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Position Paper

Consulting with energy scenarios

Requirements for scientific policy advice

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Foreword

The transformation of the energy systems at the national, European and global level is one of the great challenges of the 21st century. In the coming decades, this process will result in developments we cannot anticipate today. When it comes to designing and shaping this transformation process, energy scenarios are a valuable instrument.

Science and research must rise to the challenge of modelling scenarios that adequately take both the complexity of the energy system and uncertainties regarding future developments into account. To accomplish this, experts use extensive data sets, complex models and assumptions about long-term trends. Considering the importance of the resulting studies for the debates on energy policies, external experts should be able to verify the data, models and specific assumptions. The results of scenario studies, on the other hand, should be presented to allow even non-scientific readers to understand and assess them.

Scientific validity and unbiasedness, transparency and comprehensibility – these are the basic requirements energy scenarios should meet in order to be of value for energy policy decisions. We sincerely hope that both the present guidelines for the preparation and interpretation of energy scenarios and the policy options described will be of use for political, social and scientific stakeholders and contribute to improving consulting practices.

The present position paper was drawn up by the working group "Scenarios" in the Academies' Project "Energy Systems of the Future". We would like to express our sincere thanks to the scientists and experts who agreed to take part in our workshops to share their experiences, as well as to the reviewers for their comments.

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Summary

Energy scenarios are an important tool for the systematic transformation of the energy system: by identifying possible development paths for the energy supply, scenario studies provide guidance for political, social and economic decisions. They are an integral part of studies usually commissioned by players from politics, the industry or non-governmental organisations and carried out by scientific institutes and consulting companies.

This position paper proposes quality standards for energy scenario studies intended as scientifically sound contributions to the political and public debate. These studies attempt to analyse what future developments are possible. With a view to the multitude of factors determining the energy system, not only one but usually several scenarios are calculated and evaluated using mathematical models.

Energy scenario studies must fulfil three basic conditions: They must be a) scientifically valid, b) transparent and c) unbiased.

To be **scientifically valid,** an energy scenario study must be conducted and documented in accordance with the standards of good scientific practice. A precondition is the use of scientifically recognised methods, models and data. This could be ensured by a scientific advisory board accompanying a study throughout its evolution. Alternatively or, indeed, in addition, independent experts might be called upon to monitor the study results.

Transparency requires the publication of the studies. Particularly studies commissioned by government institutions should be available to the public. If they are to contribute to a democratic discussion and decision-making process, energy scenarios must also be comprehensible to the respective target groups. This could involve adapting the wording of different sections of a study to the level of knowledge and demands of their respective target groups. It is particularly important to point out very clearly any uncertainties in an analysis, as well as their consequences for the results and conclusions. From a scientific perspective, transparency implies not only comprehensibility, but also scientific replicability. In other words, an expert should be able to recalculate the results of the study. To this end, the scientific community, or at least reviewers, must be granted access to the basic data, the modelling principles and the underlying assumptions. This could, for example, be achieved by publishing the information on the Internet. Currently, economic considerations or contractual agreements usually prevent the institutions responsible for the development of energy scenarios from disclosing the relevant models and data. Consequently, formats and guidelines for the disclosure will have to be established. Options for increasing the transparency include the establishment and maintenance of a set of reference data, and assumptions for the German energy system and the use of open source models.

Unbiasedness implies that measures by which the commissioning institutions or other stakeholders influence the study are only permissible if they are

openly communicated along with their possible effects on the results and conclusions. Transparency is pivotal in this instance, as the choice of assumptions and the determination of target values narrows the number of calculations down to only a few of many possible scenarios.

The commissioning and the implementing organisation share the responsibility for the generation of energy scenarios. While the practical conditions of consulting are largely set by the commissioning organisation, the implementing institution will usually determine the methods at its discretion. The development and establishment of general standards for energy scenario studies can improve these interaction processes. The identified requirements of scientific validity, transparency and unbiasedness constitute the basis for such standards. Public authorities, in particular, are well placed to establish such standards for publicly funded studies by including them in their tenders: A separate document with these standards could be formally attached to future tenders.

The main requirements for energy scenarios:

- Energy scenario studies must employ scientifically accepted state-of-the-art methods, models and data to ensure **scientific validity**, and they have to be prepared in an **unbiased** manner.
- The presentation of (a) the methods, models and data and their consequences for the results and (b) the extent and significance of the uncertainties inherent in the scenarios must **meet the respective addressees' requirements**.
- Any measures by which the commissioning organisations (or other stakeholders) might **influence** the modelling of a scenario are to be **disclosed**.
- The documentation must ensure that the **results** are both **comprehensible** to the addressees of the study and **scientifically replicable**.

1 Motivation and objectives

Energy scenarios are a central element in the discussions about the design of the energy system. They set reference points for energy policy decisions and offer orientation to stakeholders from various backgrounds. Typically, energy scenarios are elements of larger studies launched by ministries, environmental organisations, associations, companies and other organisations, and carried out by scientific institutions or consulting companies. We already have a large and constantly increasing number of such studies available for the German energy system, to which must be added those focusing on the European or global energy supply.

Most of these studies have the twofold objective of advising the political echelons – to which the commissioning organisations will usually belong – and of contributing to the public debate on the transformation of the energy system. Therefore, they are, as a rule, publicly available and comprise a rather easily comprehensible summary. Some of these studies, e.g. the recent *Energy Reference Prognosis* launched by the Federal Ministry of Economics and Technology,[1] primarily address decision-makers; others target a broader public, for instance the study *Energy [R]evolution* commissioned and partly conducted by Greenpeace[2]. The present position paper focuses on energy scenario studies mainly intended as input for political decisions, their public reception being of secondary importance.[3]

Energy scenario studies are a scientific challenge dealing with the multilayered complex of interacting technical, economic, social and environmental factors known as the energy system. In order to analyse these interactions, the system is described using models that simplify it. The fact that the future development of the energy system depends on factors difficult to predict adds to the challenge. As a consequence, energy scenarios are fraught with uncertainty. The authors of energy scenario studies are confronted with the additional challenge of describing their statements and the scientific methods by which they were developed in such a way as to reach a largely non-scientific set of addressees.

This challenge has yet to be adequately met. This realisation is the starting point of the present position paper. Typical shortcomings include inadequate descriptions of the models, deficient documentation of the data and underlying assumptions, and a lack of clarity as to the uncertainties inherent to the conclusions. It is also frequently unclear whether and how the results and conclusions are affected by specifications prescribed by the

1 EWI et al. 2014.

2 Most recently Greenpeace et al. 2015.

3 The creation and use of energy scenarios involve multilayered, complex processes. These processes are by no means solely science-based, nor is their target confined to gaining knowledge. Studies can likewise be launched, for instance, to substantiate established convictions. The goal of this position paper is not to analyse such processes. Rather, it is centred on meeting the claim of scientific validity and the ensuing requirements. Identifying the crucial points where these requirements threatened to clash with non-scientific criteria and devising appropriate ways to get around these problems is the objective of the present paper.

commissioning institutions. In such cases, both the political purpose and the scientific validity of the studies are difficult to assess. If energy scenarios are to play a part in democratic discussions and decision-making processes, these shortcomings need to be addressed. To this end, this position paper attempts to point out specific approaches.[4]

The policy paper is aimed primarily at those shaping the framework of scientific policy advice based on energy scenarios. Amongst them are representatives of the respective commissioning organisations, in particular employees of public institutions such as ministries, as well as researchers responsible for the modelling of the studies. More generally, the paper addresses every person wishing to read and assess energy scenarios, e.g. journalists, members of non-governmental organisations and the informed public.

The position paper is structured as follows: Readers on a tight schedule will find the key messages and the main requirements for energy scenarios summarised in the abstract. Those primarily interested in practical aspects are referred to chapters 4 and 5. Chapter 4 outlines the responsibilities the commissioning organisation and the institutions conducting the study have with regard to practical consulting. Chapter 5 contains specific options for action for both sides. The responsibilities and options are developed and substantiated in chapters 2 and 3, with chapter 2 examining the subject of "Energy Scenarios" and chapter 3 elaborating on the requirements they must fulfil. Chapter 6 summarises challenges and options, viewing them in a broader context.

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4 Droste-Franke et al. 2015 analyse the role of energy scenarios for decision-making processes in the context of the energy transition and give recommendations regarding the evolution of established advisory practices. The present position paper extends this analysis by detailing and specifying central requirements for energy scenario studies and options to improve them.

2 On energy scenarios[5]

An energy scenario describes a possible future development (or a future state) of the energy system. The exact (sub)system analysed and the specific approach depend on the issues to be examined. A study can, for instance, consider the energy system of a single city,[6] examine the systemic characteristics in a specific country,[7] or else consider the energy system from a global perspective.[8] Some scenarios cover only the power supply system, while others include the heat supply or the mobility sector. From a technical point of view, some scenarios evolve around the basic question of financing, whereas others focus mainly on issues of technical feasibility.

A scenario describes a possible future development. A development is possible if it is consistent with our available knowledge of the energy system and of the relevant factors shaping its evolution. Hence, scenarios differ significantly from (deterministic) prognoses which predict future developments or states.[9] Additionally, a scenario does not imply any statement as to the probability of a development or state.[10]

With a view to the multitude of factors determining the energy system, most scenarios are created by means of computer models. The variables of the model reflect the characteristics of the system and the most important influencing factors. Such features are, for instance, the installation and operating costs of different technologies for energy generation and use, their technical efficiency rates, or the amount of carbon dioxide (CO_2) emissions they account for. To compute a scenario, numerical assumptions will have to be made, i.e. specific figures determined, for all variables not calculated by the model. This refers to e.g. fuel prices, the development of the energy demand or the development of the efficiency rates of individual technologies. By determining specific values for each of these parameters, one scenario is selected from the range of possible ones. Based on that, the values of the other variables are computed, for instance the total amount of carbon emissions or the overall cost of energy generation. Taken together, the numerical assumptions and the calculation results describe a possible development of the energy system in question – in other words, they form a scenario.

Usually, a model is used with different sets of assumptions to calculate several possible developments. A study will typically aim at proving whether these developments are possible or determining the potential effects of certain energy policy measures or other events on these developments. The study *A carbon-neutral Germany in 2050*, for instance, claims to describe a technically possible energy system for Germany in 2050, boasting a reduction in greenhouse gas emissions

5 This chapter is mainly based on Dieckhoff et al. 2014. A more detailed analysis of how energy scenarios are generated in scientific policy advice and which order of statements they are supposed to substantiate is provided in Dieckhoff 2015.

6 The WI-study 2012, for example, considers the case for the city of Dusseldorf.

7 The features of the Germany system were, for instance, the object of various studies referred to in this paper.

8 For instance the World Energy Outlook (IEA 2014).

9 However, not all energy scenarios distinguish clearly between the terms “prognosis” and “scenario”.

10 Occasionally, the scenarios presented in energy scenario studies are classified as “probable”, without this probability being quantified. In such cases it is usually unclear what feature of the “more probable” scenarios is responsible for their increased “probability”. We must assume that what is really meant is that “relevant” scenarios are considered; the criteria of this relevance, however, remain equally unclear.

by 95 per cent compared to 1990.[11] The *Trend Analysis Electricity 2022*, on the other hand, established as a "stress test for the energy transition", claims to report the consequences of various risk factors, such as the power demand remaining stable until 2022 (instead of declining).[12]

Uncertainties in the available knowledge are a critical element in the development of energy scenarios. This affects not only the development of individual parameters – resulting in so-called "parameter uncertainties" – but also the interactions of those parameters, which are reflected in the modelling and are accordingly referred to as "model uncertainties". The former type of uncertainty is primarily a result of the numerical assumptions necessary for the calculations. The challenge is to establish specific values for conditions in the far future, as many of the relevant variables, e.g. the price of oil, are difficult to predict.[13] Even the basic act of determining the system boundaries and thus, incidentally, the model boundaries, implies the possibility of model uncertainties, since relevant aspects may be omitted. A second type of model uncertainty results from the exact layout of the model which is realised by means of equations, algorithms and computer programmes intended to describe certain interactions between real parameters. As available data and computing capacity are limited, in particular, the representation of economic or social interactions tends to be imprecise.

Usually, computer models are not used if a study consists of qualitative scenarios only ("narrative" scenarios). Such scenarios are the best choice in case of highly uncertain developments or if the lack of knowledge about causal relationships prevents formal modelling. However, these scenarios are not exempt from proving their consistency with the available knowledge if they claim scientific validity. As yet, such scenarios play a minor role in scientific policy advice in the energy sector.

An energy scenario study is typically launched by an organisation – e.g. a ministry, an association or a company – commissioning a scientific institute or consulting company with the preparation of the study. Basically, the proceedings resemble a dialogue where the commissioning organisation frames a question in the field of energy policy the institution conducting the research attempts to answer with scientific methods.

11 UBA 2013. The study includes not only emissions arising in the context of energy provision, but also from agriculture and other sectors.

12 EWI 2013.

13 Occasionally, the term "parameter uncertainty" refers only to the uncertainty inherent to the so-called model parameters. These are usually the variables that are considered part of the system description once their numerical values have been determined by means of calibration or statistical estimation.

3 Requirements for energy scenarios

Energy scenario studies are to provide input for political decisions and the public debate by giving reliable indications as to the scope of action we have in the energy system. To this end, three basic conditions must be fulfilled. In an abstract wording, they apply to any form of scientific policy advice. In the following chapter, these conditions are first outlined on this general level before being applied to the specific requirements of energy scenarios.

The present position paper is guided by established codes and principles, the most important of which can be found in the *Guidelines for Scientific Policy Advice* published by the Berlin-Brandenburg Academy of Sciences and Humanities,[14] in *Safeguarding Good Scientific Practice* by the German Research Foundation (DFG),[15] in a publication by the German Academy of Science and Engineering under the title of *Guidelines on advising policy makers and society*,[16] as well as in the *Standards and quality criteria for futures studies*[17].

The first condition is that the results presented in energy scenario studies are **scientifically valid**. In other words, the scientific community must consider the methods, databases and particularly the models employed for their creation appropriate for answering the respective questions. The conclusions of such a study must be well-founded and comprehensible. Any uncertainties require explicit mention along with an estimate of their relevance for the robustness of the results. The fact that energy scenarios provide mere statements of possibilities presents a special challenge.

Secondly, these studies have to be **transparent**. To fulfil the requirement of transparency, a study must provide all of the information necessary to enable the addressees to understand its results, and other scientists to verify them. Publicly funded studies should invariably be published – even if the results do not meet the commissioning organisation's expectations. However, publication alone is not sufficient. Rather, the documentation will have to make both the chosen approach and the basic reasoning behind the study comprehensible – particularly with regard to the conclusions drawn from the model results. Above all, normative assumptions must be disclosed. Experts should be able to replicate the results. Since the studies will typically address different target groups, the documentation and communication will have to be adjusted to the respective addressees' requirements.

Thirdly, scenario studies need to fulfil the condition of **unbiasedness**. Above all, this implies that the commissioning institution does not unduly influence the results and conclusions. Such interference could, for instance, come in the guise of restrictions on the choice of methods – thereby prejudging cer-

14 Weingart et al. 2008. The guidelines deal with policy advice realised in formally organised bodies – e.g. the Commissions of Inquiry or the Ethics Councils (ibid. p. 12). Consequently, the principles they promote cannot simply be applied to the conditions assumed in this position paper. Whereas, for instance, the principle of transparency (along with the claim of public availability) is adopted, the claim of pluralistic committees is not heeded. The principle of distance is discussed in a modified form as requirement of unbiasedness.

15 DFG 2013.

16 acatech 2010.

17 Gerold et al. 2015.

tain results – or of attempts to exclude undesired results and conclusions from the documentation. In the case of energy scenarios, scientific viability is, in particular, jeopardised by the possibility of one-sided or biased assumptions. Incidentally, the implementing institutions are under an equal obligation to ensure that the results are not distorted on their end, for instance by taking precautions to avoid personal biases influencing the study without this being openly communicated.[18]

We will now apply the three basic requirements to the specific case of energy scenarios. To this end, we resort to an idealised model, identifying three typical phases in the creation of an energy scenario study, each centring on different requirements: The first phase – the creation of the scenarios – involves the calculation of numerical results by a computer model on the basis of numerical data and assumptions. In the second phase, these model calculations are interpreted and conclusions are drawn from the different simulation threads. In the third phase, the model calculations and the conclusions are recorded and processed in a study and in other documents.[19]

These criteria are basically valid for qualitative scenarios, too – with the obvious difference that here, there is no question of reproduction in the numerical sense. In the case of qualitative scenarios, replicability means that they are consistently and comprehensibly documented. This particularly requires transparency with regard to the assumed causal relationships.

18 Strictly speaking, unbiasedness is merely a specific aspect of scientific validity and could thus be subsumed under this requirement. However, the importance of this aspect justifies its separate consideration.

19 In reality, especially the first and second phases are often reiterated several times, for instance because the interpretation of the calculation results calls for different numerical assumptions and recalculations. From an analytical point of view, drawing conclusions from energy scenarios could likewise be seen as part of the first phase. Similarly, the conclusions could also be treated as a part of the documentation. However, as the use of energy scenarios in policy and society consulting is centred on the findings they yield, the drawing of conclusions is treated as a separate phase in the creation of a scenario and is hence discussed separately.

3.1 Requirements for the creation of energy scenarios

A central requirement for the creation of energy scenarios is scientific validity: Not only must the methods employed be scientifically recognised in the specific research field, but their application and use must likewise follow scientific standards. Hence, while energy scenarios are products of scientific policy advice, they must still comply with the requirements of the respective scientific community and the general standards of good scientific practice.[20]

In energy scenario studies, the choice of the models requires special attention. There are, after all, a variety of different approaches, all of which are more or less suited to address different questions.[21] It is important to openly communicate the uncertainties of the respective models and the extent to which they limit the validity of results and conclusions. One option to estimate the extent of model uncertainties is to conduct model intercomparison studies. This involves using the same set of input data in different models. The scope of variance in the results is an indication of the model uncertainties. Although a number of comparative model analyses have been done for models used in policy advice in Germany[22], the bulk of such analyses is currently carried out at a global level. For instance, the Intergovernmental Panel on Climate Change (IPCC) draws on extensive model intercomparison studies, such as the ones conducted by the Stanford Energy Modeling Forum (EMF).[23]

20 Cf. especially DFG 2013.

21 Mai et al. 2013 provide an overview of these approaches.

22 This refers to the so-called model experiments by the Forum for Energy Models and Energy Economy Systems Analysis in Germany, most recently FORUM 2007.

23 Weyant/Kriegler 2014 provide an overview of the EMF's latest comparative model calculations.

Next to model uncertainties, parameter uncertainties present a further challenge with regard to the establishment of scientific validity and unbiasedness. A precise determination of potential future values being impossible for many factors relevant for the development of the energy system, we are reduced to accepting a range of possibilities as the closest reasonable approximation. Ideally, a study would compute all possible combinations of values within this range, yielding a comprehensive picture of the developments conceivable within the framework of the respective model. Owing to the enormous computing capacities this would require in more extensive models, such a procedure has so far not been part of common advisory practice. Instead, specific values from the range of values are singled out – thus numerical assumptions are made – and used to calculate a number of scenarios from the respective spectrum of possibilities.[24] In the case of particularly uncertain factors with a distinctive significance for the results, additional sensitivity analyses are carried out.

The setting of the assumptions is a pivotal element in the creation of such studies. After all, it is basically this step that settles which scenarios are considered in the first place. Scenarios that cloud over or even contradict the conclusions of a study could thus be omitted. This, of course, would take its toll on the unbiasedness of the study. It is therefore essential to lay open the criteria upon which the selection of the assumptions and thus of the scenarios were based. It should be made clear where the selected values should be located within the range of possibilities and why they were chosen.

How far the selection follows normative criteria should also be disclosed – if, for instance, only scenarios were considered that respond to certain objectives or lie within certain limits. Such normative criteria have, indeed, been defined, for example by the German Advisory Council on Global Change: In a study published in 2003, the Council established a number of normative guiding principles for a sustainable energy transition. They recommend, for example, that only scenarios be accepted in which poor households would have to spend no more than ten per cent of their income to cover their basic individual energy demand.[25] It should also be clear who sets the normative specifications. Usually, this will be the organisation launching the study, particularly if the scenarios considered are selected according to certain political aims.[26] Naturally, the implementing organisation can likewise set forth normative settlements – as long as they are openly communicated.

It is up to those involved in the creation of the study, in particular the commissioning organisation, to implement the requirements outlined in this chapter. However, the effects can only be appreciated from the outside if the study in question can be accessed and assessed by independent experts. The most effective established way to ensure this is transparent documentation. A different, as yet little used option involves the establishment of independent quality assurance mechanisms in scientific advice – for instance by introducing an evaluation procedure for energy scenario studies.

Moreover, here, as in many scientific fields, we face the challenge of jointly establishing and maintaining knowledge under the current rather adverse conditions: Energy scenarios are, for the most part, created in advisory projects,

24 The concept of the "spectrum of possibilities" is described in detail in Dieckhoff et al. 2014, chapter 2.2 and 2.3.

25 WBGU 2003, p. 3.

26 Details regarding normative assumptions are provided by Dieckhoff et al. 2014, chapter 2.4, with a special focus on the distinction between explorative and normative scenarios and the methods of fore- and backcasting.

frequently resorting to the expertise of various institutions with different competencies. It is precisely the knowledge gained in such partnerships – for instance through the combination of different models – that often falls into oblivion once the project is over. To improve the situation, we need to foster the scientific exchange within the community of energy scenario creators. The recently established Research Network Energy Systems Analysis constitutes an important step toward this objective.[27]

3.2 Requirements for conclusions from energy scenarios

When it comes to drawing conclusions from energy scenarios, the central challenge is an asymmetric distribution of competencies among the involved parties: The competence to interpret the energy scenarios – including the results of the model calculations – lies primarily with the institution carrying out the study. However, as the Berlin-Brandenburg Academy of Sciences and Humanities points out in its *Guidelines for Scientific Policy Advice*, the commissioning organisation, too, will typically and justifiably claim the authority to interpret the respective results. This asymmetrical relationship is inherently prone to conflicts.[28] The challenge is to ensure that the conclusions drawn from the scenarios range within the scope of possibilities the methods and results allow for – i.e. that they are scientifically valid. At the same, it jointly behoves the commissioning and implementing organisations to ensure that the conclusions are relevant for decision-making – without compromising the unbiasedness of the analysis. Here again, a transparent disclosure is the best way to tackle the challenge. A simple documentation of the procedure, e.g. by describing how a model served to calculate certain results, will therefore not suffice. Rather, the reasoning based on and resorting to this procedure will have to be explained comprehensibly as well. This is the precondition to enable third parties to challenge the argumentation.[29]

In energy scenario studies a particular challenge lies in the fact that scenarios provide statements on possibilities and are consequently particularly susceptible to misinterpretation. From the fact that individual scenarios are proved possible it does, as a general rule, not automatically follow that other scenarios are likewise possible or, indeed, impossible. A study can show, for example, that a certain target state the energy system is to feature by 2050 can be achieved by following certain development paths. This does, however, not exclude the existence of other, perhaps even better development paths leading to the same goal. The situation is comparable when robust developments or measures are identified by filtering out the common points of several scenarios. In order to qualify as robust, the analysis must take into account all developments that are both possible and relevant.[30]

Energy scenarios are also used to justify recommendations for action. As a matter of principle, such a recommendation is a normative statement. A scenario, on the other hand, is in itself merely a descriptive statement about what is considered possible. Using scenarios to justify recommendations for action therefore involves two necessary basic steps: Firstly, the scenarios in question must be shown to be possible – for instance by means of models. Secondly, at least one normative statement must be

27 Cf. PTJ 2015, the website of the research network.

28 Weingart et al. 2008, p. 12.

29 Chapter 2.8 of Dieckhoff et al. 2014 exemplifies how the reasoning of an energy scenario study can be reconstructed as an argument. A comprehensive analysis can be found in Dieckhoff 2015.

30 A more detailed description is provided in Dieckhoff et al. 2014.

made, allowing e.g. for the evaluation of the scenarios, and must be included in the justification of the respective recommendation. It could, for instance, be claimed that from amongst all scenarios considered, the altogether most cost-efficient is to be selected for implementation. A study must by all means disclose such normative premises and point them out accordingly.

3.3 Requirements for the documentation of energy scenarios

The most important means of meeting the requirement of transparency is the adequate documentation of the energy scenarios. This can be complemented by lectures or expert discussions. Usually, transparency is a prerequisite to fulfilling the other requirements. This means that, basically, an unbiased study can only be created if the assumptions and selection criteria for the scenarios are transparently communicated.

The documentation of a study must fulfil two conditions to ensure transparency: Firstly, the addressee of the study must be able to **understand** it. Secondly, it must be possible for independent scientists to verify it – in other words, the documentation needs to be conducted so as to enable the **replication** of the study.

To ensure traceability, the documentation will have to observe the following minimum requirements: It must be clear to the addressee what methods – particularly, what models – were used and how they served to extract the results from the empirical data and assumptions. However, this alone will not suffice, since what line of argumentation is subsequently followed will likewise have to be explained comprehensibly. Above all, it must be clarified how the conclusions are justified by the numerical assumptions and the results and to which extent uncertainties are involved. In addition, the documentation should contain all of the information the addressee requires to place the study in the larger context of energy policies. This is especially important regarding the research questions and conclusions. For example it should be clarified whether the energy policy objectives adopted by the German Federal Government are considered in a study. Also, references to other relevant studies and comparisons with their results and methods should enable the addressee to place the study in the scientific context. This will also contribute to establishing a joint pool of knowledge within the expert community. The documentation is also to give clear indications regarding the study's parameter settings and premises along with their authorship. In particular, any influence the commissioning organisation or other stakeholders may have had on the study and its findings will have to be explained. The requirement of replicability extends these conditions, as it implies a presentation of the methods, data, assumptions and results sufficiently comprehensive as to enable independent scientists to reproduce the results.

One challenge is that the addressees differ depending on the study and, more importantly, that in most cases different parts of the same study address different target groups.[31] The additional exigency therefore consists in **adjusting** the documentation and communication – viz. all means of creating transparency – to the **respective addressees' requirements**. The project NUSAP (Numeral Unit Spread Assessment Pedigree) elaborated this requirement on a more general level for scientific consultancy at large. The following considerations are based on

31 From a more general perspective, this challenge was also discussed at the symposium "The language of science" (a documentation of which can be found in Leopoldina 2015).

the results of this project, especially on the *Guide for Uncertainty Communication*.[32] We begin by assuming two groups of addressees for a typical energy scenario study: the public and the commissioning organisation on the one hand, and the specialised public, i.e. scientists from the fields of energy systems analysis and energy economics, on the other. Studies claiming to contribute to the scientific debate and thus compelled to ensure replicability must invariably factor in the scientific community as an addressee, although not as the primary one.

Every energy scenario study requires the individual definition of specific target groups and the selection of appropriate means of communication. Here, we can resort to the "Progressive Disclosure of Information"-concept (PDI).[33] Its core idea is to distinguish several layers of information that a study will typically provide and to assign them to the respective target groups. The outermost layer consists of information primarily addressing the public and is accordingly phrased in common terminology. By contrast, the innermost layer includes specific information that will only be intelligible to experts. The crucial point is that a deeper layer does not simply add more detail. Rather, the entire form of communication is adapted to the corresponding target group – including the contents as well as the types of text and the presentation.

Basically, the task of defining these layers will be jointly carried out for every study by the commissioning and the implementing institution. This involves first determining the target groups, then the exact information relevant for each of those groups, and finally, the respectively suitable forms of presentation and communication. How many such layers a study should reasonably contain, can only be decided individually. If an energy scenario study aims at reaching different types of addressees, it may be useful to adapt the wording of different sections within the study to the demands of their respective target groups. For instance, the summary of the study could be formulated for a general public's scope of comprehension, while the main text addresses a more specialised readership.[34] In accordance with the two target groups previously identified for a typical energy scenario study, two levels are distinguished hereinafter.

The **outermost layer of a typical energy scenario study** addresses the public as well as the commissioning organisation: They should be able to **comprehend** the study. Within this level of communication, the addressees may vary significantly. If the general public is targeted – in which case we must include people with no specific expertise – the aforementioned contents will have to be phrased in a commonly understandable way. If, on the other hand, the target group consists of individuals with an expertise allowing them to place the study in its scientific context, specialised vocabulary is unobjectionable. Information from the outermost layer of communication will typically be found in press releases and in the summary of the study.

Conveying uncertainties and their reasons and impacts to a non-scientific audience, i.e. to those people the outer communication layer of an energy scenario study will typically address, presents a special challenge. For this pur-

32 Wardekker et al. 2013.

33 We refer primarily to its use and specific adaptation in Wardekker et al. 2013, esp. p. 14-16. In addition, we resort to the related background study by Kloprogge et al. 2007. Both sources attribute the PDI concept to Pereira and Quintana 2002.

34 Options for the documentation of an energy scenario study include press releases, a summary for the relevant policymakers, the main text of the study, the annex to the main text, specialist literature, as well as documents and databases on the Internet. Cf. Wardekker et al. 2013, esp. p. 14.

pose, useful indications can be found in the *Guide for Uncertainty Communication*[35] as well as in the corresponding IPCC-guidelines[36]. An adaptation of these guidelines to energy scenarios is beyond the scope of the present paper. It is, however, important that non-expert readers are able to comprehend the main uncertainties and their impact on the conclusions from the information provided in the outermost communication layer. This includes adapting the language level accordingly. For instance, numerical data will be more difficult to understand for a non-scientific readership than verbal information.[37]

The **inner layer of such a study** addresses individuals wishing to trace and thoroughly comprehend the genesis of the results, including the methods. In the case of energy scenarios, this typically refers to researchers from the fields of energy systems analysis and energy economics. This target group should be able to **replicate** the results. The necessary information can be appropriately conveyed in the annexes to a study in citations from specialist publications, as well as in supplemental documentation that can, e.g., be made available on the Internet.

When it comes to practical implementation, replicability is hampered by considerable financial and practical obstacles. In some cases, the respective models and data sets are, in fact, commercial products purchased by the implementing organisations for use in the preparation of studies. Frequently, contracts prohibit the disclosure of these models and data. In other cases, the models and data are the outcome of the respective institutions' own developments or surveys, thus accounting for a large part of their operating capital. In particular, the resources for data collection and maintenance are not to be underestimated. In this situation, disclosing the models and data would clearly be detrimental to the institutions' competitiveness. But even if an institution were legitimated and willing to disclose its models, for instance by publishing the source code, it would have to bear the ensuing additional expenses: As yet, the project budgets usually do not provide for such publications.

These obstacles are largely a consequence of the framework conditions established by the advisory practice. Hence, any amendments would foremost be the responsibility of the commissioning organisations, above all the governmental authorities. Evolving the practice toward more model and data transparency will undoubtedly meet with opposition from various quarters. We will probably have to endorse a gradual adjustment of tendering practices, particularly ensuring the continued existence of such institutions that are at present vitally dependent on the protection of their models and data. This, however, in no way reduces the necessity of these alterations.

There are also practical challenges: It remains to be seen, for instance, how a complex model can be documented so as to allow scientists unfamiliar with its features to understand, critically test and eventually use it. Simply publishing the source code on the Internet will not always suffice, as the codes are usually not self-explanatory. It will therefore require commenting either in writing or through a contact person.

The publication of large data sets is not without challenges either, but in that instance the obstacles seem to be less serious. At any rate, it is up to the scientific community to embark without delay on the development of adequate methods and concepts for the publication of models.

35 Wardekker et al. 2013.
36 Mastrandrea et al. 2011.
37 Cf. esp. Wardekker et al. 2013, p. 18-25.

With regard to the disclosure of models and data, we are clearly in urgent need of strategies – for the adaption of the framework conditions as well as in terms of practical implementation. The ideal is a practice of scientific policy advice providing for the publication of all models and data used. This could, for instance, be realised by ensuring the availability of commented source texts and records on the Internet. For the reasons stated above, it is, however, difficult to assess to what extent this goal can be achieved. Alternatively, access to the models and data used in a study could be limited to a panel of experts who would be given appropriate explanations, e.g. in a workshop.[38]

38 The recently launched Open Energy Modelling Initiative, an association of scientists from the field of energy modelling, likewise aims at developing concepts to address these issues (cf. Openmod 2015).

4 Distribution of responsibilities in the implementation process

Three stakeholder groups are crucial in determining what use is made of energy scenarios in the public debate. Each of these groups has different specific responsibilities in the implementation of the requirements outlined above.

- By deciding on the tender specifications, selecting the offers and negotiating the contract details with the implementing institution, the **commissioning organisations** determine the standards and conditions of energy scenario-based consultancy. This not only applies to certain studies. Rather, by repeatedly issuing tenders, the commissioning organisations shape the consultancy standards at large. Via the tenders, they also have a say in selecting the scenarios to be examined and publicly discussed.
- The **implementing organisations**, on the other hand, are responsible for creating and documenting energy scenarios in accordance with basic scientific standards and the requirements outlined in this paper. As members of the scientific community it is their responsibility to ensure that policy advice based on energy scenarios resorts to the best available knowledge. By evolving their own methods they can take a part in shaping the advisory practice.

We can see that the responsibility for good energy scenarios lies by no means with the implementing organisation alone. By setting the framework conditions, the commissioning organisations likewise play an important role. Were the scenarios set in the context of a company's internal strategic decisions, the main responsibilities would, in essentials, be divided between these two groups. In science-based policy advice, however, such a bipolar structure would mean that a small circle of politicians and scientists determine the general direction of research efforts regarding our future energy supply between themselves – by launching research demands, processing the respective studies and implementing the results, to say nothing of largely influencing the foci of public discussion. Such a constellation was criticised as an expertocracy as early as the 1960s.[39] In a more participatory approach to democracy, the public has to be involved, at least as an instance whose claims to transparency will have to be met. In addition, it may be useful to include the public in the early stages of identifying and formulating the central questions for scenario studies. This concept of democracy is, indeed, the basis of the requirements this paper sets up with regard to energy scenarios. Besides the commissioning and the implementing organisations, therefore, we have to include a further, albeit abstract group of stakeholders, i.e.:

- the **democratic public** in its function as – at least indirectly – addressee of energy scenario studies and represented by e.g. political parties, non-governmental organisations and the mass media.

In the interests of this group of stakeholders, it is particularly important to create the preconditions for an open debate on the contents of energy scenario studies. This should be actively initiated by both the commissioning and implementing or-

39 Cf. Habermas 1968.

ganisations. Especially the commissioning institutions – above all public authorities such as ministries – can easily include a comprehensive and transparent presentation of the studies for a non-scientific readership as a binding condition in their tenders.

In the established practice of policy advice based on energy scenarios, the public is often only indirectly involved. This gives a special responsibility to those instances representing the public, such as the media in their role as a "fourth power" in a democratic state. The media can, for instance, claim compliance with the requirements described above and make defaults and failures public. But not only in this sense do the media bear a particular responsibility for the adequate representation of studies. They must also avoid distorted or biased coverage, for instance by presenting energy scenarios as prognoses or by ignoring central premises. Incidentally, these requirements correspond to the standards for good science communication.[40]

40 As documented for instance in Leopoldina et al. 2014.

5 Options for implementation

The current practice of policy advice based on energy scenarios already resorts to a number of techniques to meet the above-mentioned requirements of scientific validity, transparency and unbiasedness. In some studies, sensitivity analyses are used to enhance the robustness of the results; others contain meticulous descriptions of the methods. Nevertheless, as stated at the outset, there are still many cases in which the requirements have not yet been satisfactorily met. This is partly owing to the lack of workable concepts, for example regarding the addressee-specific presentation of uncertainties.

In the following chapter we describe options aimed at developing the current practice to better meet the requirements outlined above. Where possible, reference is made to examples where the option in question was implemented at least to some extent. Also, the principal addressee of the respective option is named.

Before we come to the policy options aimed at better fulfilling the individual requirements, an option should be mentioned that is relevant for all three requirements: This is the **development and introduction of standards for energy scenario studies** in accordance with the requirements in this paper. Public authorities, in particular, are well placed to establish standards for publicly funded studies by including them in their tenders. A separate document with the corresponding specifications could be formally attached to future tenders. The present position paper could serve as a basis for such standards. An essential part of such standards should consist in determining which aspects definitely need to be made transparent in a study and in what form (adapted to the needs of different target groups). The obligation to publish all publicly funded or co-funded studies should be set up as an independent requirement.

5.1 Options to improve scientific validity

A precondition for scientific validity is the possibility of scientific quality controls. As yet, only a rudimentary form of such a control instrument is available in energy scenario-based policy advice; an appropriate mechanism therefore remains to be introduced. Moreover, quality controls will only yield reliable results if the studies fulfil the requirement of transparency.

Basically, every commissioning organisation may introduce mechanisms of quality assurance for its own projects. The more appropriate approach would be for the most important commissioning organisations, especially the public authorities, to come to an agreement on the essential points –thereby also including the academic umbrella organisations in this discussion. The following mechanisms are conceivable as options:

a) **Peer reviewing of publications in scientific journals:** The publication of some parts of studies in peer-reviewed journals subjects the respective contents to the established mode of scientific quality assurance. This quality assurance mechanism is particularly suited to monitor methods and models, especially those used repeatedly.

The same applies to the results of sensitivity, comparative model and meta-analyses. A practical limitation lies in the fact that the review processes of the journals usually exceed the time frame of an advisory project.

Example: The study Role of Renewable Energy in Climate Mitigation: A Synthesis of Recent Scenarios[41] *ranks among the most comprehensive existing meta-analyses of global energy scenarios and thus constitutes an important basis of the fourth IPPC Assessment Report.*

b) **Peer review of studies:** A peer review unconnected with any scientific journals is conceivable. The commissioning organisation would be called upon to appoint the reviewers based on their expertise.

Example: The mechanism of an independent project results evaluation from the German Academy of Science and Engineering could serve as a model.[42]

c) **Individual advisory board for each study:** Rather than waiting for a written review of a finalised study, a scientific advisory board could be appointed to monitor the entire preparation and documentation of the results. The nomination of the board members should take the disciplines, theoretical approaches and methodological skills best suited to the study's purposes into account.

Example: The preparation of the study The development of the energy markets until 2030. Energy Prognosis 2009[43] *was monitored by a four-member scientific advisory board whose scope of duties and involvement are faithfully recorded in the study.*

d) **Permanent body:** Alternatively, a permanent body could be entrusted with the peer review of several studies, or could serve as an advisory board for various studies. Moreover, such a body might pool the findings of different studies. In this case, it is especially important that the appointments reflect a broad range of disciplines, theoretical approaches and methodological skills.

Example: The IPCC evaluates the worldwide research efforts on climate change as a basis for the Assessment Reports it publishes to inform political decisions.

In order to ensure the scientific validity of energy scenarios, we must also find an effective and reasonable way of dealing with uncertainties. So far, model uncertainties are usually not explicitly taken into account in most energy scenario studies. This could be remedied by introducing established concepts from other fields, e.g. model intercomparison studies, into policy advice based on energy scenarios. Most studies already take parameter uncertainties into account, for instance through partial sensitivity analyses or because they will typically present several scenarios. However, we require approaches that would enable a comprehensive analysis of wider spectrums of possibilities. To this end, the following options exist:

e) **Evolution of existing methods for the systematic analysis of uncertainties**, in particular the development of comparative model, sensitivity and meta-analyses. This should be supported with appropriate research funding.

Examples: The Energy Modeling Forum at Stanford University has been carrying out comparative model cal-

41 Krey/Clarke 2011.
42 acatech 2015.
43 IER et al. 2010, esp. p. 323-326.

culations since the 1970s;[44] *and from 1999 to 2007, a similar approach was used for the model experiments of the Forum for Energy Models and Energy Economic Systems Analysis in Germany*[45].

f) **Integration and increased use of methods for the systematic analysis of uncertainties in advisory projects.** Many of these methods are already used in science and research. It is up to the commissioning organisations to likewise establish them in consultancy – for instance by including respective claims in their tenders.

   Example: The scenario study published by the Federal Government's Commission of Inquiry on Sustainable energy supply under the conditions of globalisation and liberalisation *is one of the few studies for Germany in which comparative model calculations were used.* [46]

5.2 Options to improve transparency

Transparency is a key requirement of energy scenarios, since it is a necessary precondition for scientific validity and unbiasedness. Amongst the points significantly preventing transparency is the lack of appropriate representation formats and the fact that in many cases, economic or contractual conditions impede the disclosure of models and data. The options for action include:

a) **Development of formats and practical guidelines for target group-specific representation and the communication of energy scenarios:** Especially the adequate communication of uncertainties and normative stipulations must be ensured. The commissioning organisations can already contribute to this by including the issue of representation and communication of studies as an independent aspect in their tenders and giving appropriate instructions. This does not reduce the necessity of systematic concepts. The efforts of interdisciplinary projects in the field of science communication to develop such concepts should be promoted and fostered. A first step could involve the integration of a form listing a study's central features into the documentation of future studies.

   Examples: The NUSAP project's Guide for Uncertainty Communication *offers basic assistance.*[47] *A good example of an innovative approach for presenting energy scenarios is the project* RE Futures,[48] *which resorts to elements like video animations to illustrate development paths of the US energy system.*

b) **Development of methods to integrate diverging interests:** The success of the energy transition depends significantly on its public acceptance. In this instance, methods for the integration of diverging interests in decision-making processes need to be developed and implemented. This has a direct bearing upon the creation of energy scenarios, since they are the primary basis of such decision-making processes. Science, politics and civil society, which include the commissioning and implementing institutions, should jointly develop and implement such procedures.

   Examples: Public consultations have already been incorporated into various decision-making processes in the energy sector: The French Government's procedure in the drafting

44 Cf. EMF 2015, the website of the Forum.

45 Most recently FORUM 2007.

46 IER et al. 2002.

47 Wardekker et al. 2013.

48 NREL 2015.

of the law on the transformation of the French power system ("transition énergétique"),[49] *the German Federal Government's approach to the acceleration of the power grid expansion in Germany*[50] *and the development of a climate protection plan by the regional government of North Rhine-Westphalia*[51] *are cases in point.*

c) **Promoting the public's systemic understanding of the energy system:** Beyond established energy scenario studies, we face the necessity of conveying to the public a basic understanding of the energy system, its transformation and particularly its many systemic interactions. To this end, interactive media like computer games ("serious gaming") appear to be particularly expedient. Also, teaching materials might be devised. This option is especially relevant for the commissioning organisation.

Examples: The British government's energy model 2050 Calculator is offered in three versions. Along with detailed model tables for experts and a web-based version for stakeholders, it contains a third, easily accessible version for laymen.[52] *The energy game ENERGETIKA 2010 is another example: Here, the players have to create a stable and efficient energy system.*[53]

d) **Development of formats and practical guidelines for the transparency of models and data:** This task is primarily the scientific community's responsibility. Yet, their implementation in the consultancy practice requires close cooperation with the commissioning organisations. In particular, the question of how far models and data may be disclosed in advisory projects, for instance by using open source models, requires assessment; a softer version would involve disclosure to a review panel only.

Example: The Open Energy Modelling Initiative documents a variety of open source energy models already available and addresses practical and conceptual issues regarding their development and application.[54]

e) **Creation and maintenance of a set of reference data and assumptions for the German energy system:** Such a set of reference data might, for instance, contain data on key variables describing the energy system. It could also include several consistent sets of assumptions regarding the future development of these variables. This data could be collected and administered as an element of departmental research. First, however, clarification is necessary as to whether this might be useful and, if so, for what data and assumptions. The definition of reference assumptions, for instance, harbours the risk of collectively limiting the spectrum of possibilities to be examined, thus jeopardising the diversity of the scenarios discussed. The commissioning and implementing institutions should jointly decide which data and assumptions should be included in the set. This will probably improve two shortcomings: Firstly, data and assumptions would become more transparent if such information were freely available. Secondly, such a set of data and assumptions could serve as a reference

49 A rough description of the process is provided in Gautier 2014.

50 Cf. BNetzA 2015, the website of the Federal Network Agency. Weingarten et al. 2013 provide an analysis of the participation procedures.

51 Cf. MKULNV 2015, the website of the Ministry for Climate Protection, Environment, Agriculture, Nature and Consumer Protection of North Rhine-Westphalia.

52 Cf. DECC 2015, the corresponding website of the British Government.

53 Dialogik 2010.

54 Openmod 2015 also lists and describes the open source models registered by the Initiative.

for future studies. Deviations from the reference could then be pointed out in individual studies, which would increase both their transparency and their comparability.

Example: To that purpose, a database with technical, economic and environmental data regarding the German energy system was set up as part of the IKARUS project (term: 1990-2003).[55]

5.3 Options to improve unbiasedness

Energy scenario studies seeking to contribute to the scientific debate must conform to scientific criteria. All provisions restricting the unbiasedness of an analysis must be made transparent in the respective study. It must particularly be evident how the inclusion or indeed exclusion of available scenarios into the study is affected by the respective choice of the basic assumptions. Here, the selection criteria have to be disclosed along with the role of the stakeholders involved in the selection, above all the influence of the commissioning organisation. The implementation is to be realised jointly by the commissioning and implementing institutions. Both parties are called upon to claim and actively foster unbiasedness. This is to be complemented by adequate monitoring by an independent body in the process of scientific quality control. The options for action in this field were already laid out in section 5.1.

55 For the final documentation of the project, cf. Markewitz/Stein 2003.

6 Conclusion

Scientific policy advice uses energy scenarios to provide scientifically valid answers to energy policy issues. Describing the energy system with all of its complexities and uncertainties sufficiently succinctly and accurately as to allow for sound results and conclusions is a central challenge the scientific community faces in this context. The subsequent challenge will then be to present these complex results sufficiently comprehensibly to enable a non-scientific readership to understand and assess them. Only then can they serve as a sound basis for decisions.

There are numerous methods and models to adequately render the complexity of the energy system. These need to be continually developed, for instance, in order to take into account the increasing connectivity of the power, heat and mobility sectors in the energy system. It is also essential that science and research systematically develop concepts for dealing with uncertainties.

Consequently, alterations are necessary in the basic design of current advisory practice. Binding quality assurance mechanisms are the key to improving scientific validity. By means of specific formats and practical guidelines, scenario studies can be presented and communicated according to the respective addressees' requirements. In order to further develop policy advice based on energy scenarios by implementing all policy options described above, close cooperation is necessary between the commissioning and implementing organisations. In addition, both the public and the larger scientific community need to be involved. The present position paper aims at incentivising such cooperations.

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The Academies' Project

With the initiative 'Energy Systems of the Future' acatech – National Academy of Science and Engineering, the National Academy of Sciences Leopoldina and the Union of the German Academies of Sciences and Humanities provide input for an evidence-based discussion of the challenges and opportunities inherent to the German energy transition. Eight working groups (WGs) pool expert knowledge and identify relevant issues. Interdisciplinary ad-hoc groups develop policy options for the implementation of a secure, affordable and sustainable energy transition.

The Academies' Project seeks to provide systematic expertise and a set of reference points for decisions concerning the common goal "energy transition" on the basis of the following principles:

The energy supply of our country is a complex system

Raw materials and resources, technology, economy, society and law: In the energy system, we find multiple, cross-sectoral interactions. If not sufficiently taken into account, selective interventions can have paradoxical, unintended consequences. A prudent conversion of the energy supply system therefore requires a comprehensive understanding and assessment of the system as a whole. This must be developed in a common effort and in accordance with the highest scientific standards. However, there can be no master plan for the transformation because energy transition implies the continuous transformation of the energy system with all its inherent dynamics.

The aim of the energy transition is sustainability

Therefore, we have to agree on the criteria to apply to a sustainable energy supply and on how progress toward more sustainability can be benchmarked. In the energy concept of the German Federal government, supply security, economic efficiency and environmental sustainability form the basic conditions for a sustainable energy supply. Equally, social acceptability and social justice must be adequately taken into account. To determine whether or not these aims must be accorded equal significance, a discussion on values and suitable mechanisms for dealing with conflicts of values is required.

Science and research develop alternative approaches

Based on academically sound alternative options, players from politics, business and civil society can make well founded, ethically responsible and politically feasible decisions. In contrast to recommendations promoting one specific proposal, such options sketch out the consequences to be expected from one or the other approach. Thus, science can specify the advantages and disadvantages each solution would entail according to the current state of knowledge. The task of dealing with conflicting goals and the uncertainty invariably inherent to any such decision-making process is then a political one and requires a constant dialogue with the social groups involved.

Project participants

Eight working groups (WGs) pool expert knowledge and identify relevant issues. Interdisciplinary ad-hoc-groups then develop policy options to address these problems.

WG Current Situation	WG Legislation	WG Technologies
WG Society	WG Resources	WG Options for Implementation
WG Economics	WG Scenarios	

WG Scenarios
The group of scientists listed below worked out the present position paper which was presented to three reviewers. Their respective annotations were considered in the final version along with the comments by the Board of Trustees of the Academies' Project and the Standing Committee of the National Academy of Sciences Leopoldina.

Prof. Dr. Armin Grunwald (chairman)	Karlsruhe Institute of Technology
Prof. Dr. Hans-Jürgen Appelrath	University of Oldenburg
Dr. Christan Dieckhoff (research consultant)	Karlsruhe Institute of Technology
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Dr. Wolfgang Weimer-Jehle	University of Stuttgart

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Dr. Knut Kübler	formerly Federal Ministry for Economic Affairs and Energy
Dr. Uwe Remme	International Energy Agency

Workshops

A draft version of the position paper was submitted for discussion in two expert workshops on 4 July 2014 and on 9 March 2015. The feedback was considered in the further development of the text. The following persons attended one or both workshops:

Christian Bantle	Association of the German Energy and Water Industries BDEW
Dagmar Dehmer	Der Tagesspiegel
Dr. Ulrich Fahl	University of Stuttgart
Robert Germeshausen	Centre for European Economic Research
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Dr. Michael Kilpper	Federal Ministry for Economic Affairs and Energy
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Erduana Shala	Fraunhofer Institute for System and Innovation Research

Institutions und committees

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acatech – National Academy of Science and Engineering (lead institution)

German National Academy of Sciences Leopoldina

Union of the German Academies of Sciences and Humanities

Steering committee

The steering committee coordinates the activities in in eight interdisciplinary, thematic working groups.

Prof. Dr. Robert Schlögl (chairman)	Fritz Haber Institute of the Max Planck Society und Max Planck Institute for Chemical Energy Conversion
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Board of Trustees

The Board of Trustees determines the strategic orientation of the project activities.

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Prof. Dr. Klaus Töpfer	formerly Executive Director of the Institute for Advanced Sustainability Studies
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Project coordination

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