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Sufficiency in energy scenario studies: Taking the potential benefits of lifestyle changes into account

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ABSTRACT

In recent years, a number of energy scenario studies which aim to advise policy makers on appropriate energy policy measures have been developed. These studies highlight changes required to achieve a future energy system that is in line with public policy goals such as reduced greenhouse gas emissions and an affordable energy supply. We argue that behavioural changes towards energy-sufficient lifestyles have considerable potential to contribute to public policy goals and may even be indispensable for achieving some of these goals. This potential should, therefore, be reflected in scenario studies aiming to provide comprehensive advice to policy makers. We analyse the role that energy-sufficient lifestyles play in prominent recent global energy scenario studies and find that these studies largely ignore the potential of possible behavioural changes towards energy-sufficient lifestyles. We also describe how such changes have been considered in several other scenario studies, in order to derive recommendations for the future development of global energy scenarios. We conclude that the inclusion of lifestyle changes in energy scenarios is both possible and useful. Based on our findings, we present some general advice for energy scenario developers on how to better integrate sufficiency into future energy scenario studies in a quantitative manner.

1. Introduction

In recent years, a number of global, regional and country-level scenario studies which aim to advise policy makers on appropriate energy policy measures have been developed (e.g. European Commission, 2011; IEA, 2015a, 2015b; Jeffries et al., 2011; Nagl et al., 2011; Teske et al., 2015). These studies highlight the changes that are needed to achieve a future energy system in line with public policy goals such as reduced greenhouse gas (GHG) emissions, reduced import dependency and/or an affordable and reliable energy supply. Ideally, such scenario studies should highlight the full range of credible options for achieving these public policy goals available to policy makers and societies, who should then choose the options they deem to be preferable or the most promising (Edenhofer and Kowarsch, 2015).

Lifestyles in which users consume less goods and services, have the potential to make a considerable contribution to achieving public policy goals associated with the energy system (Faber et al., 2012; Hallström et al., 2015; Stehfest et al., 2009; van Sluisveld et al., 2016). Consequently, it might be expected that available scenario studies investigate to what extent and under what conditions energy-sufficient lifestyles can contribute to these goals. This article analyses whether this potential is actually discussed in prominent global energy scenario studies published by the International Energy Agency (IEA) and others. We contrast our findings from these studies with selected energy and emission scenario studies which explicitly include the role played by energy-sufficient lifestyles in their respective scenarios. This article aims to contribute to the theory and practice of energy scenario development by outlining the advantages of including future lifestyle changes in scenarios in a manner that is conducive to providing good energy policy advice.

In the next section (Section 2), we explain how we define the term "sufficiency" for the purpose of this article. We do so by differentiating sufficiency from efficiency and consistency and describing three types of sufficiency. In Section 3, we discuss key characteristics of energy scenarios and demonstrate why it is important for energy scenario studies to include scenarios highlighting the potential of future changes towards more sustainable lifestyles. In Section 4, we analyse to what extent prominent global energy scenario studies published recently by the IEA and Greenpeace et al. take the potential of sufficiency into account. We contrast the findings of this analysis by describing a number of scenario studies that have assumed considerable future changes towards energy-sufficient lifestyles. Finally, in Section 5, we draw upon

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the findings and arguments presented in the article to derive some general advice for energy scenario developers and the broader research community on how to better integrate sufficiency into future energy scenario studies in a quantitative manner.

2. Defining sufficiency

Depending on the scope of an analysis and the question to be answered, different aspects and boundaries are highlighted in the definition of sufficiency. The scientific discussion on sufficiency as a strategy was, among others, coined by Wolfgang Sachs. He developed the idea that the two strategies of efficiency and sufficiency should be combined. "While efficiency is about doing things right, sufficiency is about doing the right things" (Sachs, 1999).

Two authors who place the ethical dimension of sufficiency at the centre of their research are Princen (2003) and Muller (2009). Both point out that consumption limits should be defined not only on an individual level, but also on a societal one. Princen (2003) argues that "there can be enough and there can be too much." Defining limits of resource- and energy-intensive behaviour is one of the most difficult and debated aspects of sufficiency. Even though there might be a broad consensus in the literature of the existence of certain thresholds, determining these thresholds is highly contested. Muller (2009) holds the view that energy sufficiency is a duty of all liberal societies to ensure social justice and to avoid external impacts from energy consumption which are harmful to other people.

There is a consensus among supporters of sufficiency that it can result in wellbeing and satisfaction. "Sustainable sufficiency is defined as achieving economic objectives consistent with the principle of right livelihood, ensuring the preservation of the natural environment and the welfare of each individual and society at large. […] The concept of sustainable sufficiency focuses attention on unsustainable consumption patterns within a society obsessed with maximizing short term economic growth whilst ignoring the reality of limits resulting from a finite supply of natural resources" (Lamberton, 2005). This quote indicates that the concept of sufficiency is closely connected to the degrowth paradigm.[1] If widely adopted, sufficiency can be expected to affect economic growth, as it calls for a reduction in consumption levels. There is a debate among researchers whether or not economic activity in affluent societies needs to be reduced in the future in order for human activities to remain within planetary boundaries (Bergh and Kallis, 2012; Jakob and Edenhofer, 2015; Loske, 2015).

For the purpose of this article, sufficiency is especially relevant in regard to its potential to reduce *energy* consumption. It can be seen as an option to reduce GHG emissions from the energy sector. In the following, we develop a specific definition of sufficiency, bearing in mind how sufficiency can be relevant in the development of energy scenarios. In energy scenarios, political choices for achieving sustainability goals are among the main drivers of the energy system. At the highest level of aggregation, these options can be divided into three pillars: efficiency, consistency and sufficiency. Based on a literature review, these are the three main categories of options for achieving sustainability goals (e.g. Huber, 2000; Linz and Scherhorn, 2011; Mundaca, 2010).

Therefore, sufficiency can best be defined by contrasting it with efficiency and consistency. Efficiency is an option in which the input-output relation is improved (*better*). Fewer inputs of material or energy are needed per service unit, or more services are produced from the same amount of material or energy. Consistency aims at fundamental changes in production and consumption by substituting non-renewable resources with renewable resources (*different from today*). A prominent example is the use of renewable energy sources instead of fossil fuels. The option of sufficiency is linked to the level of demand for goods and services – in this context specifically to the level of demand for energy-intensive goods and services. This demand should be limited to a level which still allows for a "good life". In industrialised countries, fulfilling this requirement would certainly lead to a reduction in demand for such goods and services (*less/enough*) (Muller, 2009).

Regarding the implementation of behavioural changes towards energy-sufficient lifestyles, two general leverage points can be identified. On the one hand, there is the purchase, rental and investment phase (e.g. the purchase of a refrigerator, an apartment or a car). In this phase, sufficiency policies target a reduction in the equipment rate and size, or they promote the shared use of goods ("sharing economy", as opposed to individual ownership). On the other hand, reductions can be made in the usage phase; for example by aiming to reduce journey frequency or length, or by moderating room temperature choice in winter.

In terms of energy scenarios, sufficiency can be categorised by the drivers that foster its implementation. Sufficiency in the context of energy-intensive goods and services can be achieved by:

A) Modification of individual preferences
A change in the preference structure of individuals, leading to lower levels of consumption or more sustainable consumption patterns, constitutes one type of sufficiency. In this type of sufficiency, changes in consumption are made voluntarily by individuals and are not associated with any kind of sacrifice. The associated preference changes can be the result of cultural changes or changing societal ideas about what constitutes wellbeing and a "good life" (Schneidewind and Zahrnt, 2014). These changes may be triggered by a pioneer group causing others to follow (Linz, 2012). Policy can try to induce preference changes, e.g. through information campaigns or educational initiatives (Jackson, 2005). An example of the modification of individual preferences is a change in vacation patterns, when destinations that can be reached by bicycle or public transport are preferred over destinations that can only be reached by plane.

B) Modification of relative prices
Consumer demand for goods and services can also be altered by external incentives without the premise of changes in preference structures. Policies can achieve desired changes in the demand for goods and services by changing their relative prices.[2] An example is an increase in taxation levels for energy or emission-intensive goods and services. It should be noted that political measures taken to influence the relative costs of goods and services should ideally result in market prices that mirror their actual societal costs, as only then do markets lead to a socially optimal allocation of goods and services, according to economic theory (Dahlman, 1979). In other words, any political modification of relative prices should be limited to the internalisation of external effects, such as the health costs associated with air pollution or the climate change damages caused by burning fossil fuels.

C) Politically imposed bans or limits
It is also possible to bring about a reduction in the demand for energy-intensive goods and services by banning or limiting their sale or use. From a microeconomic point of view, such political measures lead to "forced sufficiency" and have cost impacts by cutting off certain options within consumers' individual preference structures.[3] This third type of sufficiency is, therefore,

[1] Degrowth can be defined as "the intentional limiting and downscaling of the economy to make it consistent with biophysical boundaries", (Bergh and Kallis, 2012).

[2] Another way for policy makers to reduce the demand for an environmentally harmful product without restricting its sale is to make an alternative and less environmentally harmful product more attractive. For example, public transport could be improved by increasing its comfort level, its frequency and/or its reliability, ideally leading to a reduction in car use. We consider such changes in goods or services to be a special case within our sufficiency type B.

[3] However, it may be justifiable to challenge the typical assumption in economic theory that consumer preferences are formed in a sovereign way and that forced changes necessarily lead to reductions in welfare (e.g. Norton et al., 1998; Penz, 1986; Schubert and Chai, 2012). Furthermore, looking at society as a whole, orders and restrictions may result in positive net effects if they lead to reductions in adverse ecological impacts and if the saved resources are used, for example, to alleviate poverty.

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structurally different from types A and B discussed above and, in narrow definitions of the term, is not considered to constitute sufficiency. An example of this type of sufficiency is the ban of the use of private cars in city centers.

Fig. 1a to c illustrates the microeconomic differences between these three types of sufficiency. For simplicity, each figure assumes that consumers choose between only two products: one is environmentally harmful while the other is environmentally benign. It should be noted that the environmentally benign option does not necessarily need to be a type of consumer product in the traditional sense; it could, for example, be a walk in the park or another form of (non-material) activity. Consumers are restricted in their demand for these two products by their individual budgets and/or time constraints (indicated by the budget line b). Their preferences are depicted by the so-called indifference curves I. Each indifference curve represents those product combinations which lead to the same utility for a consumer.

3. The need for energy scenarios to consider sufficiency

Scenario building is a method for anticipating possible future developments. Scenarios represent causal relationships between diverse input parameters and describe, as output, possible futures within a vast range of plausible future development trajectories. As policy is essentially about choosing between different policy options which result in different future outcomes, policy makers need to be informed about the likely nature of these outcomes. The more complex the system is that is addressed by policy makers and the more far-reaching their decisions are, the more knowledge they need about the likely outcomes of their decisions. The scenario method offers a way to analyse and compare the future consequences of different political decisions in a consistent and transparent manner. The method is frequently used in the energy policy domain, as this domain is characterised by long planning horizons (e.g. in regard to power plants and energy infrastructure) and complex technological, economic and social interactions. The scenario method is therefore of special relevance for providing advice to energy policy makers (Nielsen and Karlsson, 2007).

Scenario developers need to define external elements, i.e. elements which they assume the scenario actors either cannot modify or do not wish to modify. These elements, once specified (and possibly quantified), can be referred to as a scenario's boundary conditions. Embedding the interactions of a scenario's internal elements into a wider environment (the boundary conditions) is a crucial characteristic of scenarios (Hamrin et al., 2007; Kahn and Wiener, 1967; Nielsen and Karlsson, 2007; Opaschowski, 2009; Reibnitz, 1987). Alternative human behavioural options are represented in scenarios by varying the parameters of their internal elements, allowing for an analysis of the interrelationships between internal and external elements. This concept demonstrates two different explanations of the unpredictability of the future:

a) The inability to predict the future development of factors that are within the control of human beings, as the precise choices that human beings will make cannot be anticipated[4]
b) The uncertainty of the status or evolution of the factors that human beings either cannot control or do not wish to control (i.e. uncertainty about the boundary conditions)

Consequently, the combination of these two types of uncertainty leads to the unpredictability of the future. In scenario studies, the boundary conditions are usually described in so-called *storylines*. The distinction between factors that are within the control of human beings on the one hand and boundary conditions on the other is important

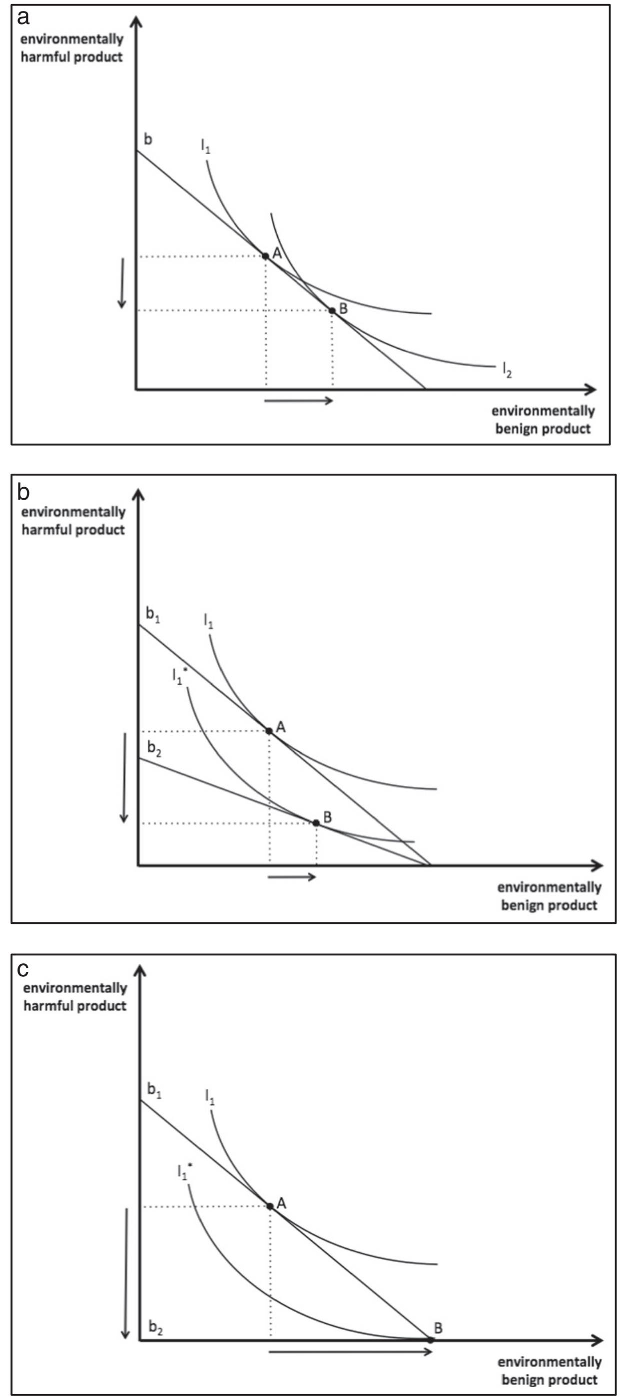

Fig. 1. Illustrations of our three types of sufficiency. a: In sufficiency type A, the location of the indifference curve changes from I_1 to I_2 as a result of changing preferences in favour of the environmentally benign product. This change in preferences leads to a reduction in the demand for the environmentally harmful product and an increase in the consumption of the alternative product, even though the relative prices of both products remain unchanged. b: In sufficiency type B, the environmentally harmful product becomes more expensive, for example due to higher taxation. Consumers can now afford less of this product, which is reflected by the shift in the budget line from b_1 to b_2. As a consequence of the change in relative prices, consumer demand for the environmentally harmful product reduces, even though consumer preferences have not changed. Consumers fall to the lower indifference curve I_1^* because they can no longer afford the combination of products on the indifference curve I_1. c: Finally, in sufficiency type C, the government prohibits the sale of the environmentally harmful product, resulting in the new budget curve b_2 running on the x-axis. Clearly, in this case, the demand for the environmentally harmful product is reduced to zero (assuming the government is able to fully enforce the ban), while demand for the alternative product increases.

[4] The term "human being" here refers to individuals as well as to the collective (i.e. politics).

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when considering how to integrate sufficiency into scenario analysis. This is due to the fact that it leads to the question of whether sufficiency should be introduced in scenarios through the storyline or through the specific actions and measures of scenario actors such as policy makers or societal groups.

While it is obvious that individuals and societies have significant choice about the type and volume of goods and services that they consume, in most cases scenario developers treat consumption patterns as an external element. If sufficiency is taken into account at all in a study's scenarios, it is usually assumed to simply emerge – with no detailed discussion on how the accompanying lifestyle changes are initiated (see Section 4). Fig. 2 depicts schematically a number of elements that influence energy system development and how these are typically classified within energy scenarios. Some elements clearly have to be treated as external (e.g. fossil fuel resources), while others clearly have to be treated as internal (e.g. taxation rates for different energy sources). Additionally, there are a number of elements for which classification is less clear and these include sufficiency or consumption patterns.

Scenario developers intending to integrate sufficiency into their scenarios need to decide whether to treat sufficiency as an internal or an external element. We argue that it is preferable to treat sufficiency as an internal element, i.e. a human behavioural option. Only by treating sufficiency in this way can scenarios illustrate which political measures or social dynamics need to be implemented or initiated in order to induce energy-sufficient lifestyles. Treating sufficiency as an external element that may simply emerge in the future has a key disadvantage: it may lead the readers of the scenarios, including policy makers, to believe that no measures need to be taken to promote energy-sufficient lifestyles.

Regarding energy scenarios, we see a particular need for these to take into account the possibility of a future with lifestyles that are based on sufficiency. Over the past two decades, there has been growing concern among policy makers around the globe about the need to significantly reduce energy-related CO_2 emissions in order to prevent the worst possible consequences of global warming. National, regional and global energy scenarios have, therefore, increasingly focused on illustrating how significant reductions in these emissions can be achieved. Good policy advice should highlight all the possible options for achieving political goals and leave it to political and societal debate to choose the preferred options (Edenhofer and Kowarsch, 2015). We argue that sufficiency is an important option for achieving GHG emission reductions and should, therefore, be reflected in energy scenario studies. However, as the following section (Section 4) will show, today's prominent global energy scenario studies largely neglect the potential of sufficiency.

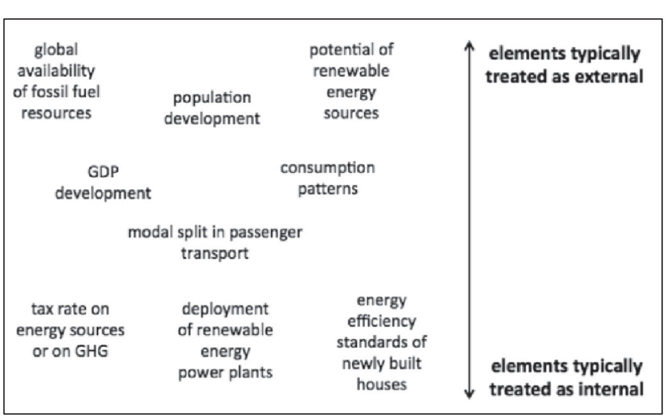

Fig. 2. Schematic illustration of the differentiation between internal and external elements in the energy scenario literature.

Instead, these studies typically illustrate that ambitious CO_2 mitigation is feasible by means of technological solutions requiring only minor lifestyle changes (or no changes at all), despite the assumption of further economic growth in all regions of the world. We argue that a detailed look at the results and assumptions of the scenarios calls this view into question. Specifically, we point out the following four aspects that we believe indicate the significant risk of relying solely on technology to achieve the desired major reductions in energy-related CO_2 emissions:

- Uncertainty about whether efficiency improvements can actually be achieved
  All mitigation scenarios assume much greater improvements in energy efficiency in the future than in the past. While in principle such improvements are technologically feasible, it is unclear whether society will actually be able to achieve these potential efficiency improvements and whether all the cultural, political and economic barriers to greater efficiency can really be overcome. Furthermore, it can be argued that energy scenarios tend to overestimate the overall impact of efficiency measures on energy reduction by neglecting possible rebound effects.[5]
- Uncertainty about whether the supply side can be transformed as quickly as envisioned
  On the supply side, the sustained introduction of new low-carbon energy technologies would be required on a massive global scale. For example, in the IEA's 2DS scenario (IEA, 2015b), 21 GW of new nuclear power plants are built every year on average in the period from 2026 to 2050, while in the recent past (2008–2012) there was an annual increase of less than 3 GW. Likewise, new Concentrated Solar Power (CSP) plants in the scenario are assumed to be installed at an annual rate of 27 GW between 2026 and 2050, while annual installation in the recent past was less than 0.5 GW. While there may be no actual technological barrier to increasing the use of each technology on the scale envisioned in the scenarios, it is likely be a considerable challenge from a system perspective to achieve the proposed increase and parallel implementation of *all* the different technologies. This challenge is further complicated by the fact that, simultaneously, the energy system's infrastructure needs to be adjusted in order to ensure a stable supply of energy.
- **Mass implementation of low-carbon technologies may violate non-climate related sustainability criteria**
  Relying heavily on supply side low-carbon technologies risks neglecting sustainability criteria other than CO_2 mitigation. For example, the use of Carbon Capture and Storage (CCS) in combination with either fossil fuels or bioenergy is associated with a number of negative effects on the environment and on human health, caused among other things by airborne emissions (Corsten et al., 2013; Siirila et al., 2012). Nuclear power, on the other hand, continues to provoke debate regarding long-term waste disposal, its role in the proliferation of nuclear weapons and the risks associated with potential large-scale accidents or terrorist attacks (Ahearne, 2011). Even the use of renewable energy technologies can lead to undesired impacts e.g. on biodiversity or resource requirements (Kleijn et al., 2011; Viebahn et al., 2015) if the implementation of these technologies is not carefully managed. The level of risk associated with neglecting social and/or ecological needs obviously increases relative to the scale of the implementation of these low-carbon technologies.
- **The broad societal support required for successful transformation cannot be guaranteed**
  Scenario studies show that achieving ambitious CO_2 mitigation targets will require higher energy system investments than in a business-as-

[5] The rebound effect describes the phenomenon in which improvements in energy efficiency can lead to an increase in demand for goods or services. This increased demand leads to additional energy consumption which can (partially) negate the original energy savings.

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usual scenario (IEA, 2015b; Teske et al., 2015). During the initial phase of the transformation, these higher investments will not be offset by lower fuel expenses. Accepting higher costs is likely to require broad societal support for the transformation of the energy system. From today's perspective it is unclear whether this support will be adequate, especially given that stakeholders with vested interests are likely to use these upfront costs to try to persuade the public to demand a slow-down of the transformation process.

Similar arguments against focusing solely on technological solutions in climate change mitigation are also put forward by other authors, including Franceschini and Pansera (2015), van den Bergh (2013) and van Sluisveld et al. (2016).

The doubts raised above about the prospects of attaining mitigation pathways as described in published decarbonisation scenarios should not be misunderstood. We wholly support efforts to significantly increase energy efficiency and to rapidly grow the share of renewable energy sources in energy supply. However, simply hoping for the flawless development of energy efficiency and energy supply decarbonisation to materialise is, in our view, an over-optimistic assumption given the highly complex nature of society and its energy system – and the considerable risks associated with unmitigated or inadequately mitigated climate change.

4. Sufficiency in global energy and emission scenarios – a literature review

In this section we consider the role that sufficiency plays in the literature on global energy and emission scenarios. The first part of the section reviews three recently released global energy scenario studies that are frequently referred to in scientific and political discussions on the future of the global energy system. We find that these studies' scenarios do not take sufficiency into account or do so only marginally. In the second part of this section we contrast this finding by discussing selected global energy and emission scenario studies that include scenarios which assume changes towards energy-sufficient lifestyles. These latter studies are not as frequently cited in global energy and energy policy discussions. Most of these studies also do not describe the global energy system in detail, but instead either focus on certain types of energy consumption (e.g. aviation) or investigate more generally all relevant human-induced changes to the global environment. This two-step approach aims to highlight that on the one hand much of the prominent literature on global energy scenarios lacks consideration of sufficiency, while on the other hand energy and emission scenario studies released in the past have shown that it is possible and useful to integrate sufficiency into energy and emission scenarios.

4.1. Examples of prominent recent global energy scenario studies

We initially consider three global energy scenario studies from two different organisations to evaluate the role that sufficiency plays in some recently released, prominent global energy scenario studies (IEA, 2015a, 2015b; Teske et al., 2015). Two of the studies were published by the International Energy Agency (IEA) and the other one was published by Greenpeace and two renewable energy industry associations. Scenarios from these three studies were selected for this review for the following reasons:

- All three studies include detailed descriptions of their scenarios, including information about energy service demand.
- All three studies include ambitious mitigation scenarios (see Table 1), meaning that potential emission reductions through lifestyle changes would be especially valuable.
- The two IEA studies are part of two prominent series of scenario studies. Results from these series have been cited frequently by researchers (e.g. Haley, 2012; Islam et al., 2013; van der Zwaan et al., 2016) and policy makers (European Commission, 2011; G7 Energy Ministerial Meeting, 2016).
- The study commissioned by Greenpeace, GWEC and SolarPower Europe is also part of a series of publications that has been cited by many researchers, including the IPCC (e.g. Esteban and Leary, 2012; Fischedick et al., 2011; Haley, 2012).

The following table provides an overview of the three scenario studies analysed and the energy system CO_2 emission reductions achieved in each study's most ambitious mitigation scenario.[6]

Our analysis established that none of the mitigation scenarios in these three global energy scenario studies explicitly assume that people will significantly modify their consumption patterns over the next decades compared to a business-as-usual (BAU) scenario.[7] In all the studies' mitigation scenarios, behavioural changes are only assumed to take place in the transport sector compared to a BAU scenario. All three studies explicitly assume in their most ambitious mitigation scenarios that there will be a shift towards more energy efficient modes of transportation compared to BAU (higher shares of travel by rail, bus, cycling and/or walking and smaller shares of travel by car and/or plane). As changing the mode of transport requires users to make significant behavioural changes, the modal shift towards less energy and carbon-intensive modes is here considered to be a mitigation option that can be classed under sufficiency.[8]

In addition to this modal shift, two of the three studies (with IEA, 2015a being the exception) assume in their most ambitious mitigations scenarios that transportation volumes are reduced to some extent in comparison to the respective BAU scenarios. In its most ambitious mitigation scenario the study by Greenpeace et al. (Teske et al., 2015) also explicitly assumes the future purchase of smaller cars than in its BAU scenario. Similarly, in their policy recommendations, the authors of the Energy Technology Perspectives 2015 study (IEA, 2015b) suggest that one way to make passenger road transport more efficient is to switch "towards smaller and/or less powerful vehicles".

This indicates that in the transport sector some (limited) form of sufficiency is taken into account in all of the scenario studies analysed. The limited information provided by the studies indicates that this is mostly assumed to be a collective form of sufficiency (our "type B" sufficiency); for example, "massive policy intervention" (Teske et al., 2015) and "travel demand management" (IEA, 2015b) are mentioned as prerequisites for achieving modal shift in the transport sector. The study by Greenpeace et al. (Teske et al., 2015) states that in its mitigation scenarios "transport pathways do not rely on the very few idealists who always do 'the right thing'. Among the policy measures proposed by the study to reduce transport demand are "charge and tax policies that increase transport costs for individual transport". Furthermore, according to the authors, cities particularly need to change "so that making the 'right choice' will be also the 'easiest choice'".

However, at the same time, the authors of the Greenpeace et al. study (Teske et al., 2015) appear to suggest that some changes in

[6] However, in the BAU scenarios of the analysed studies, consumptions patterns are expected to change in the future, as average income continues to increase. As in the past, per capita demand for many products and services is expected to increase, including for energy-intensive amenities like air travel, residential floor area or air conditioning.

[7] We recognise that a case can be made to classify modal shift as efficiency rather than sufficiency. After all, the overall volume of passenger transport does not change in the case of modal shift, but merely becomes less energy-intensive. However, our view emphasises the fact that people typically not only wish to travel from one point to another but also wish to do so within a short time or with a certain level of comfort and flexibility. Taking these additional demands into account, it becomes clear that switching, for example, from car to bus or from airplane to high-speed train may be interpreted as switching to a service which has other characteristics, some of which are likely to be judged as less favourable by a number of travellers.

[8] It should be noted that both IEA studies include not only energy-related but also process-related CO2 emissions from the industrial sector, while the study by Greenpeace et al. does not account for process-related CO2 emissions.

Table 1
Overview of the analysed global energy scenario studies.
Sources: IEA, 2015a, 2015b; Teske et al., 2015.

Name of the study	Organisation	Publication date	Change in energy system CO_2 emissions compared to 2010 in each study's most ambitious mitigation scenario	
			by 2030	by 2050
energy [r]evolution – A Sustainable World Energy Outlook 2015	Greenpeace/GWEC/ SolarPower Europe	September 2015	−32%	−100%
Energy Technology Perspectives 2015	IEA	May 2015	−16%	−55%
World Energy Outlook 2015	IEA	November 2015	−18%	–

individual preferences leading towards energy-sufficient lifestyles (our "type A" sufficiency) will be required in the coming decades. "The transport sector requires sufficiency especially in regard to usage of individual cars and aviation." No specific reference to sufficiency or similar remarks about the need for changes in individual preferences can be found in the other scenarios analysed. Nor do we find statements in any of the three scenarios arguing that behavioural changes can or should also be triggered by strict policy mandates (our "type C" sufficiency).

While none of the analysed scenarios seem to include in their quantitative modelling more dramatic changes towards sufficient lifestyles (e.g. a reduction in demand for consumer goods), the potential for behavioural changes to contribute to sustainable development is recognised as a central principle in the Greenpeace et al. study (Teske et al., 2015). It stresses that "alongside technology driven solutions, lifestyle changes […] have a huge potential to reduce greenhouse gas emissions". At the same time, the study states that "[n]o behavioural changes or loss in comfort levels" are assumed for the quantitative scenarios.

Table 2 provides an overview of the types of lifestyle changes considered in the most ambitious mitigation scenario of each of the three global energy scenario studies analysed. The table also contrasts the types of lifestyle changes included in the scenarios with examples of lifestyle changes that, according to the literature, can significantly reduce energy demand and CO_2 emissions.

Table 2 suggests that, currently, many scenario developers are cautious in quantitatively implementing assumptions about far-reaching

Table 2
Overview of the types of lifestyle changes considered in the analysed scenario studies and examples of additional types of lifestyle changes.
Sources: Faber et al., 2012; Hallström et al., 2015; IEA, 2015a, 2015b; Teske et al., 2015; Tom et al., 2015; van Sluisveld et al., 2016.

Lifestyle changes explicitly (and mostly moderately) taken into account in each analysed study's most ambitious mitigation scenario	
energy [r]evolution – A Sustainable World Energy Outlook 2015	• Shift towards more energy efficient modes of transportation • Reduction in transportation volumes • Use of smaller cars
Energy Technology Perspectives 2015	• Shift towards more energy efficient modes of transportation • Reduction in transportation volumes • Use of smaller cars (mentioned as *one* way to increase efficiency)
World Energy Outlook 2015	• Shift towards more energy efficient modes of transportation
Examples of additional lifestyle changes that can significantly reduce energy demand and CO_2 emissions, according to the literature	
• Reduction in room temperatures in winter • Reduction in floor area per person • Reduction in the number and sizes of household appliances and their use • Reduction in the purchase of consumer goods (incl. sharing consumer durables with other people) • Reduction in average meat consumption	

lifestyle changes. The analysed scenario studies assume limited behavioural changes in the transport sector only, mostly in the form of modal shift. The effect of these changes on total energy sector CO_2 emissions are limited. For example, in the Energy Technology Perspectives 2015 study (IEA, 2015b), modal shift and transport reductions combined result in annual CO_2 emission reductions in the 2DS scenario of about 2.5 Gt by 2050 compared to the baseline scenario. This represents only 6% of the overall energy sector emission reductions (41 Gt) by 2050. In contrast, technological solutions in the transport sector (more efficient vehicles and low-carbon fuels) are assumed to result in almost three times this reduction in annual emissions (about 7 Gt).

4.2. Global energy and emission scenario studies taking sufficiency into account

The fact that the prominent global energy scenario studies analysed in the previous sub-section only take marginal account of the potential for lifestyle changes to reduce energy demand and GHG emissions may come as a surprise. After all, other global energy and emission scenario studies have, in the past, explicitly included scenarios assuming significant changes towards energy-sufficient lifestyles. Some of these studies are discussed in the following. While we limit our discussion to *global* scenario studies, it should be noted that there are also some *country-specific* scenario studies that have included scenarios assuming energy-sufficient lifestyles (e.g. Emelianoff et al., 2013; Prime Minister's Office, 2009; Skea et al., 2011). Furthermore, while our focus is on studies released since 2000, some older energy scenario studies have considered the future potential for lifestyle changes (e.g. Carlson et al., 1980).

Among the most prominent international studies examining lifestyle changes within scenarios are two publications by the United Nations Environment Programme (UNEP). The *Global Environment Outlook 3* (Bakkes et al., 2004; UNEP, 2002) and *Global Environment Outlook 4* (UNEP, 2007) both include one scenario that explicitly assumes lifestyle changes compared to today and compared to a future BAU scenario. The reports develop distinct scenarios to gain a better understanding of possible future developments in various parts of the global environment up to the year 2032 (UNEP, 2002) and 2050 (UNEP, 2007). In the "Sustainability First" scenario, people increasingly emphasise the values of solidarity, reciprocity, sufficiency and stewardship. This shift in values is assumed to be driven mostly from the bottom up by individuals and grassroots organisations, which become increasingly involved in setting the policy agenda. Specifically, the authors note that "as the limits of a top-down, policy-driven approach are realized, the shift toward sustainability is increasingly accomplished through lifestyle changes" (Bakkes et al., 2004). Not surprisingly, various indicators of environmental damage are lower in the "Sustainability First" scenario for the coming decades than in the three other scenarios presented by each report.

The 2013 study *World Energy Scenarios* by the World Energy Council (World Energy Council, 2013) developed two different global energy scenarios to 2050. These scenarios differ, among other things, in regard

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to lifestyle assumptions. In the Symphony scenario, global final energy demand in 2050 is 20% lower than in the Jazz scenario due to environmentally-conscious citizens. Lower consumption levels are one reason for energy-related CO_2 emissions in the Symphony scenario peaking by 2020, while they peak 20 years later in the Jazz scenario. By 2050, energy-related CO_2 emissions in the Symphony scenario are less than half the level of those in the Jazz scenario (19 Gt CO_2 compared to 44 Gt CO_2). However, the two scenarios also vary in the use of energy supply technologies, with all the low-carbon electricity generation options (renewables, nuclear, CCS) being more aggressively supported in the Symphony scenario compared to the Jazz scenario.

Of the four global scenarios developed within the European research project *PASHMINA* (Sessa and Ricci, 2014), one scenario assumes that consumption and travel needs will be considerably reduced by 2050 in comparison with the other three scenarios, as a result of pervasive lifestyle changes. People in this "New Welfare" scenario are assumed to become more concerned about wellbeing and quality of life than about economic wealth. Instead of material consumption, education and research are assumed to become central social values. Global GHG emissions in the New Welfare scenario see a greater reduction by 2050 than in the other three scenarios, due mainly to lifestyle changes but also supported by "radical changes of urban infrastructure, working life and goods and services delivery schemes".

Another European research project (Berghof et al., 2005) examined the consequences of future developments in air travel up to the year 2050. One of the four scenarios developed in the *CONSAVE 2050* project is the "Down to Earth" scenario, in which changing values, regional lifestyles and high levels of environmental consciousness among the general public are assumed. In this scenario, the increase in global demand for air passenger transport between 2000 and 2050 is limited to an average annual rate of 0.5%, while the increase is considerably greater (average annual rates of 1.5% to 3.8%) in the three other scenarios.

Finally, the *Global Energy Assessment* study, developed under the lead of the International Institute for Applied Systems Analysis (Johansson et al., 2012), presents a large number of mitigation pathways for the global energy system based on three distinct pathway groups. One of these groups, the GEA-Efficiency group, emphasises demand side efficiency improvements and also assumes some behavioural changes compared to today and in contrast to the other two pathway groups (GEA-Mix and GEA-Supply). These changes are largely limited to the transport sector, where shifts towards public transport and reduced car ownership are assumed. While energy demand is lowest in the GEA-Efficiency pathways, cumulative emissions are similar in all three pathway groups as GEA-Mix and GEA-Supply compensate for higher energy demand by the greater use of low-carbon energy supply.

These studies differ in regard to the detail they provide in explaining the assumed shifts in values and lifestyles and how these shifts are assumed to be triggered. In the World Energy Council study (World Energy Council, 2013), the PASHMINA project (Sessa and Ricci, 2014) and the two Global Environment Outlooks (UNEP, 2007, 2002), changes in values and/or in environmental consciousness are described and are apparently assumed to emanate from within society, but little or no information is provided to explain what triggers these changes. The CONSAVE 2050 study (Berghof et al., 2005) is more explicit, noting that "heightened environmental consciousness might be brought about by clear evidence that impacts of natural resource use, such as deforestation, soil depletion, over-fishing, acidification, and climate change pose a serious threat to the continuation of human life on Earth."

In the studies mentioned in the previous paragraph, policy changes are not described as key triggers for more sustainable lifestyles, although the two UNEP studies (UNEP, 2007, 2002) and the World Energy Council study (World Energy Council, 2013) suggest that policy makers are expected to *react* to the new social norms by enacting policies that foster more sustainable lifestyles. In contrast, the Global Energy Assessment (Johansson et al., 2012) specifically focuses on policy measures that can lead to or support lifestyle changes. It devotes several pages to a discussion of the potential role and possible limitations of government policies to promote more sustainable lifestyles.

None of the analysed scenario studies suggest that policies banning certain goods and services are required, viable or desirable.

5. Conclusion and advice for energy scenario developers

As indicated, recently released prominent global energy scenario studies analysed in this paper barely take lifestyle sufficiency into account when presenting policy options. We have argued that this lack of analysis of the potential of sufficiency to contribute to a reduction in energy demand and GHG emissions is a weakness in energy scenario studies which aim to provide advice to policy makers. We suggest that future scenario studies should quantitatively assess the potential of sufficiency. The quantitative potential of lifestyle and behavioural changes should be highlighted more prominently in these scenarios and should not be blurred by combining differences in lifestyle assumptions with unrelated differences in energy efficiency and/or energy supply – as is the case in some of the scenario studies discussed in the previous section (Johansson et al., 2012; World Energy Council, 2013). Sufficiency and changes in lifestyle should rather be embedded, discussed and quantified independently of technology decisions. Ideally, studies should also discuss and – as far as possible – model the impact on economic activity of energy-sufficient lifestyles.

Based on our analysis, we make five general suggestions to energy scenario developers and the broader research community aimed at promoting the comprehensive consideration of sufficiency in future energy scenarios:

- With energy scenario studies typically comprising several diverse scenarios, sufficiency should be integrated in at least one scenario. It should be integrated either in terms of an alternative storyline or – ideally – in terms of a political and societal course of action.
- Narratives underlying the quantitative assumptions for sufficiency potentials can help to illustrate the plausibility of the envisaged development. Narratives can create a picture depicting sufficiency-oriented lifestyles, can indicate how fulfilling they may be and can highlight the central issues that policy makers and society need to manage. A participative development of these narratives can enhance their acceptance and their strength.
- In recent years, a number of studies have attempted to quantify the potential of sufficiency measures (Faber et al., 2012; Hallström et al., 2015; Stehfest et al., 2009; van Sluisveld et al., 2016). Future scenario studies could draw on these studies when devising scenarios that take into account lifestyle changes.
- Scenario studies dealing with lifestyle changes should also describe the triggers for sufficiency. Scenario authors can learn from the European research project SPREAD – Sustainable Lifestyles 2050 (see Neuvonen et al., 2014), which considers, among other things, potential triggers that may lead to lifestyles that are more sustainable.
- Further advances in the following research areas may help to better integrate sufficiency in future energy scenarios:
  (1) Understanding the potential of sufficiency to help reduce energy demand and respective emissions
  (2) Identifying promising (political) strategies to support energy-sufficient lifestyles
  (3) Understanding the dynamics and transformational potential of bottom-up sufficiency initiatives
  (4) Advancing methods to properly integrate sufficiency into existing energy models

If these general suggestions are taken into consideration, energy policy advice will be improved by outlining energy scenarios which highlight the full range of available GHG mitigation strategies. Such scenarios may be able to show policy makers and the public how

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ambitious climate change mitigation targets can be achieved without relying on excessively optimistic technological assumptions, and may possibly increase public support for changes to the lifestyles of the more affluent of the world's population.

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