderly drivers might become dangerous for other drivers. Therefore car insurance premiums for them are higher than for others. Under this simulated policy, driving licenses of voluntary elderly people are swapped with free GA[9] travelcards. This is not a mandatory but a voluntary swap. So, we assume that 8% of elderly people have the willingness to change. Hence we experiment how would be the reflections of this swap on mobility demand and consequently emissions. Laterally, if this will produce a reduction in use of car, one might infer that there will be also a fall in accident risk (not modeled).

[9]www.sbb.ch/en/travelcards-and-tickets/railpasses/ga.html

7 Results of simulation

The reference scenario without policies assumes the demographic trends as issued by the Swiss Statistical Office (BFS) and the price projections as described beforehand [27]. In the reference scenario, kilometers made grow, basically because of demographic reasons (see Fig. 4), for all modes: railway, private cars, tram and bus - called collectively Urban in the figure, walking and bikes - collectively called Non Motorised (see Table 3).

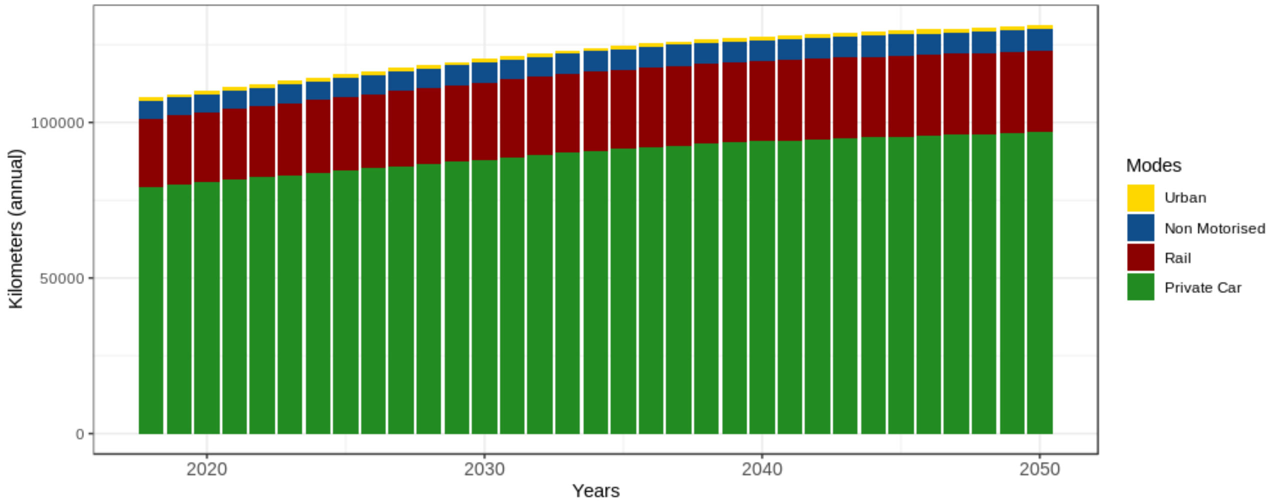

Figure 4: Total kilometers at national level according to the reference scenario (*kilometers in the y-axis are million kilometers)

Population growth varies according to cantons. So, percentage of total km increase varies for different cantons (e.g. in Zurich higher than Bern). Since there is no large-scale modal shift and the vehicle stock is static, direct emissions - generated only by non-electric motorised vehicles (buses and cars) - grow as well (see Fig. 5).

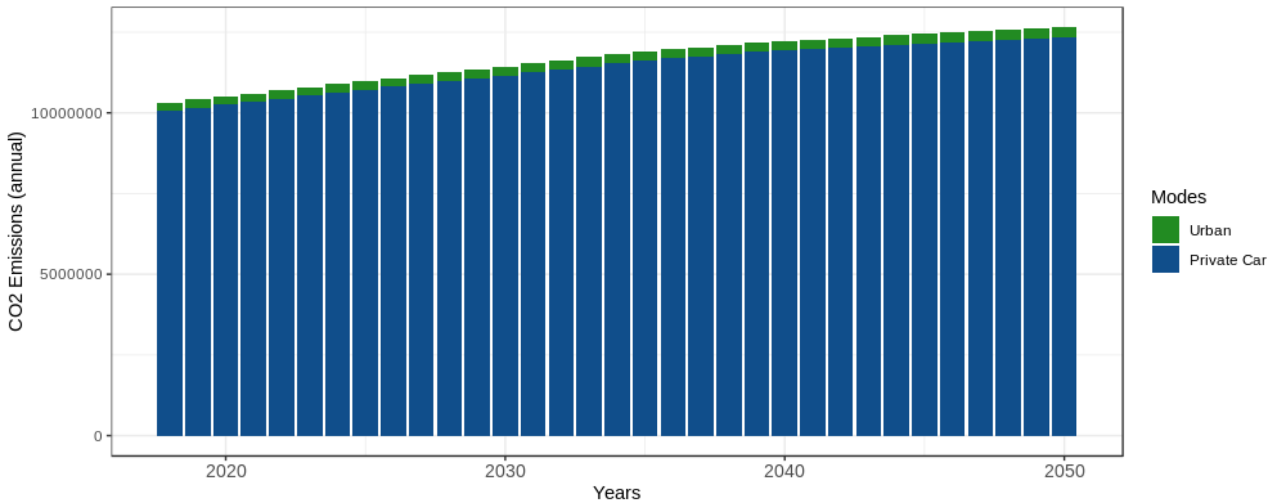

Figure 5: Direct CO_2 emissions in the reference scenario (*emissions in the y-axis are ton/km)

In case of adoption of the first policy, there is a substantial increase of railway usage, mainly substituting cars (see Fig. 6). As each year 5% of agents improve their emotional judgment towards railway, usage of railway increases significantly. Basically, 5% of agents each year perceive railway more comfortable than car (i.e. emotion increase) while importance of emotions (i.e. weight) stay steady. It shows us that individuals do not only care cost and time, but also emotions. Although railway is more expensive than private cars for particular individuals (e.g. non GA owners), due to emotional improvement, there is significant number of churners who shift toward railway.

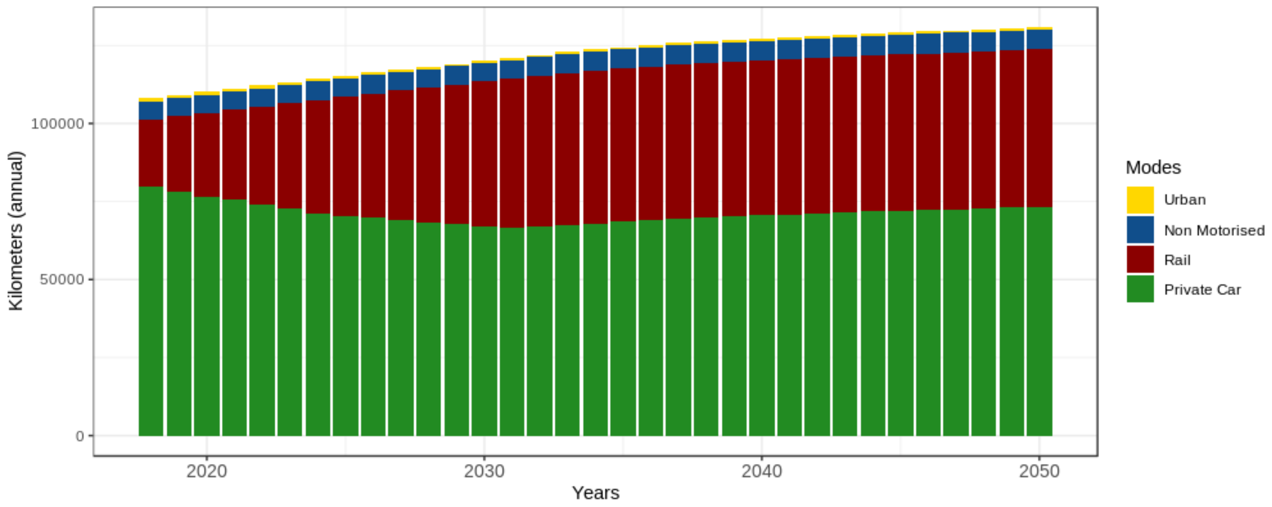

Figure 6: Total kilometers at national level according to the first policy (*kilometers in the y-axis are million kilometers)

The impact on emissions is also very significant (see Fig. 7). It is observed that there is around 25% emission reduction if the first policy is implemented (see Table 4). In other words, the leverage of emotions (including in non-users), if successful, would contribute to a considerable extent for reducing emissions.

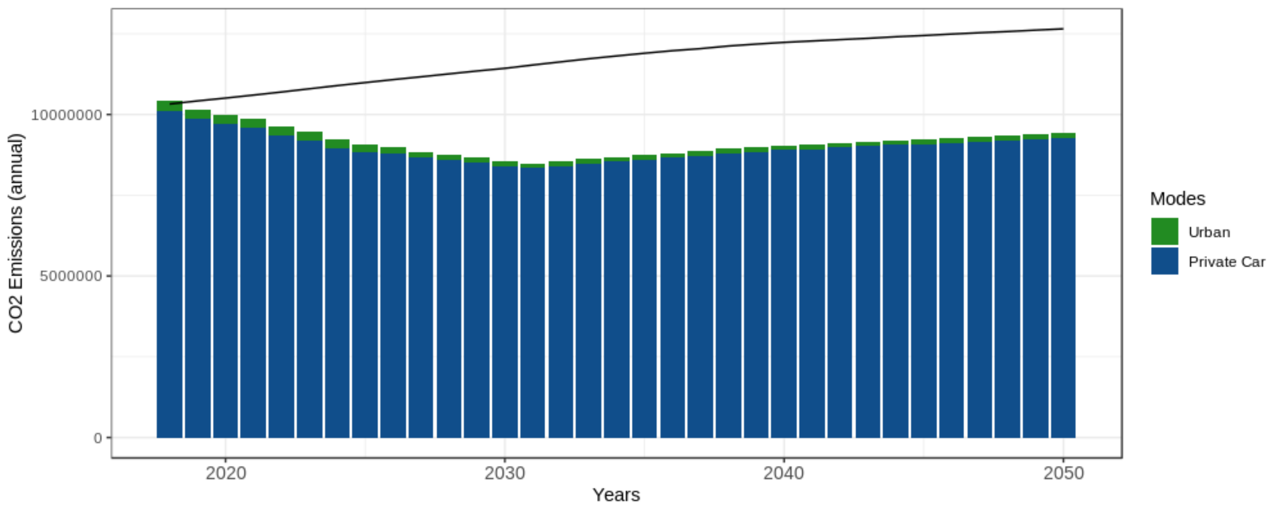

Figure 7: Direct CO_2 emissions in the first policy (*emissions in the y-axis are ton/km)

In case of adoption of the second policy (see Fig. 8), increase of railway demand is significantly higher than reference scenario (see Table 3). It means that, apart from demographic change, the second policy has impact on increasing railway demand. Due to geographic and regulative (e.g. speed limit for cars) limitations, in Switzerland trains are faster than private cars for long distances. In addition to that, as it is explained in previous parts, trains are the most punctual in Europe. Without any change in price, if railway's superiority in speed is advertised towards upper-middle and high income classes, who still do not prioritize speed over cost, a substantial demand shift towards railway can be obtained. Since people in these income groups can afford the price, if they are helped (i.e.

advertisement, promotes etc.) to put more importance (i.e. increasing weights) on speed than cost, demand increase can be achieved.

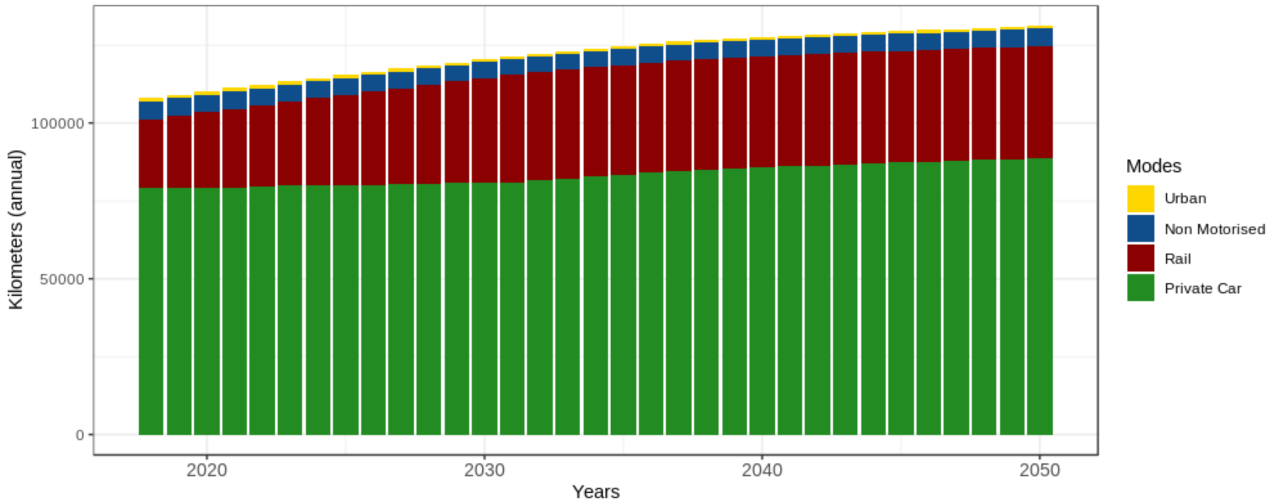

Figure 8: Total kilometers at national level according to the second policy (*kilometers in the y-axis are million kilometers)

Since total railway demand increases compared to the reference scenario by virtue of implementing the second policy, there is a substantial decrease in total emissions (see Fig. 9 and Table 4). Majority of churners who shift towards railway are private car users. Rail substitutes private car in long distance trips. In terms of time, it is better option for the agents than cars. However, for short distances (under 10 km), private cars and urban modes (i.e. tram and bus) substitute soft mobility, because they are faster than non motorized modes (i.e. bike and walking). Therefore, demand of private car and bus increase in short distances. Private car compensates a piece of its loses in long distance trips. Overall, this policy might decrease ca. 18% of the total emissions compared to the reference scenario (see Fig. 9).

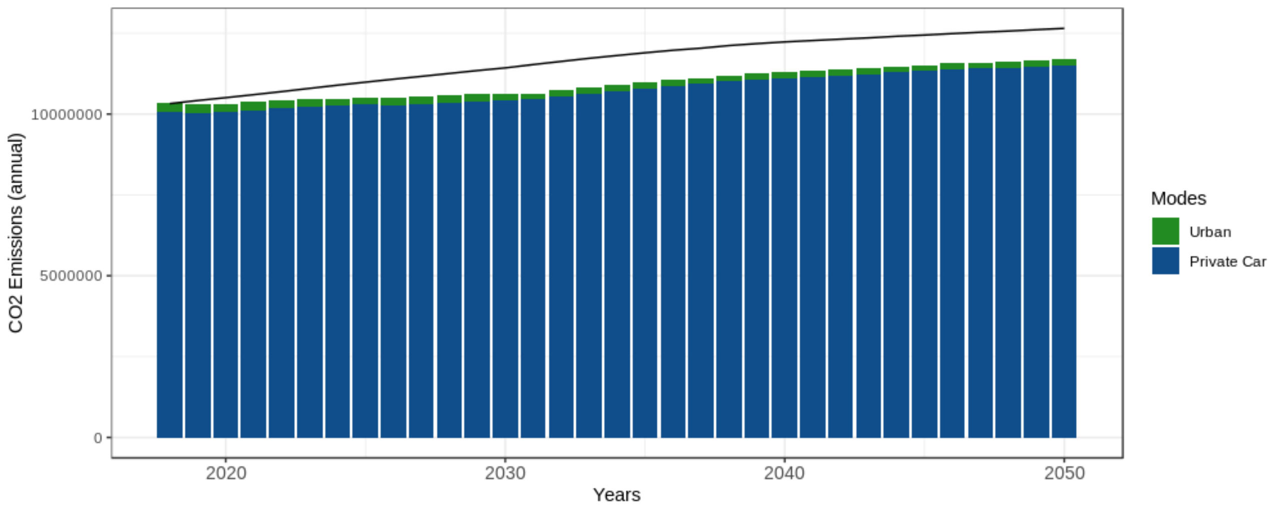

Figure 9: Direct CO_2 emissions in the first policy (*emissions in the y-axis are ton/km)

In case of adoption of the third policy (see Fig.10), at the end of the time series (i.e. 2050) railway demand increases around 1.5% more than as reference scenario (see Table 3). Since a part of elderly people swap their driving licence with a GA travel-card, in long distances railway, in short distances non motorized and urban mobility modes substitute private cars (ca. 30% increase in urban mobility modes, ca. 0.1% increase in non motorized mobility modes). This policy is not only helping to increase railway demand but also potentially reducing accident risk. Due to weakening of reflexes in time, elderly people have higher accident risk [25]. So if they are routed to public transportation modes by way of swapping driving licenses with GA, both increase of railway demand and decrease of accident risk might be gained.

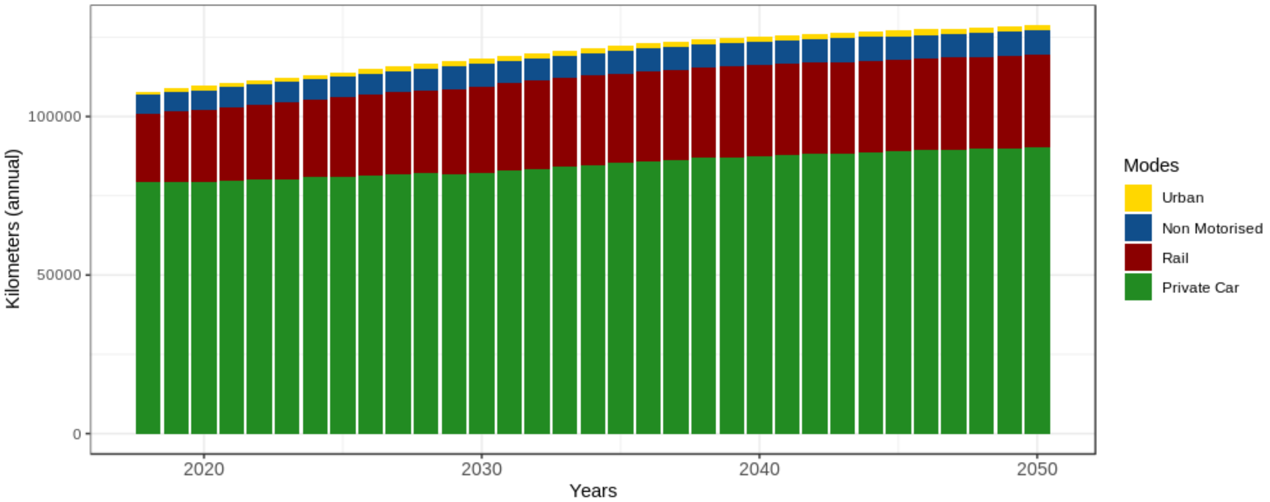

Figure 10: Total kilometers at national level according to the third policy (*kilometers in the y-axis are million kilometers)

After implementing the third policy, it is observed that total emissions become slightly less than in the reference scenario (see Fig. 11 and Table 4. The main reason is that elderly people quit private cars and pass to public transportation modes. In some years within the time series, emissions still have tendency to increase due to population growth, but rate of increase is less than in the reference scenario. Since GA covers buses, usage of them increases. In other words, total emissions from busses (i.e. a part of urban mobility modes with tram) increases. But due to reduction of private car demand, at the end of the time series, total emissions becomes less than (ca. 1%) in the reference scenario.

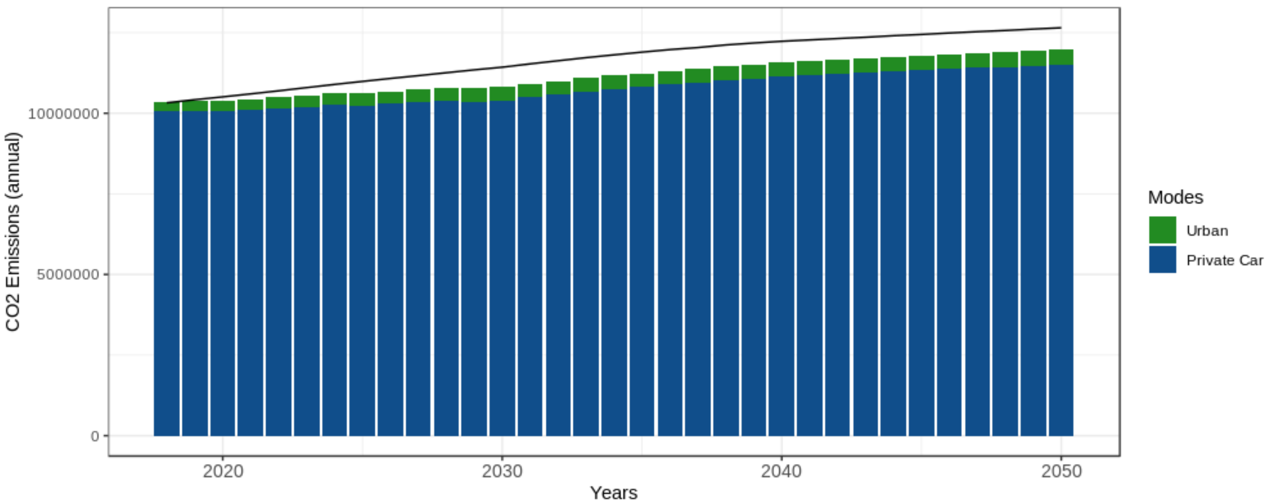

Figure 11: Direct CO_2 emissions in the third policy (*emissions in the y-axis are ton/km)

8 Policy lessons

8.1 The potential effectiveness of people-centric policies

When effectiveness of people-centric policies is evaluated in the context of the results of the experiment design of this model, including its limitation and simplification assumptions, which contributed to the calibration, it can be claimed that such policies are effective in terms of increasing demand. First, increasing emotions to a specific mode can boost demand. If each year 5% of population perceive railway more comfortable than others (i.e. positive emotions towards railway), total demand would more or less double at the end of the time series. This would reduce empty seats to about 40%. As a consequence of that increase, emissions can drop around 25% because the direct emission of railway do not increase (since no new train is added) and certain substitution from polluting modes occurs (at trip level, then in the aggregate).

In the same vein, if the importance of time (trip duration) is increased (by spontaneous dynamics or by means of different communication instruments like public advertisements), total demand of railway can increase correspondingly. Specially for long distances, railway is faster than other modes. If people-centric policies are combined with soft-supply policies, stronger results can be achieved. For example, swapping driving licenses of the elderly people is a soft-supply change that also increases demand of public transportation as we see results of the third policy.

8.2 What railway operator could do and the likely effect

If interested in increasing the occupancy rate, the railway operator should continue to improve the service, simplify access and increase the awareness of the advantages of railway for passengers. In particular, as from our model perspective, it should not underestimate the emotional reasons of non-users and may try to appeal them directly. A "wow" effect, surprising non-users and compelling them to re-assess and re-judge rail, has been shown by the simulations as being very important and could boost presences, thus revenues, without additional cost in the core business.

The most traditional way to generate it is through advertising campaigns, especially in out-door billboard located in areas where use of railway makes sense in terms of time, price and comfort, but current use is below its potential. However, in an age where social networks, both on-line and off-line, are increasingly substituting traditional advertising, engagement in such virtual and real spaces with real people, including both employees and non-employees, would be a direction to develop. This might help closing the gap between users (who may enjoy the ”wow” effect by direct experience, especially if it surpasses expectations and captures attention from unexpected angles) and non-users (who risk to be trapped in ex-ante negative judgements and stereotypes).

The model itself simply postulates that a change in emotions occurs, without explicitly modeling the process that achieve it; however it powerfully underpins the effectiveness of emotions of driving not only individual decision-making but large-scale changes in the market.

8.3 What NGOs and other non traditional subject could do to increase railway use

Subjects independent from railway operators are well positioned to express a trustworthy judgment on the emotional side of using it. Tour operators, active reviewers in services like Tripadvisor, environmental and social NGOs can have a large and durable impact on how non-users perceive the rail, thus they should be involved in the national and local conversation.

Also providers of other modes (e.g. sharing schemes) may be helped in framing their actions in synergy and not in competition to railway. This would arguably relate to trip parameters (such as time or comfort). If stations become hub of non-fossil fueled mobility, the time and comfort of their services can be combined with the advantages of railway (and vice-versa). The total cost and time of a trip can widely change if performed in steps leveraging different modes.

8.4 Railway as components of a decarbonisation strategy included in the next wave of NDCs

In international comparison, Switzerland has already a very high use of railway. By providing arguments for an even higher use in the future, thanks to specific policies, this paper provides a possible additional foundation of the request of including transport and railway in decarbonisation strategies. To the extent that the international response to the challenges of climate change hinges upon the Paris Agreement and the range of instruments it provides, the inclusion of railway in the next wave of Nationally Determined Contribution might be suggested. In particular, this can relate not only to supply (e.g. planning further infrastructure) but also to demand, for a high utilization rate, especially in substitution to current and future use of fossil-fueled vehicles. In other words, the rest of the world should better look at the historical and current experience of Switzerland, imitating and adapting many of its traits as ingredients of a successful railway system. In so doing, attention should be paid to potential venues of improvement that originate in the demand-supply interface, interpreted in an enlarged social vision of a multiplicity of interconnected active agents.

9 Conclusions and next steps

In this study, it was explored whether people-centric policies may have a system-level effect and can increase demand without changing supply. To this end, an experiment was designed with 3 different people-centric policies, which are focusing different aspects. An agent-based model BedDeM is utilized as an artificial laboratory to experiment these policies in-silico. Due to involving a decision-making mechanism (TIB) coming from psychology, BedDeM is able to reflect various psycho-socio and economic determinants that influence individual behaviors. In the first policy, reference value of comfort for railway is increased for 5% of the agents. Hence, these agents perceive railway more positively than before. Importance of emotions (i.e. weights) stays static in the overall decision making concept. After implementing this policy, a strong shift towards railway is observed. Churners are mainly from the car users who switch to railways. As the consequence, emissions reduce dramatically compared to the reference scenario. In the second policy, importance of time in the overall concept increased. Unlike the first policy, reference value (i.e. time or speed of modes in general) does not change. But the weight is increased which makes time more important than cost for the 5% of the agents. After implementing the second policy, railway demand increase significantly more than the reference scenario. Emissions still continue to increase, but acceleration is lower compared with the reference scenario. After implementing the third policy, railway demand increase slightly more than the reference scenario. As the consequence, emissions are slightly less than the reference scenario. In brief, results show that there can be significant demand increase of railway when the policies are implemented. These policies can be supported with some technology change policies (e.g. e-cars) to reduce total emissions from private cars. In long term, we aim to model purchase e.g. new car, travel-card etc. So car fleet and travel-card ownerships would evolve during the time series that helps us to capture technology shift towards more ecological mobility modes.

10 Acknowledgements

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References

[1] Ajzen, I.: The theory of planned behavior. Organizational behavior and human decision processes **50**(2), 179–211 (1991)

[2] Al-Chalabi, M., Banister, D., Brand, C.: On target? Examining the effects of information displays on household energy and travel behaviour in Oxford, United Kingdom. Energy Research & Social Science **44**, 278–290 (2018)

[3] BCG: The 2017 European Railway Performance Index. `https://www.bcg.com/en-ch/publications/2017/transportation-travel-tourism-2017-european-railway-performance-index.aspx`, (Accessed on 05/15/2018)

[4] Bechara, A.: The role of emotion in decision-making: evidence from neurological patients with orbitofrontal damage. Brain and cognition **55**(1), 30–40 (2004)

[5] BFS: Passenger transport performance. `https://www.bfs.admin.ch/bfs/en/home/statistics/mobility-transport/passenger-transport/performance.html`, (Accessed on 05/15/2018)

[6] BFS: Public transport (incl. rail freight). Annual data on public transport. `https://www.bfs.admin.ch/bfs/en/home/statistics/mobility-transport/cross-sectional-topics/public-transport-rail-freight.html`, (Accessed on 06/05/2018)

[7] ClimateAnalytics: Keeping up with the renewable revolution - updating the NDCs. `http://climateanalytics.org/files/renewables_ndcs.pdf` (2018), (Accessed on 06/06/2018)

[8] Dawid, H., Neugart, M.: Agent-based models for economic policy design. Eastern Economic Journal **37**(1), 44–50 (2011)

[9] Fishbein, M., Ajzen, I.: Belief, attitude, intention and behavior: An introduction to theory and research (1975)

[10] Frederick, R.: Agents of influence. Proceedings of the National Academy of Sciences **110**(10), 3703–3705 (2013)

[11] Frenda, A., Piana, V., Scippacercola, S.: Evaluating the Current Evolution of GDP towards Quality. Procedia Economics and Finance **17**, 138 – 146 (2014), `http://www.sciencedirect.com/science/article/pii/S2212567114008880`

[12] Fuller, J.L.: Behavior genetics. Annual Review of Psychology **11**(1), 41–70 (1960)

[13] GCA: Report transport from the facilitators to the champions. `http://climateaction.unfccc.int/media/1097/6-cop-22_gca_transport-report.pdf` (2016), (Accessed on 06/14/2018)

[14] Hager, K., Rauh, J., Rid, W.: Agent-based modeling of traffic behavior in growing metropolitan areas. Transportation Research Procedia **10**, 306–315 (2015)

[15] Hammond, R.A.: Considerations and best practices in agent-based modeling to inform policy (2015)

[16] Hogg, M.A.: Social identity theory. In: Understanding peace and conflict through social identity theory, pp. 3–17. Springer (2016)

[17] IPCC: Global warming of 1.5° c, an IPCC special report on the impacts of global warming of 1.5°c above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty special report (2018)

[18] Kelley, H.H.: Attribution theory in social psychology. In: Nebraska symposium on motivation. University of Nebraska Press (1967)

[19] Kern, F., Rogge, K.S.: The pace of governed energy transitions: agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Research & Social Science **22**, 13–17 (2016)

[20] Laird, J.D., Bresler, C.: The process of emotional experience: A self-perception theory. (1992)

[21] Loo, B., Chen, C., Chan, E.: Rail-based transit-oriented development: Lessons from New York City and Hong Kong **97**, 202–212 (05 2011)

[22] Löhr, E., Perera, N., Hill, N., Bongardt, D., Eichhorst, U.: Transport in Nationally Determined Contributions (NDCs). Lessons learnt from case studies of rapidly motorising countries - synthesis report. https://www.international-climate-initiative.com/fileadmin/Dokumente/2018/180205_GIZ-Ricardo_Transport-in-NDCs_Synthesis-Report.pdf (2018), (Accessed on 06/06/2018)

[23] Marsden, G., Rye, T.: The governance of transport and climate change. Journal of transport geography **18**(6), 669–678 (2010)

[24] Moberg, K.R., Aall, C., Dorner, F., Reimerson, E., Ceron, J.P., Sköld, B., Sovacool, B.K., Piana, V.: Mobility, food and housing: responsibility, individual consumption and demand-side policies in european deep decarbonisation pathways. Energy Efficiency (Jun 2018). https://doi.org/10.1007/s12053-018-9708-7, https://doi.org/10.1007/s12053-018-9708-7

[25] Moser, P.: Alter, Automobilität und Unfallrisiko: Eine Analyse von schweizerischen Daten des Mikrozensus Verkehr und der Unfallstatistik. Statistisches Amt des Kantons Zürich (2004)

[26] Nguyen, K., Schumann, R.: On developing a more comprehensive decision-making architecture for empirical social research: Lesson from agent-based simulation of mobility demands in switzerland, to be represented and published in the proceeding of the 20th Multi-Agent-Based Simulation (MABS) Workshop - May 2019

[27] Office, F.S.: Federal statistical office. https://www.bfs.admin.ch/bfs/en/home/statistics/mobility-transport/passenger-transport/performance.html

[28] Piana, V.: Implementing Paris: which more ambitious Nationally Determined Contributions can promote innovation in the transport system with sufficient urgency to contribute to 1.5°C-consistent global greenhouse gas emission pathways. University of Oxford Conference "1.5 Degrees: Meeting the challenges of the Paris Agreement" (2016)

[29] Piana, V.: Advertising - a key concept in Economics and Management. Economics Web Institute (2005)

[30] Piana, V.: Innovative economic policies for climate change mitigation. Economics Web Institute (2009)

[31] PostBus: Postbus: Mobile on the road with the yellow class. https://www.postauto.ch/en, (Accessed on 05/15/2018)

[32] PTFerroviaria: Research and innovation in materials applied to railways. https://www.ptferroviaria.es/docs/Documentos/2015_Documento%20de%20posicionamiento%20de%20Investigaci%C3%B3n%20en%20Materiales_Ingl%C3%A9s.pdf (February 2016), (Accessed on 06/13/2018)

[33] The Repast Suite. https://repast.github.io, [Last accessed 24-Jan-2018]

[34] Ribeiro, S.K., Kobayashi, S., Beuthe, M., Gasca, J., Greene, D., Lee, D.S., Muromachi, Y., Newton, P.J., Plotkin, S., Sperling, D., et al.: Transportation and its infrastructure (2007)

[35] Rogelj, J., Schaeffer, M., Meinshausen, M., Knutti, R., Alcamo, J., Riahi, K., Hare, W.: Zero emission targets as long-term global goals for climate protection. Environmental Research Letters **10**(10), 105007 (2015)

[36] SBB: Facts and figures - quality. https://reporting.sbb.ch/en/quality, (Accessed on 05/15/2018)

[37] SBB: SBB Ecocalculator Background Report. https://www.sbb.ch/content/dam/sbb/en/pdf/en_sbb-konzern/en_ueber-die-sbb/en_corporate-governance/Hintergrundbericht_e.pdf (October 2011), (Accessed on 05/30/2018)

[38] Scalco, A., Ceschi, A., Sartori, R.: Application of psychological theories in agent-based modeling: the case of the theory of planned behavior. Nonlinear Dyn. Psychol. Life Sci **22**, 15–33 (2018)

[39] Schwanen, T., Banister, D., Anable, J.: Scientific research about climate change mitigation in transport: A critical review. Transportation Research Part A: Policy and Practice **45**(10), 993–1006 (2011)

[40] Schwanen, T., Banister, D., Anable, J.: Rethinking habits and their role in behaviour change: the case of low-carbon mobility. Journal of Transport Geography **24**, 522–532 (2012)

[41] Sovacool, B.K.: Experts, theories, and electric mobility transitions: toward an integrated conceptual framework for the adoption of electric vehicles. Energy research & social science **27**, 78–95 (2017)

[42] Statista: Intercity rail services in the United States. https://www.statista.com/study/46507/intercity-rail-services-in-the-united-states/ (2017)

[43] Swiss Statistical Office (BFS): Mobility and Transport Microcensus (MTMC) (2015), uRL: https://www.are.admin.ch/are/en/home/transport-and-infrastructure/data/mtmc.html. Last visited on 2019/04/21

[44] The Competence Center for Research in Energy, Society and Transition - CREST: Swiss Household Energy Demand Survey (SHEDS) (2018), uRL: https://www.sccer-crest.ch/research/swiss-household-energy-demand-survey-sheds/. Last visited on 2019/04/21

[45] Triandis, H.C.: Interpersonal behavior. Brooks/Cole Pub. Co. (1977)

[46] Tyfield, D., Zuev, D., Li, P., Urry, J.: Low carbon innovation in chinese urban mobility: Prospects, politics and practices (2015)

[47] UIC: Railways and green growth. https://www.fondazionesvilupposostenibile.org/wp-content/uploads/dlm_uploads/2016/07/Railways-and-Green-Growth.pdf (2014), (Accessed on 06/14/2018)

[48] UIC: Zero carbon railways. https://uic.org/IMG/pdf/zero_carbon_final_report_2014.pdf (2014), (Accessed on 06/14/2018)

[49] Wing-tat, H.: TOD and Value Capture. http://www.unescap.org/sites/default/files/1b.4_TOD%26ValueCapture_Hong%20Kong_HungWingTat.pdf (2014), (Accessed on 06/06/2018)

[50] Wooldridge, M.: An introduction to multiagent systems. John Wiley & Sons (2009)

[51] WorldResourceInstitute: CAIT Climate Data Explorer. http://cait.wri.org/, (Accessed on 06/05/2018)

11 Appendix

Total Kilometers					
Mode	Year	Reference	Policy 1	Policy 2	Policy 3
Private Car	2020	80.8	76.4	79.0	79.3
	2030	88.0	66.9	80.8	82.1
	2040	93.8	70.6	85.7	87.6
	2050	96.9	73.2	88.8	90.3
Railway	2020	22.4	27.0	24.3	22.9
	2030	24.7	46.4	33.5	27.3
	2040	25.7	49.6	35.5	28.5
	2050	26.1	50.3	36.1	29.5
Non Motorised	2020	5.8	5.7	5.6	6.0
	2030	6.4	5.9	5.1	7.0
	2040	6.7	6.2	5.3	7.3
	2050	6.9	6.3	5.5	7.5
Urban	2020	1.0	1.0	1.1	1.3
	2030	1.1	0.7	0.9	1.6
	2040	1.2	0.7	0.9	1.7
	2050	1.3	0.7	0.9	1.7

Table 3: Kilometers by modes *kilometers are billion kilometers

Total Emissions					
Mode	Year	Reference	Policy 1	Policy 2	Policy 3
Private Car	2020	10250	9697	10051	10069
	2030	11147	8394	10421	10396
	2040	11935	8893	11111	11130
	2050	12345	9255	11514	11511
Urban	2020	256	280	265	324
	2030	280	161	186	411
	2040	296	149	189	438
	2050	305	153	194	449

Table 4: Emissions *kiloton/km