Energy efficiency first; sufficiency next?

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Abstract

The European Union has committed to 2030 targets: cutting greenhouse gases by 40 % compared to 1990, decreasing energy consumption by 32.5 % compared to a baseline scenario, and to increase the share of renewable energy to at least 32 % of gross final energy consumption.

Energy efficiency first is the key principle of this climate and energy strategy. For 2050, the EU's non-binding ambitious long-term goal is to cut greenhouse gas emissions by 80–95 % compared to 1990.

There are many ways to approach climate protection. Increasing energy efficiency and the expansion of renewable energies are two relatively familiar ways and are regularly part of climate mitigation modelling exercises. Sufficiency can also contribute to climate protection. Specifically if mitigation goals are very ambitious it could take some burden off technological mitigation options. However, sufficiency is seldom addressed explicitly in stringent climate protection scenarios due to several reasons.

Our study derives a first draft guidance that aims at motivating to systematically integrate sufficiency when modelling stringent climate protection scenarios.

In order to do this we characterize German longer-term scenarios with stringent climate protection goals in place. We investigate whether, and if yes how, sufficiency is included in these scenarios. An exemplary look is also taken beyond Germany. We address how sufficiency can be depicted systematically across all sectors included in modelling exercises. Additionally to what we learned from the literature review, our draft guidance also derives from the results of an expert meeting that took place in 2018 at the Federal Environment Agency (UBA) in Dessau. 12 German organizations all familiar with modelling climate protection scenarios discussed theses about integrating sufficiency in modelling stringent climate protection.

Introduction

The EU has climate energy targets in place which call for urgent action. Until 2020 it aims to reduce greenhouse gas emissions by 20 % compared to 1990, to have a renewable share of 20 % on gross final energy consumption and to have reduced energy consumption by 20 % compared to a baseline scenario. The so *called climate package* provides the legislation to meet these targets (EC 2008). While at least the target of reducing the greenhouse gas emission will most likely be met; targets for 2030 are more challenging:

In November 2018 key elements of the *Clean Energy for All Europeans Package* were approved by the European Parliament. These include the following 2030 targets: a binding cut of 40 % in greenhouse gas emissions compared to 1990, a binding renewable energy share of 32 % on gross final energy consumption, as well as an energy efficiency target of 32.5 % (EC 13 Nov 2018).

Furthermore, on November 28, 2018, the European Commission published its long-term strategy of a carbon-neutral Europe in 2050 (EC 2018b; 2018a). This goal implies even stronger efforts than to reduce greenhouse gas emissions by 80–95 % compared to 1990, goals previously laid out in the roadmap for moving to a competitive low carbon economy in 2050 (EC 2011).

Recent analyses indicate that the EU already needs to step up its effort in order to reach its 2030 targets (EEA 2018). Reaching 80–95 % emission reduction compared to 1990 or even 2050 carbon net-neutrality will thus even require steeper slopes of change.

Scenarios are useful for examining future changes and their effects on the basis of various assumptions. Naegler et al. (2016) describe what scenarios can achieve: "Scenarios describe in a consistent way the possible future development of the system with the best possible consideration of the current knowledge regarding the system, i.e. the internal dependencies and interactions of the system's components, but also the dependency of the system's development on external factors. Scenarios thus provide guard rails for central technical-structural, energy-political, economic and societal decisions that must accompany a targeted transformation process".

Scenarios that describe stringent climate protection goals can therefore be seen as important tools for assessing necessary changes towards a climate-friendly society.

A **model** is a construct which contains the algorithms and equations needed to depict the behaviour of a system that should be modelled (see e.g. Wikipedia 2018a).

Projections are the results of a model which depicts the behaviour of a system (see e.g. UBA 2013a on climate projections). They are a quantification of key variables (e.g. greenhouse gas emissions, renewable energy shares, energy consumption). They are generated by calibrating a model to a scenario description and by feeding the model with various parameters and assumptions derived from the scenario description. Based on its algorithms and setup the model then produces its results. For example, if the greenhouse gas emissions for 2030 are generated as a model output, one would be able to assess whether the 2030 climate target would be met under the given scenario assumptions.

Samadi et al. (2017) found that while model based energy policy scenarios are used to advise policy making, behavioural changes towards energy-sufficient lifestyles are seldom included. This is despite their considerable potential to contribute to public policy goals and despite them possibly being indispensable for achieving some of the (more stringent) goals. These results were confirmed in UBA (2018).

Therefore, Samadi et al. (2017) argue that the potential of sufficiency should be reflected in scenario studies which aim to provide comprehensive advice to policy makers.

In this paper we derive draft guidance on how sufficiency can systematically be included into models which project climate and energy scenarios. The aim is to provide value added beyond the German speaking modelling community and to start a thread of communication on this topic; specifically on the value of quantitative sufficiency analyses with regard to stringent climate and energy objectives. Ideally this paper provides a starting point to lower the impediment of including sufficiency aspects into modelling stringent climate and energy scenarios.

The paper builds on results from a project funded by the Federal Environment Agency (UBA) called *Möglichkeiten der Instrumentierung von Energieverbrauchsreduktion durch Verhaltensänderung* (FKZ 32EV 16 124 0).

The structure of the paper is as follows: We first introduce our methodology and some important notions. The methodology consists of two elements: a literature review of German and, a selection of European scenario studies as well as an expert workshop. Based on these two elements we derive the results, which will be organised into three topics:

1. main findings from the literature review, including a systematic overview of how to address sufficiency across all modelled sectors;
2. the results of the expert meeting; including the identification of impediments; and
3. draft methodological guidance and strategic aspects based on the findings from above.

At the end we discuss the results and provide an outlook towards further research needs.

Terminology & Methodology

The results we derive in the subsequent section are based on a literature review as well as on outputs from an expert workshop. Both approaches are laid out below. The specific terms we adopted throughout the paper are introduced first.

TERMINOLOGY

Sufficiency: changes in consumption patterns that help to remain within the ecological carrying capacity of the earth, whereby aspects of utility of consumption change, see Fischer et al. (2013). "Energy sufficiency is a strategy aiming at a limitation and reduction of the input of technically supplied energy towards a sustainable level" (Thomas et al. 2017).

Instrument: a State's intervention with the aim of triggering changes that promote the implementation of measures, see Fischer et al. (2016):

Measure: based on CEN/CLC TR 16103:2010 technical code and the European EMEEES project: an energy efficiency improvement measure is an activity that usually leads to a verifiable, measurable or estimable improvement in energy efficiency. Similarly, we define an energy saving measure as an activity which results in verifiable, measurable or estimable energy savings. The term measure is used as a generic term for both, see Fischer et al. (2016)

Model: simplified representation of reality: Description of a system of interest using mathematical concepts and language (Wikipedia 2018b). A model operates on the basis of defined functional relationships that describe the system to be represented (e.g. energy system) and its dynamics and interdependencies. For a model to deliver results, the scenario to be investigated must be translated into model language with the help of input data and then processed according to the functional definitions.

Input (data): information that a model needs to calculate its defined functional relationships. Input data for greenhouse gas projections include, for example, assumptions about the future development of population, energy prices or living space per capita.

Target scenario: specifies a target, which is to be achieved by a variety of measures and instruments; i.e. the target (e.g. greenhouse gas reduction level) acts as a constraint to the model.

Table 1. Selection criteria.

Criteria	Specification	Reasoning
Time horizon	At least 2050	Shorter-term targets can and are usually achieved in scenario studies by exploiting technical potentials. Instruments and measures for behavioural change are therefore more likely to be used in longer-term scenario studies.
Stringency	Greenhouse gas neutrality, or, in 2050, at least 80–95 % emission reduction compared to 1990	The more stringent the emission reductions, the more likely behavioural changes will play a role.
Modelling	Quantitative assessment using at least one model	Qualitative descriptions of the scenarios do not ensure a consistent scenario in itself. Only via (sectoral) modelling all relevant aspects of greenhouse gas reduction and their effects can be mapped.
Sectors	Coverage of as many sectors as possible	Greenhouse gas emission reductions in all sectors are necessary to achieve stringent climate targets, while sufficiency may not be represented in all of them.
Scenario type	Target scenario	A target scenario specifies the emission reduction level, which is to be achieved by a variety of measures and instruments. A measure scenario would instead show how much measures could contribute to the achievement of stringent climate targets.
Publication date	Publication by the end of January 2018	As the work was conducted during a limited duration of time, only scenarios published up to this date were considered. A recent screening has revealed that, to date, no further studies can be added.

Source: own representation.

Measure scenario: describes the development of a system under continuation or further development of measures. In this case, for example the greenhouse gas emission reduction level would be a result constraint.

Impact chain: a general representation of how a stimulus propagates through a system of interest via the direct and indirect impacts it entails (definition adopted and generalised from PIK 2018).

LITERATURE REVIEW

The literature review was based on a sample of studies that could fulfil several selection criteria. We chose the criteria to increase the probability of sufficiency being included in the study, and to pick studies which do not only describe a scenario qualitatively, but also include quantification of effects based on modelling. The criteria and their specification were the following:

Table 2 shows possibilities to systematically address sufficiency in models and across several key sectors. It highlights which model parameters (column 3) could be targeted for calibrating sufficiency measures, in which unit (column 4) these may be implemented in models and what sufficiency measure could justify the modification of the corresponding parameter (column 5). The last column provides examples of instruments which could, in principle lead to the implementation of the measures.

This table served as a starting point for the assessment of the literature. The table is to be understood exemplarily: not all models will depict the sectors in the same manner as depicted here. Nevertheless, the listed parameters are common and can be found in many models. Depending on their system boundaries and sector definitions, the parameters may be found in other sectors than presented in Table 2[1].

EXPERT WORKSHOP

To learn more about challenges of including sufficiency into models, we organised an expert workshop. This workshop aimed at discussing several hypotheses about sufficiency and its relation to modelling. Experts from 12 German institutions participated in the workshop hosted at UBA. The discussed hypotheses were the following, organised by topics:

Legitimacy and acceptance

Sufficiency is necessary to achieve stringent climate targets in scenarios. Assumptions made about sufficiency in scenarios need to be documented transparently.

If there is no independent and significant trend towards sufficiency that justifies corresponding parametrisation, it is necessary to explain which instruments trigger the changes that result in the parameter modification.

Sufficiency requires a change in consumption patterns. Despite ethical concerns, the precautionary principle and the damage principle legitimise political instruments that facilitate changes in consumption patterns.

Public acceptance of sufficiency needs to be increased. Differentiated and target-group-specific communication is necessary.

1. Examples of instruments, dwelling and construction/electric appliances: A feebate system combines discounts and fees. Devices that meet certain criteria would be subject to discounts, while devices that do not meet these criteria would be subject to an additional levy. See also Fischer et al. (2016), chapter 6.6.2.

Table 2. Systematic overview of parameters that can be varied to depict sufficiency in models.

Area/ sector	Area of need	Parameter	Example of units	Sufficiency measure to justify parameter modification	Example of instruments
Transport	Mobility	Newly registered cars	Number per year; number of cars per 1,000 inhabitants	Less demand for individual transportation; more use of public transport	Taxation of private cars; car toll; more frequent public transportation; taxation of company cars, 30 km/h speed limit in cities
	Mobility	Size of cars	Cubic capacity; car model	Use of smaller cars	Higher parking fees for larger cars
	Mobility	Distance travelled	Kilometres per person	Reduction of kilometres travelled by car	Promotion of telework; construction towards city of short ways
	Mobility	Air travel	Number of short/ medium/long haul flights per year; number of person kilometres per year	Reduction of private and business air-travel	Increase of aviation tax; reduction of subsidy for aviation fuels
Agriculture	Nutrition	Animal stock	Number of animals per livestock species or hectare; kilogram meat consumption per person and year	Reduction of meat consumption	Change of transfer payments to farmers; limit on number of livestock per hectare; grassland uprooting ban; increase of VAT on meat and dairy; obligation to be self-sufficient regarding fodder; tax on animal feed; stronger nitrogen limits
	Nutrition	Food waste	Kilograms per household and year	Reduction of food waste; better meal planning; targeted food shopping	Media campaigns; waste diary; producer–trade cooperation to avoid waster
Buildings	Dwelling & construction	Heating temperature	°C room temperature	Heat rooms less strongly	N/A
	Dwelling & construction	Floor space	m^2 per person	Reduction of floor space per person	Taxation of living space; support for division or swapping of living space
	Dwelling & construction	Warm water use	Litres per household and year	Reduction of warm water temperature	N/A
	Dwelling & construction	Electric appliances	Number per household; size of appliances; usage rate per hour/ day	Reduction of multiple equipment; sharing of appliances; size reduction of appliances; reduction of usage rate	Electricity customer account; feebate system; scrappage premium; promotion of appliance sharing/repair; obligation to identify life-cycle costs and lifetime of products
	Dwelling & construction	Electricity consumption	Kilowatt hours per household and year	Reduction of electric drying, reduction of TV usage	N/A

Source: own representation.

Modelling

Barriers towards integrating sufficiency in modelling, including the following:

- Models are expected to produce quantifiable results with a high probability of occurrence.
- Model development is path-dependent and therefore often slow.
- To date, there is relatively little empirical data on guiding the parameterisation of behaviour. This is relevant for the modelling of sufficiency, but also of consistency and efficiency.
- Models have only been able to map complex chains of action and actor preferences to a limited extent.
- Methods for implementing sufficiency instruments exist (see for example Table 2) but they need to be further developed.
- If sufficiency instruments are to be integrated into models, impact chains should be documented in order to increase robustness of results. It is thus important to consider lead times from cause to impact. Ex-post evaluations of instruments may help to establish good impact chains

- An early and strong dialogue between client/policy maker and scenario developer on impact chains is necessary. This will enable policy makers and scenario developers to act more closely interlinked, which would/could increase the likelihood of policy implementation.

Results

LITERATURE REVIEW RESULTS

We assessed a sample of 16 studies which could fulfil the criteria introduced above. Several studies contained more than one scenario. Six of the 16 studies were from Germany, including a total of 11 scenarios. Nine studies/strategies from European Member States were also assessed (Finland, France, Italy, Poland, Sweden, United Kingdom).

The modelling methodology plays a role in the ability to integrate sufficiency aspects. Several of the scenarios in Table 3 consist of a complex coupling of various models rather than the application of a specific model type. Often, the demand side is modelled using sector specific bottom-up simulation models that generate energy demand. The energy supply side models in turn take the demand as given and run an optimisation to generate energy at least-cost. This, or a very similar approach, is taken for example for Oeko-Institut und Fraunhofer ISI (2015), Bundesregierung (2017), Fraunhofer ISI et al. (2017b) and Association négaWatt (2017b).

Other approaches can be taken, too. For example TIMES models that follow a bottom-up intertemporal optimisation approach, were applied in Pye et al. (2015) and Virdis et al. (2015). The latter also applied multi-sector and multi-region computable general equilibrium models to explore macroeconomic effects. Such macroeconomic models are often applied only after the energy system modelling that derives energy demand and supply has been completed and builds on the results. In some of the studies the modelling methodology was not explicitly described.

Table 3 summarises the findings based on the introduced assessment criteria of Table 1. The two scenarios highlighted in bold print (Table 3) are the only scenarios that fulfilled all of the assessment criteria, these are the Klimaschutzszenario 95 (climate protection scenario 95; abbr. KS95) from Germany, and the scenario négaWatt from France. While in UBA (2018) these scenarios were characterised in more detail we focus here on summarising their commonalities in order to highlight the similarity in how two independent scenarios approached sufficiency in many areas (see Table 4). This may be a first indication that systematic inclusion of sufficiency will likely happen in similar ways across modelling approaches; i.e. also in other studies, albeit probably sometimes not explicitly addressed yet. Please also consult Toulouse et al. (forthcoming) to learn more details about the justification of sufficiency in general and Association négaWatt (2017a), Association négaWatt (2017b), Association négaWatt (2018) and Oeko-Institut und Fraunhofer ISI (2016) to learn more about both scenarios.

EXPERT WORKSHOP RESULTS

On March 2018 representatives from 12 German organisations discussed, at the UBA, the statements introduced in the methodology section and obstacles of integrating sufficiency into models.

The outcome of the discussion points are briefly summarised below in order to demonstrate the complexity of the topic. Furthermore, the findings presented here include information from two interviews with experts who were unable to participate in the expert workshop (Scheffler 2018; Gores 2018).

Contributions to the discussion that contained recommendations and led to the derivation of the guidance do not appear in this section but in the subsection *Guidance* below.

- Sufficiency measures are sometimes used selectively to ensure that a sector achieves its targets.
- Hesitations against modelling behavioural change are disproportionate. System boundaries and shifting effects also play a role in efficiency and consistency. The "modelability" of sufficiency does not differ significantly from the "modelability" of efficiency or consistency. In all three areas, parameterisation is often difficult.
- Existing models, in principle, are already flexible enough to meet the requirements of integrating sufficiency. Uncertainty about how individuals react is not a specific problem to sufficiency.
- Existing models focus on technical aspects and may lack the depiction of individual behaviour. Those models were often developed for specific questions and cannot (easily) integrate further requirements. Calls for tenders often do not include budget for developing new models. New research questions can therefore only be implemented with difficulty.
- Whether sufficiency is necessary at all depends on various factors, such as the desired degree of emission reduction. Less stringent targets therefore make sufficiency less necessary. The need for sufficiency differs from sector to sector. In sectors where more technical options are available, less sufficiency may suffice. In the industry sector, less (domestic) demand may not result in reduced production due to export relationships.
- Climate targets can be achieved without sufficiency, but social costs may be larger. Scenarios can help to inform about the ranges of costs based on different scenarios (i.e. with and without sufficiency and various combinations).
- Although climate goals may be achieved through efficiency and consistency measures only, the simultaneous achievement of sustainability goals becomes increasingly unlikely.
- It is risky to model trends, as they can change quickly resulting in uncertainty. Bandwidths in the results need to be acknowledged.
- Enforcing instrumentation is seen critically. The potential of sufficiency measures needs to be explored first, then it should be shown which measures are necessary. Initially, instrumentation is not necessary but should take place afterwards in the political discussion.
- The caution regarding instruments and measures that target at changing consumer behaviour is disproportionate. Many existing regulations represent constraints on behaviour. One should not be afraid to demand sufficiency more strongly.

Table 3. Summarised results of literature review.

General information			Assessment criteria fulfilment						Sufficiency
Country	Study title	Scenario name	Stringency	Time horizon	Modelling	Sectors	Scenario type	Publication until 31.01.2018	Sufficiency description included?
Germany	**Klimaschutzszenario 2050, 2. Endbericht**	**KS 95**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes (2015)**	**Yes**
	Politikszenarien VIII	MEMS	No	No	Yes	Yes	No	No	No
	Projektionsbericht 2017	MWMS	No	No	Yes	Yes	No	Yes (2017)	No
	Transformationsprozess zum treibhausgas-neutralen und ressourcenschonenden Deutschland	GreenEe*	Yes	Yes	Yes	Yes	Yes	Yes (2017)	Partially
		Green	Yes	Yes	Yes	Yes	Yes	No	NA
		GreenMe	Yes	Yes	Yes	Yes	Yes	No	NA
		GreenLife	Yes	Yes	Yes	Yes	Yes	No	Yes
		GreenSupreme	Yes	Yes	Yes	Yes	Yes	No	NA
	Langfristszenarien für die Transformation des Energiesystems in Deutschland	95% Szenario	Yes	Yes	Yes	Yes	Yes	Not completely	NA
	Treibhausgasneutrales Deutschland im Jahr 2050	THGND 2050*	Yes	Yes	Yes	Yes	Yes	Yes (2014)	Partially
	BDI-Klimapfade der Industrie	NA*	Yes	Yes	Yes	Yes	Yes	Yes (2018)	No
Finland	Energy and Climate Roadmap 2050	Change*	Yes	Yes	Yes	Yes	Yes	Yes (2014)	No
France	Stratégie nationale bas carbone	NA	Yes	Yes	No	Yes	Yes	Yes (2015)	NA
	Scénario négaWatt 2017–2050	**Scénario négaWatt**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes (2017)**	**Yes**
Italy	Pathways to deep decarbonisation in Italy	Demand Reduction Scenario*	Yes	Yes	Yes	Yes	Yes	Yes (2015)	No
Poland	2050.pl The journey to the low-emission future	Modernisation Scenario	No	Yes	Yes	No	No	Yes (2013)	No
Sweden	The Climate Act	–	Yes	No	No	NA	Yes	Yes (2018)	NA
United Kingdom	The Clean Growth Strategy	–	Yes	Yes	No	Yes	Yes	Yes (2017)	No
	Pathways to deep decarbonisation in the United Kingdom	Reduced Demand Scenario*	Yes	Yes	Yes	Yes	Yes	Yes (2015)	Partially
	Zero Carbon Britain. Making it Happen	Zero carbon Britain	Yes	Yes	No	Yes	Yes	Yes (2017)	Yes

*Notes: NA = not available; scenarios marked with * fulfil all of the criteria except a lack of the sufficiency measure(s) description.*

Sources: derived from Association négaWatt 2017b; 2017a; Fraunhofer ISI et al. 2017a; UBA 2017; Ministry of Employment and Economy Energy and the Climate, Finland 2014; Oeko-Institut und Fraunhofer ISI 2015; Centre for Alternative Technology 2017; low-emission Poland 2050 2013; Virdis et al. 2015; THEMA 2016; UBA 2013b; Gerbert et al. 2018; Bundesregierung 2017; HM Government of the United Kingdom 2017; Government of Sweden 2018; Pye et al. 2015

Table 4. Sufficiency aspects across areas in scenarios KS95 and négaWatt.

Area of need	Sufficiency parameter	Used in KS95	Used in Scénario négaWatt
Dwelling	Reduce heating temperature	Yes	No
Dwelling	Reduce floor space per person	No, it increases	Yes
Dwelling	Reduce warm water use	No	Yes
Dwelling	Reduce warm water temperature	No	No
Dwelling/ consumption	Reduction of multiple equipment; sharing of appliances; reduction of size of appliances; Reduction of usage rate	Yes	Yes
Dwelling/ consumption	Reduction of electric drying, reduction of TV usage	No	Yes
Mobility	Less demand for individual transportation; more use of public transport	Yes	Yes
Mobility	Use of smaller cars	No	Yes
Mobility	Reduction of kilometres travelled by car	No	Yes
Mobility	Reduction of private and business air-travel	No, demand increases up to 2050 (national and international aviation)	Yes
Nutrition	Reduction of meat consumption	Yes	Yes
Nutrition	Reduction of food waste	No	Yes

Source: own representation based on Oeko-Institut und Fraunhofer ISI (2015), Association négaWatt (2017a), Association négaWatt (2017b), Association négaWatt (2018).

- Since there is no acceptance of sufficiency yet (see also Gerbert et al. 2018), it needs to be modelled in order to discuss itself and possible ways of how to shape it.
- On the one hand one needs to depict impact chains in order to represent the relevance of sufficiency. On the other hand, however, the establishment of such impact chains is very challenging: they can be complex, specifically due to uncertainty about the time delay between the introduction of an instrument (e.g. an information campaign) and a change in behaviour. Behavioural changes can be triggered by several circumstances, which make it difficult to map a single instrument to a behavioural change.
- In highly globalised sectors, such as agriculture, international interdependencies need to be taken into account by using appropriate global models in order to establish impact chains. However, this is currently very difficult.
- Data availability is poor and poses a challenge. Data through ex-post evaluation still seems to be at the very beginning.

METHODOLOGICAL DRAFT GUIDANCE

On the basis of the insights gained above via the literature review and experts workshop, we formulated draft methodological guidance for modellers:

We recommend to always address the integration of sufficiency in *stringent climate protection scenarios* and across all depicted areas. The omission of sufficiency should at least be justified. The draft guidance reads as follows:

1. Formulate and document justification and derivation for sufficiency in all areas considered. In particular, consult the scientific literature for this purpose where available.
2. Identify relevant parameters for each sufficiency measure and document why they are relevant and which direction of change is necessary. In addition, possible data sources for the parametrisation should be identified and documented.
3. Integrate sufficiency measures in the model by either calibration (if the necessary parameters are already present) or by addition of parameters into the models functional relationship (model development; more time consuming).
4. Where possible, justify the level of change of the parameters on the basis of scientific literature. It may also be possible to derive a calibration from policy objectives. If neither is possible, determine the level of change using expert judgement and document the implementation transparently.
5. Establish and describe impact chains per measure and document the model parameters settings including their temporal development.

In addition, the following methodological recommendations should be implemented:

- All measures adopted, regardless of which group of measures they belong to, should be well justified. Furthermore, limits of predictability and modelability should be addressed.
- Studies should provide recommendations on how the probability of measures being realised can be increased and se-

cured. It then remains the task of policy makers to build on these recommendations.

- Particular challenges in the modelling of behaviour should be documented. This is important since individual reactions to changes are not necessarily rational. Thus, the relationship between input and output can be subject to various uncertainties. Transdisciplinary collaborations may help to better understand such issues.

STRATEGIC RECOMMENDATIONS

Recommendation 1: Exploration of possibility spaces

Political feasibility and social acceptance should not initially determine the choice of measures. Climate protection modelling should be free to explore the effects of different combinations of measures in all areas combined: efficiency, consistency and sufficiency. Then, the order of magnitude of effects can be explored. This can help to identify promising areas for action and the need for appropriate instrumentation. Coarser models may be more helpful than very detailed ones: They are able to pay more attention to interdependencies between sectors and regions. Priority should be given to creating a space of opportunity in which the policy instruments to be developed and the measures to be implemented can move. Which of the instruments and measures from the multitude of calculated scenarios appear acceptable and feasible should only subsequently be discussed and analysed in detail.

Recommendation 2: Base parameterization on adequate groundwork

In order to model sufficiency well, the parameterization should be based on adequate groundwork. For this purpose, we suggest to develop an open-source database including the following elements, ideally in a standardised and structured way:

- List of sufficiency measures including potentials for social transformation and climate protection;
- Overview of existing evaluation results (e.g. Blanck et al. 2014; Federal Government 2017; Fischer et al. 2016; Fischer et al. 2013; Schumacher et al. 2017; Andor and Fels 2017);
- Overview of data and disclosure of assumptions;
- List of data gaps and data requirements;
- Proposals for policy instruments (including an analysis of the advantages and disadvantages);
- Examples of impact chains for instruments.

Like any other database continuous operation and maintenance need to be guaranteed in order for it to provide continuous value added.

Recommendation 3: Factual and positive communication

Sufficiency modelling requires factual and positive communication at various instances: It starts with the communication between the client and the consultant, then spans over process-accompanying communication (e.g. stakeholder driven scenario development), and ends with the translation of results into target-group based language and images.

Communication in this context serves various purposes: the improved understanding of sufficiency, the reduction of prevailing reservations and obstacles and the creation of public acceptance for sufficiency. The latter should also be understood as a design and translation task from science to public. In addition, attempts should be made to communicate sufficiency strategies positively, for example by highlighting co-benefits.

Discussion & further research

The present study emphasised the following: It is necessary to deal with sufficiency in stringent climate protection modelling. If all conceivable climate protection options are examined, political decisions can be based on a sound understanding of the multitude of possible combinations of measures.

Sufficiency is yet to be systematically considered in the modelling of stringent climate protection. This applies at least at German and European level.

The reasons for the lack of consideration are various reservations, for example e.g. regarding system boundaries, shifting effects and the modelability of sufficiency. There are also “technical” obstacles to the modelling of sufficiency, such as restricted model flexibility, missing data and lack of expertise. Further, different modelling methodologies provide varying capabilities of integrating sufficiency. The level of detail of the modelling approach also plays a role on the capability to include sufficiency aspects, including the depiction of the whole sufficiency rationale via impact chains. Future research into systematising the ways of sufficiency integration based on model types therefore is needed.

The draft guidance for systematic integration of sufficiency in climate protection scenarios formulated above provides a first step towards a more systematic integration of sufficiency in modelling and opens up space for further collaborative development. In order for the guidance to provide the intended support, it needs to be further developed according to the needs of modellers. It should cover all relevant areas. We therefore strongly recommend to allocate sufficient time for a series of dialogues with modelling experts to ensure that their requirements are taken adequately into account.

Additional research questions that should be addressed in the future:

- Scenario studies should analyse potentials of sufficiency. In particular, sufficiency potentials with positive incentives should be highlighted. This requires studies to explore bandwidths of sufficiency potentials. Research should be conducted on suitable instruments with simultaneous consideration of associated impact chains. For this purpose, we deem interdisciplinary approaches and incorporation of special expertise in behavioural science and (social) psychology a helpful approach.
- The proposed open-source database on sufficiency should be established and filled successively. This requires a close collaboration of research and modelling.
- Comparative studies, exploratory test modelling and the presentation of good practice examples may facilitate the way on how to integrate sufficiency into models.

The focus of our analysis was on national scenarios. Further analyses on local and regional scenarios will be necessary in order to get an overview of the whole range of current modelling practice, including EU-wide modelling. For example, Schmitt et al. (2015) show that sufficiency is increasingly considered in regional scenarios – at least for selected sectors. Therefore, more in-depth analysis here will be helpful. In highly globalised sectors such as agriculture, appropriate global models that take account of international interdependencies and technical details in an adequate manner will need to be developed.

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