Impact chains of energy sufficiency policies: A proposal for visualization and possibilities for integration into energy modeling

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RESEARCH ARTICLE

Impact chains of energy sufficiency policies: A proposal for visualization and possibilities for integration into energy modeling

Carina Zell-Ziegler*,[1], Johannes Thema[2]

Abstract • Impact chains are used in many different fields of research to depict the various impacts of an activity and to visualize the system in which this activity is embedded. Research has not yet conceptualized impact chains specifically for energy sufficiency policies. We develop such a concept based on current evaluation approaches and extend these by adding qualitative elements such as success factors and barriers. Furthermore, we offer two case studies in which we test this concept with the responsible climate action managers. We also describe options for integrating these impact chains into different types of energy models, which are key tools in policy consulting.

Wirkketten von Energie-Suffizienzpolitiken:
Ein Vorschlag zur Visualisierung und Möglichkeiten der Integration in die Energiemodellierung

Zusammenfassung • *Wirkketten werden in vielen verschiedenen Forschungsfeldern angewandt, um die Effekte einer Aktivität aufzuzeigen und das System zu visualisieren, in das die Aktivität eingebunden ist. Ein spezielles Konzept für Wirkketten von Energie-Suffizienzpolitiken fehlt bislang. Wir entwickeln ein solches basierend auf aktuellen Evaluierungsansätzen, erweitert durch qualitative Elemente wie Erfolgsfaktoren und Barrieren und wenden es in zwei Fallbeispielen zusammen mit den verantwortlichen Klimaschutzmanager*innen an. Zudem beschreiben wir Optionen, wie diese Wirkketten in verschiedene existierende Energiemodelle integriert werden können, die Schlüsselelemente der Politikberatung sind.*

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Introduction

Despite the huge potential of energy sufficiency policies and the fact that they are needed in order to meet the climate and sustainability targets (IPCC 2022; Faber 2012; Samadi et al. 2017), they are seldom considered as options for climate protection. They do not play a substantial role in the plans of European Union Member States to fulfill their mid- and long-term climate targets (Zell-Ziegler et al. 2021) and hardly feature in non-official scenarios for decarbonization on a global or country level (Samadi et al. 2017; Zell-Ziegler and Förster 2018; Wiese et al. 2022).

One reason for this is the lack of existing impact quantifications for these policies. However, the science base is broadening (e.g. Creutzig et al. 2021; Vita et al. 2019; Akenji et al. 2019; Fischer et al. 2020). An important obstacle is the frequently perceived complexity of sufficiency (Zell-Ziegler and Förster 2018), especially in relation to technical emission abatement options like efficiency and renewable energy policies. Sufficiency policies often concern more general questions of sustainable development and commonly entail socio-economic aspects outside the techno-economic realm of most existing models (Fuchs et al. 2021; Darby and Fawcett 2018; O'Neill et al. 2018).

Impact chains in theory and practice

Impact chains are a means to structure and illustrate the stepwise logic for an action from cause to impact (Gross 2018). This approach enables the different effects and impacts to be traced, especially in complex systems. A concept for impact chains that is geared to (energy) sufficiency policies has not yet been developed.

In this paper, we develop such a concept and propose the elements which such impact chains should encompass, e.g., the manifold effects which (energy) sufficiency policies have and the requirements for and the barriers to unfold their potential. In addition, we propose a visualization of these impact chains, as this increases transparency and helps to improve the understanding of energy sufficiency policies. With two climate action managers, we evaluate the impact chain using sufficiency policies which they recently implemented.

In a further step, we explore ways in which and to what extent energy sufficiency impact chains can be integrated into energy models and what alternatives there are for integrating important aspects of the impact chain into models. This is important because models are key tools for policy consulting. Only if sufficiency policies can be quantified like efficiency and consistency policies will they have a chance to play a similar role in policy design.

Definitions and methods

We define the relevant terms for this research as follows:

- "*Sufficiency policies* are a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries" (IPCC 2022, p. 41, emphasis by the authors). In this paper, we focus on energy sufficiency; we sometimes use the more abbreviated term "sufficiency" in the text.
- *Causal/Impact chains* are "[s]equentially linked mechanisms and their enabling background conditions." (Gross 2018, p. 1)
- "A *policy instrument* is a governmental interference with the aim to realize interventions which promote the implementation of measures." (translated from Fischer et al. 2016, p. 76, emphasis by the authors)

Impact chains are widely used in policy evaluation and (model-based) impact assessments of policies which take a variety of approaches: qualitative theory-based evaluations and quantitative accompanying or ex-post evaluations/impact assessments (Schlomann et al. 2020; OECD 2009; DeGEval 2016). The aim in using impact chains is to attribute effects such as behavioral change and greenhouse gas (GHG) emission reductions to an activity, e.g., a funding program or an information campaign. We take the standard concept as described in IMWG (2014) and further develop it to a conceptual model for energy sufficiency impact chains by extending and revising the elements. Therefore, we compile the requirements and translate them into the impact chain logic. The resulting model is described and visualized in the results chapter below.

We assessed the chain model for workability and we selected two recently implemented energy sufficiency policies at the local level in Germany within the mobility sector, which use different types of policy instruments: the ban of short-haul flights at the Eberswalde University for Sustainable Development and a pedelec rental service in the Lüchow-Dannenberg district in Lower Saxony. Next, we applied four steps in setting up the impact chains: 1) We developed a first draft based on public and internal material for Lüchow-Dannenberg and a preliminary talk with the sustainability manager for Eberswalde. 2) We interviewed each climate action manager for about 30–60 minutes; the interviews were semi-structured according to the elements of the impact chains. The climate action managers seemed suitable as interview partners because they planned and implemented the policies and thus have an interest in its success and know barriers from their own experience. The aim of these interviews was to revise or verify the impact chain drafts. 3) We consolidated the impact chains and 4) the final draft was sent to the climate action managers for approval. The visualized impact chains for the case studies can be found in the results chapter.

On a general level, we took into account conditions and options for ways in which impact chains may be integrated into different model types. To this end, we screened an exemplary list of energy modeling approaches from energy supply and demand models, reviewed model documentation and discussed with model developers specific modeling logic and potential model developments to integrate impact chains. These documents and discussions gave insights into the circumstances under which impact chains can potentially be implemented endogenously in models or have to be quantified exogenously. From these, we derived four possible quantification cases.

Results

Developing a conceptual model for impact chains for energy sufficiency policy

The basis for developing a concept for an impact chain geared to energy sufficiency is the widely used impact chain described in, for example, IMWG (2014): Input – Activity – Output – Outcome – Impact. We have amended this as follows:

As our focus is on policy impact, it seems important to emphasize this in the impact chain. We have thus split the "input" into an input in the narrow sense as the project-specific means to reach the intended effect (e.g. staff and financial resources; this effect can be relevant at different stages of the impact chain) and a *stimulus* which triggers the activity and starts the impact chain as PIK (2014) proposes. The stimulus can be external or internal, e.g., a regulation, subsidies or investment in infrastructure (fiscal instruments), taxes or market reform (economic instruments according to UNFCCC (2000)) or an organization's sus-

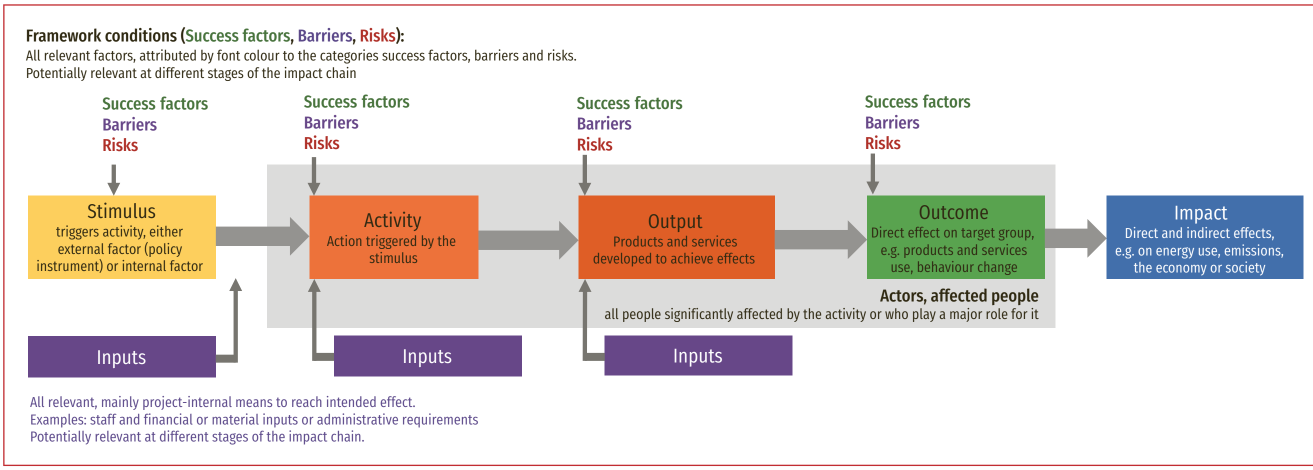

Fig. 1: Conceptual model of impact chains for energy sufficiency policies. Explicit qualitative aspects are visualized without a box so as to differentiate these from aspects where quantifications can potentially be added. *Source: authors' own compilation*

tainability target. Within this conceptual approach, sufficiency is not the intrinsically motivated individual action, but rather the activity change resulting from a stimulus. Sufficiency is thus a genuine field for policy design like efficiency and renewable energy policy (Schneidewind and Zahrnt 2013).

Energy sufficiency policies often have an overarching nature (Sandberg 2021; Creutzig et al. 2022; O'Neill et al. 2018). It seems helpful for the comprehension and replicability of the policies, therefore, to add qualitative aspects to the different elements of the impact chain. As risk assessment is often associated with impact chains (Aall and Korsbrekke 2020; PIK 2014), *risks* that accompany the policy are added. Other additions with regard to the framework conditions of the policy are *success factors* and *barriers* as these are often mentioned in sufficiency literature as important factors (e.g. Toulouse et al. 2017; Stengel 2011). Contrary to risks, barriers can lower the effectiveness of the policy but will not lead to its failure.

Furthermore, we have added a box for *actors/affected people* with the field of policy design in mind. "Actors" can show who should be involved when designing the policy and "affected people" can give hints on the need for a socially aware policy design (Cludius et al. 2022). If, for example, negative impacts on social groups occur, these would be included as a box in the (blue) impact category.

These elements added to the "classical" impact chain are not specific to energy sufficiency policies but seem especially important for comprehension, replicability and transparency of these policies so that they can better enter the political arena (Zell-Ziegler and Förster 2018). The method is able to include quantifications (elements in Fig. 1 with a box) so that impact chains can be coupled with or inserted into energy models and the impacts can be compared to efficiency and renewable energy policies. Arguments based on quantified effects seem to be crucial to take energy sufficiency into account in the design of political mitigation efforts.

Our concept is visualized with an explanation of the elements in Fig. 1.

Test of the conceptual model in two case studies

To test our model, we applied it to two case studies in which energy sufficiency projects were recently implemented. The first case study is the ban of short-haul flights for the staff of the Eberswalde University for Sustainable Development imposed in 2019 by the executive committee of the university. For all destinations which can be reached by train within ten hours, air travel is banned (with exemptions), concerning especially flights to Brussels. Due to the COVID-19 pandemic, the effects of the ban are difficult to assess because virtual meetings effectively replaced all business trips and will be an attractive option in the future. The impact chain is visualized in Fig. 2.

Implementing this case study in the impact chain was relatively straight-forward. Two main threads could be found: the policy will either lead to a substitution of flights with rail trips or will replace the flights by virtual meetings. One difficulty was the formulation of the output, as the instrument type *regulation* means that no products or services are developed and the implementing body and the target group are almost identical. The main risk lies within the acceptability of the policy by staff, which could lead to arbitrary use of exemption requests.

The second case study is part of the promotion of sustainable mobility in the municipality of Lüchow-Dannenberg: the pedelec rental system. It was free-of-charge when it started in 2019; now, the three pedelecs and one e-cargo-bike can be rented for a small charge. The system was extremely well used from the start. A project-specific survey revealed that in more than 50 % of the cases, trips by car could be replaced. The impact chain is visualized in Fig. 3.

Implementing this case study in the impact chain was also straight-forward. It can be seen that a lot of input from the project side was and is necessary and that a barrier for the policy

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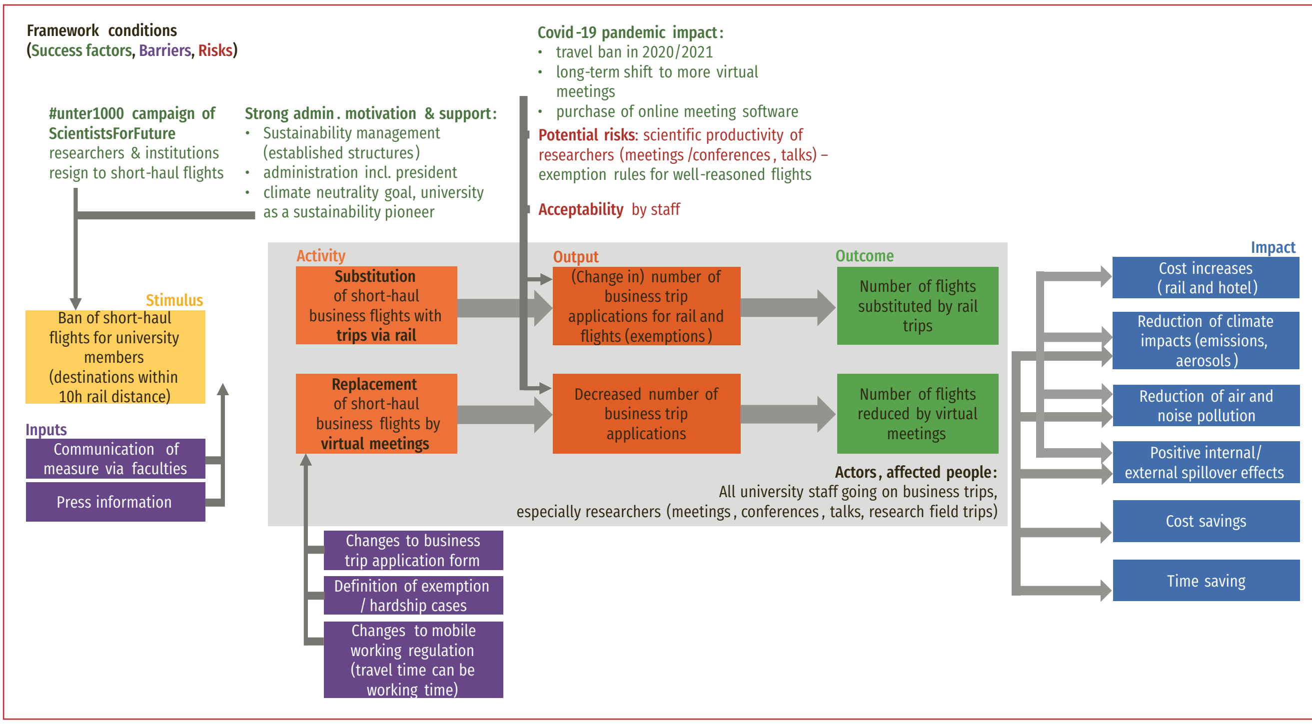

Fig. 2: Impact chain for the ban of short haul flights at the Eberswalde University for Sustainable Development. *Source: authors' own compilation*

or an expansion of the rental service is that it is very work-intensive. By using the mobility data and the survey results, even quantitative results can be generated for the GHG emission reduction of the first project phase.

Implementing impact chains in models

For planned or potential energy sufficiency policies, ex-post evaluations are not available. To assess their potential impacts, the inclusion of impact chains in existing energy models can make a valuable contribution to broadening the scope of ex-ante impact assessments. However, most existing models are not currently able to represent energy sufficiency endogenously due to the modeling approach and logic.

Whether and to what extent such impact chains can be endogenously modeled within an existing model depends on the policy-specific impact chain, its impact mid- and endpoints and its match with the logic of the target model. Impact chains can

a) be fully covered endogenously within a model, as the logic fits well. This would be beneficial as any modeled changes enter the entire modeling parameters.

b) be partly covered. Those parts that cannot be covered by the model logic need to be quantified exogenously and fed to the model for parts of the impact chain quantifications. This is the case if a model has a different scope (e.g. technical features and key determinants of the building stock) than the impact chain (e.g. focusing on skilled labor shortage and training programs).

c) not be covered by a model. They need full external quantification with outputs/outcomes being fed as inputs to the model. This is the case if a model does not cover any part of the impact chain, but outputs (e.g. in terms of energy consumption) can be fed as inputs into the model for final impact quantifications (e.g. GHG emissions).

d) not fit at all with a model logic. In this case, the impact chain needs full external quantification.

Fig. 4 visualizes these different cases. Impact chains for energy sufficiency policies as developed above focus on the energy demand side with policies and other input factors that influence activities, ultimately leading to impact endpoints. The likelihood that a model covers the logic of a given sufficiency impact chain is thus higher for a respective sectoral demand model.

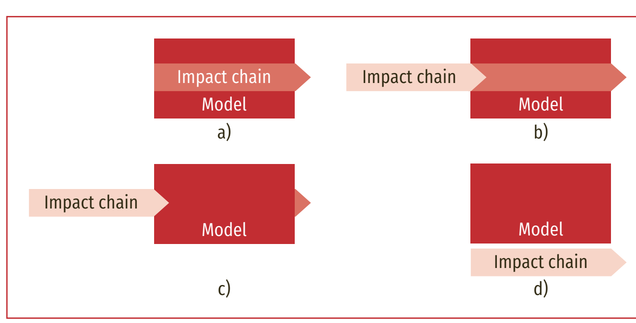

Fig. 4: Different options for implementing impact chains in energy models. *Source: authors' own compilation*

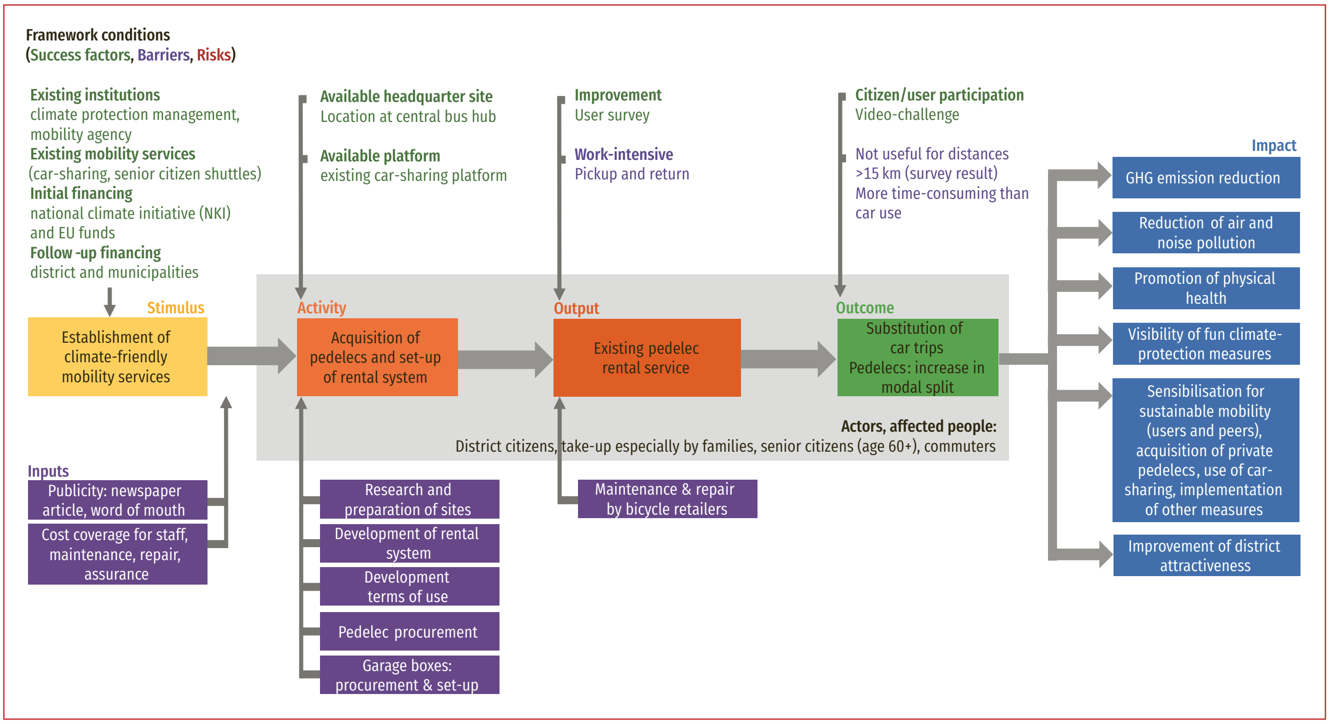

Fig. 3: Impact chain for the pedelec rental service in Lüchow-Dannenberg. *Source: authors' own compilation*

Since energy sufficiency policy is not currently a well-researched field despite widespread recognition of its necessity, only limited experience has been gathered with modeling. Moving from a situation like d) or c) to b) or a) would be conducive to the ex-ante assessment of energy sufficiency policy. In the following, we briefly discuss some typical models and current ways of depicting energy sufficiency policy impact chains.

For the *supply side* (often called energy system) models, typical approaches are optimization (cost-minimization algorithms) and equilibrium models. The task of these models is to find least-cost or economic equilibrium energy systems, in most cases covering electricity and centralized heat generation facilities and deployment, within given boundary conditions such as GHG emission caps, carbon prices, capacity expansion limits etc. (for a non-exhaustive overview of 75 models see Ringkjøb et al. (2018)). By definition, these models cover the supply side and, in most cases, do not encompass the major part of energy sufficiency impact chains, but take energy consumption, for example, as the input (case c).

Demand-side models typically cover one sector in high detail. They apply various approaches such as stock simulation, (e.g., cost) optimization, discrete choice modeling or agent-based micro-simulation. There is a multitude of sector models with different methodologies, which we cannot discuss in detail here. Rather, we have drawn conclusions from a review of several important building sector and transport models.

We reviewed building sector models from ifeu (2022), Soukup et al. (2012), Cordroch et al. (2021), Prognos (2022), FIW and ITG (2021) and Öko-Institut (2022), see appendix 1. These represent the building stock in a detailed technical resolution with building age, energetic standards and heating technologies and its development over time depending on key input parameters such as renovation, decommission and new build rates, heating technology deployment rates, or per-capita living spaces. For energy sufficiency policies that directly concern the building stock (e.g. limitation of living space), these models can already endogenously represent (parts of) the impact chains (case a/b). If, however, policies target changes in the decision-making of individuals (behavior or investments) by means of, for example, tax incentives or subsidies, it is not included in the model realm and needs separate quantification (case c) or substantial model development (case b).

For transport, the methodological landscape is more diverse, see appendix 2. Simulation models like TREMOD (ifeu 2020), or DEMO (Winkler and Mocanu 2020) can (like the building stock models) endogenously implement policy impact chains (case a) concerning the regulation of the rolling stock (e.g. emission/consumption standards, technological phase-outs or mandatory phase-ins). With approaches that model transport onto the existing/future transport network infrastructures (as DEMO, Quetzal_Germany (Arnz 2022), or MATSIM (Horni et al. 2021)), policies that directly alter the transport network can be modeled (e.g. build-up of new rail connections, car-free zones, limitation of air connections). As these model choices also base on costs and time, monetary instruments that affect costs for specific trips (fuel taxes, road tolls) or such that affect travel time (rail connection speed, speed limits) can be modeled. Agent-based models like MATSIM or partially TEMPS (Repenning et al. 2021) offer the best possibility for including impact chains related to individual transport decisions. Whether a specific policy can be endogenously modeled depends on the specific impact chain and its match with the specific modeling framework under consideration.

Where endogenous modeling is not possible, but the policy impact shall be modeled, exogenous quantifications (case b, c) or model development is necessary.

Impact chain examples in models

We briefly sketch the possible inclusion of the two above-mentioned impact chains in a model. As explained above, this has to be done with respect to a specific model at hand. We use Quetzal_Germany as an exemplary open-source transport model for Germany (a model outline is provided in Arnz 2022). The model currently includes a mode choice model for car and public transport modes that models given trips on certain connections (segmented by trip purposes) onto the existing German transport infrastructure. The first case of a short-haul flight ban can be included according to its two split impacts. On the one hand, short-haul flight connections can be simply removed from the transport network (if entirely banned). On the other hand, the number of business flight trip reductions (due to virtual meetings) needs to be exogenously quantified. A problematic restriction is the geographic scope: Quetzal_Germany only represents domestic transport; international flights cannot be covered. It is not currently possible to represent the second case (substitution of car trips by pedelecs) in Quetzal_Germany as local mobility is not explicitly modeled and bicycles/pedelecs are not represented as separate mode. If the exogenous impact chain quantification yields a reduction in the number of local trips, it can, however, be included in the underlying input data to reduce total trips. Further model development (i.e. coverage of international flights, explicit modeling of local transport, bicycle/pedelec as mode) would be required in order to explicitly model impact chains within the Quetzal_Germany model.

Discussion

The development and visualization of impact chains increases transparency and comprehension with regard to the ways in which energy sufficiency policies work and their effects, the conditions for unfolding their potential and the associated societal effects. The impact chains are useful for replicating projects and for sensitizing policy makers or administrations to the difficulties and uncertainties (barriers, risks) before designing new policies, or to improve planned or implemented policies. It thus raises the attractiveness for energy sufficiency to become a political option.

We are not aware of a comparable proposal for impact chains of energy sufficiency policies. Our results therefore present a value added to the discussion of impacts, success factors and barriers to energy sufficiency policies. It was possible to apply the concept in two case studies, which shows the effects and impacts of two different policy instruments within the mobility sector. The sample size, however, is too small to draw conclusions on general patterns of different policy instruments at this time. The method used to test our concept only incorporates one perspective from the planning and implementation side per policy. This approach seems to be appropriate for the purpose of initial testing.

Concerning the modeling of energy sufficiency policies, a first result is that existing sectoral demand-side models can already depict some policy impact chains, but depending on the specific chains and models, the development of exogenous chain quantifications and/or further model developments are needed. For their inclusion in energy supply/system models beyond exogenous assumptions, supply models need to be coupled to adequate demand-side models that can explicitly represent policy impacts and feed them as inputs into the system models.

Conclusion and outlook

We plan to apply our concept to a range of energy sufficiency policies. We will start with those included in the recently developed "Energy Sufficiency Policy Database" (Best et al. 2022). We are particularly interested in the comparison of the impact chains for different policy instruments (stimuli) that target the same outcome. Additionally, we plan to discuss as many of the impact chains with stakeholders as possible in order to integrate a broad range of perspectives, especially for the framework conditions and multiple impacts. For the validation of impact chains, the development of outcome/impact indicators is also very useful (Wolff et al. 2019).

The assessment of more general energy sufficiency policies on a level higher than the local one will add impacts such as those on GDP and employment to the impact chain. Due to the development with the two climate action managers, there are few uncertainties, and we are confident that we have included the most relevant success factors, barriers, and risks. For the development of more abstract and higher-level impact chains and for those that have not (yet) been discussed with stakeholders, it seems necessary to include uncertainties, e.g., with dashed arrows. Further conceptual and visual development is needed to outline which success factors, barriers or risks of an impact chain are the most important and have the greatest potential to lead to success or failure of the policy.

Once impact chains for the policies in the database of Best et al. (2022) are developed, we plan to test their integration in existing models and add quantifications. The goal is to model them entirely endogenously. Where this proves impossible due to model limitations, we plan to develop exogenous pre-calculations for feeding impact mid-points to models.

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Competing interests • The authors declare no competing interests.

Appendix 1 (Building sector models)

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