Modelling Narratives of Sufficient Mobility: A case study for Germany in 2040

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Limiting global temperature increase to 1.5 °C requires high-income countries to be climate neutral between 2035 and 2040. In the past, the decarbonisation focus was on the power sector. However, in Germany, transport is responsible for 20 % of overall GHG emissions with motorised individual traffic accounting for 60 % of it. While most trips are done on short distances, most emitting trips range on medium to long distances. Therefore, the exploration of decarbonisation pathways for trans-regional transport[1] is crucial.

Transport decarbonisation can follow three main strategies: *Avoiding* unnecessary traffic, *shifting* traffic to more climate friendly modes, and *improving* transport technologies (Creutzig 2015). The rigid time limitation requires technological change, but also behavioural change in order to be feasible within the decarbonised energy system. While technologically oriented efficiency measures, such as high market penetration of electric vehicles, have seen a lot of attention in long-term decarbonisation pathways[2], research and society discuss avoid and shift measures far less (Gota et al. 2019).

Zell-Ziegler et al. (2021) define sufficiency in transport as a change in service quality yielding lower energy demand, which comprises avoid and shift strategies. Waygood et al. (2019) define sufficiency in transport from another perspective as "to achieve the best quality of life given global constraints". Given the above emission constrains and high externalities of car and air travel (Sovacool, Kim, and Yang 2021), this definition again, comprises avoid and shift strategies. In the following, we therefore use the term sufficiency interchangeably. We define our research questions as: i) How can sufficient mobility futures look like in trans-regional passenger transport?; ii) Which impact does sufficiency in passenger transport have on trans-regional traffic and its emissions?

Schwanen et al. (2011) remark, that the qualitative research basis which ensures valid quantitative outcomes should receive more attention. In addition to this, a participatory perspective, is deemed important to explore demand perspectives in its full complexity (Nikas et al. 2020; Hirt et al. 2020). Some studies addressed these points in the past: Köhler et al. (2020) combine qualitative mobility narratives, derived with the Multi-Level Perspective (MLP) (Grin, Rotmans, and Schot 2010), and an agent-based model in order to describe the Dutch low-carbon mobility transformation. A Danish study of transport and energy system decarbonisation uses a participatory and narrative-based research design, following the Story and Simulation approach (Alcamo 2008), in order to model long-time policy scenarios (Venturini, Hansen, and Andersen 2019). Several other approaches exist in the domain of transport

[1] We define trans-regional transport as medium- to long-distance trips between rural, urban, and sub-urban areas, but not within them. In Germany today, commuting, leisure/holiday and shopping trips make up the biggest share on these distances.

[2] See (Yang et al. 2018; Meyer, Leimbach, and Jaeger 2007; Bosetti and Longden 2013; Grahn et al. 2009; Gül et al. 2009; Kyle and Kim 2011; Juul and Meibom 2011; Densing, Turton, and Bäuml 2012; Mathiesen, Lund, and Nørgaard 2008; Bunch et al. 2015; Göransson et al. 2019)

modelling (Varho and Tapio 2013; Banister and Hickman 2013; Hickman et al. 2012), where participation of stakeholders is very common, but use of social science theory is rare.

In this paper, we develop scenarios for sufficient mobility on trans-regional passenger transport in Germany by 2040. We analyse different storylines and model their *total passenger kilometres* and *modal shares* as well as economic transport system indicators *cost of mobility* and *accessibility*. Resulting scenarios can be used in energy modelling, but also to draw policy recommendations. They depict different narratives towards sufficient mobility and its impacts on transport demand.

Research Design:

This goal requires a suitable combination of qualitative and quantitative methods in a participatory way. We use the literature on driving forces of the transport sector and the Multi-Level-Perspective (MLP) from socio-technical transition research together with aggregated transport modelling, wrapped into a participatory research design. It divides in two main phases: *development of storylines* as qualitative basis and *scenario modelling* yielding the quantification (see Figure 1).

The first phase encompasses three steps: Based a literature review, we identify lever categories for avoid and shift strategies in trans-regional passenger transport (e.g. rail infrastructure or activities change), called driving forces in the following (e.g. Javaid, Creutzig, and Bamberg (2020)). Then, we conduct an expert workshop with transport transformation experts to determine concrete drivers of change (e.g. increased bus frequency or car-free inner cities) and their deemed relevance for each driving force. For the development of storylines we use the MLP and a 2x2 typology along the uncertainties dimensions avoid and shift (see Figure 2 and e.g. Pedro Crespo del Granado et al. (2019)). This allows us to analyse the socio-technical transport system in a structured way (see Box 1) and develop storylines designed as reconfiguration pathways (Geels and Schot 2007). During the whole process, we neglect barriers towards more sufficient mobility in line with the research aim of describing normative mobility futures.

The second phase starts with the translation of drivers into parameters of the aggregated open source model quetzal_germany[3]. Again, using the MLP ensures that parameters represent the same relevance of each driving force as their corresponding drivers. For the quantification of the parameters we use fuzzy set theory as described in Alcamo (2008): The first step of making subjective statements regarding the rate of change of the parameters is trivial, because we do not include barriers. This results in high levels of change for every driver included into the corresponding storyline. Then, we include expert opinion on the quantification of parameters through a survey, producing the translation keys. Following fuzzy set theory, these are used by the research team to generate membership functions, which yield a single value with the least arbitrariness for each parameter. quetzal_germany, then, calculates transport system indicators in 2040 for each storyline: total passenger kilometres, modal shares, cost of mobility and accessibility. These numbers turn the qualitatively derived storylines into quantitatively enriched scenarios, which are discussed to ensure consistency.

[3] quetzal_germany simulates passenger transport demand between NUTS3-level zones in Germany and is openly available on GitHub: https://github.com/marlinarnz/quetzal_germany

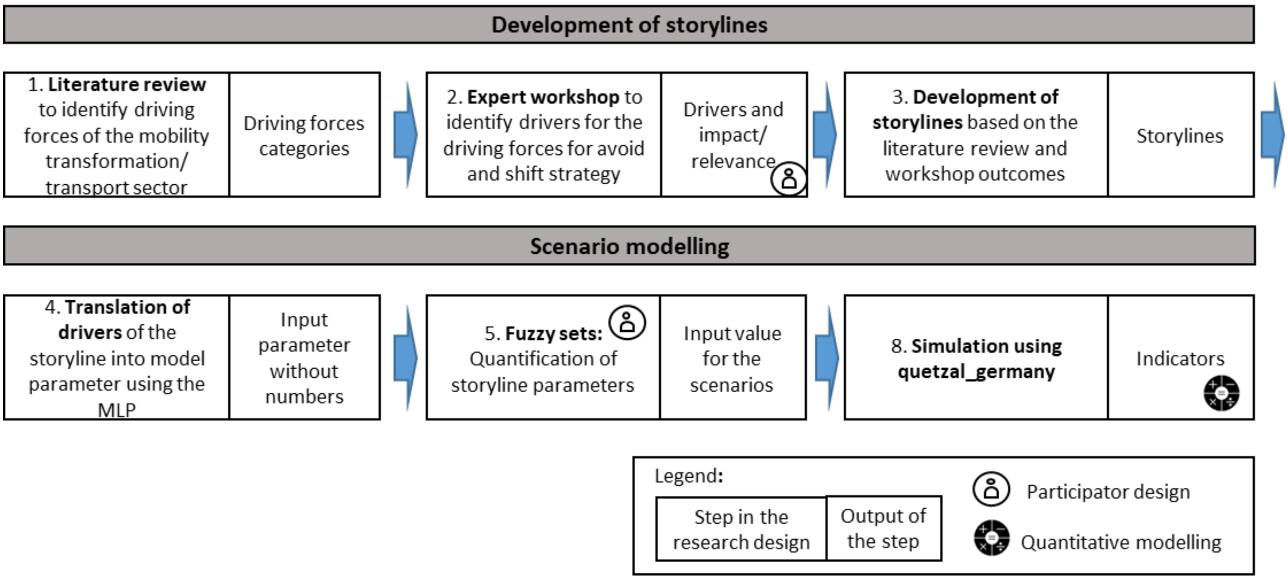

Figure 1: Steps of the research design, own illustration

Box 1: Storyline generation using the Multi-Level Perspective theory

The Multi-Level Perspective (MLP) is a socio-technical framework for analysing long-term system changes and innovations in many areas of society (Geels 2002). It frames system change as the counter play of niches with innovative actors and existing regimes with dominant actors within a landscape of external conditions. Many studies use it in sustainability transitions, also in the transport sector; however, mostly focussing on passenger cars (Moradi and Vagnoni 2018).

We use the MLP for its following properties, which match with transport system dynamics and thus transport modelling capabilities (Geels 2012): it is dealing with complex dynamics rather than simplistic cause-effect-relationships; it accounts for various groups of actors; it focuses on the co-evolution of technology and society; it addresses both stability and radical change at the same time.

We apply the MLP in three steps:

1) Analysis of existing regimes, niches, and the landscape including their stabilising and de-stabilising forces, based on literature available

2) Finding of future drivers of change

3) Development of reconfiguration pathways using a 2x2 typology

In the second step, we focus on drivers of change, rather than barriers towards sufficient mobility, which are included in stabilising forces of regimes already. Geels and Schot (2007) introduce four possible pathways for socio-technical transitions, of which the reconfiguration pathway fits a sufficiency transformation of the German mobility system best. It describes a process of niche adoption leading towards changes in the whole system architecture. Following this concept, we generate four storylines based on a 2x2 typology along the axes “avoid” and “shift” (see Figure 2). This allows us to create consistent and delineated storylines, of which the bottom right one refers to a non-sufficient transport system.

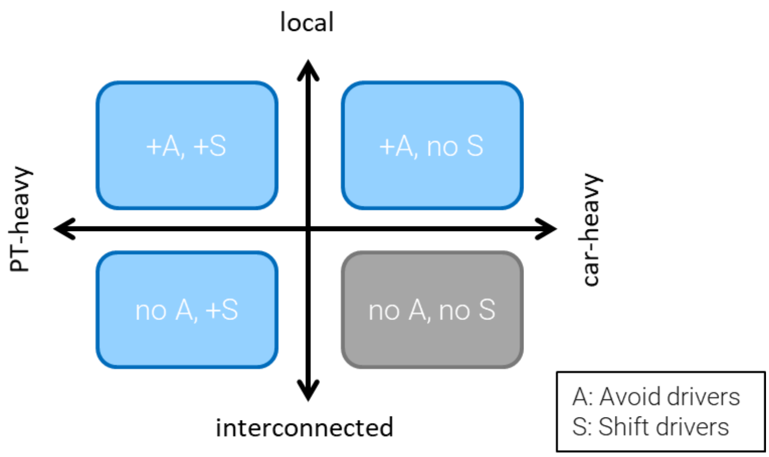

Figure 2: 2x2 typology for generation of storylines along the uncertainty dimensions "avoid" and "shift", own illustration

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